WATER QUALITY ASSESSMENT AND POLLUTION STATUS OF UPPER GANGA CANAL

Ph.D. THESIS

by

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INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247 667 (INDIA)
AUGUST, 2018


भारतीय प्रौद्योगिकी संस्थान रुड़की
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A THESIS

Submitted in partial fulfilment of the
requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY

in

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ROORKEE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled "**WATER QUALITY ASSESSMENT AND POLLUTION STATUS OF UPPER GANGA CANAL"** in partial fulfilment of the requirement for the award of the Degree of Doctor of Philosophy and submitted in the Department of Water Resources Development and Management of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from July, 2012 to August, 2018 under the supervision of Dr. Ashish Pandey, Associate Professor, Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, and Dr. Pradeep K. Jha, Associate Professor, Department of Mechanical and Industrial Engineering, Indian Institute of Technology Roorkee, Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

(TESFAMARIAM ABREHA BAHITA)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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The Ph.D. Viva-Voce Examination of Tesfamariam Abreha Bahita, Research Scholar, has been held on ....

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Signature of Supervisor(s)
Dated:

Head of the Department

ABSTRACT

Availability of good quality water is an indispensable feature for irrigation to improve the quality of agriculture and crop production, as well as for livestock and human drinking purposes to prevent the diseases through water consumption. Undesirable changes in the physicochemical nature and the toxicity of heavy metals in available water can be dangerous, thereby making it unsuitable for domestic and agricultural uses. The Upper Ganga Canal (UGC), Roorkee is being polluted due to disposal of sewage, industrial waste and other human activities. Keeping this in mind, the present study has been carried out to assess the UGC water quality for irrigation, livestock drinking, human drinking, and numerical modelling of pollution dispersion.

In this study, water samples were collected from 18 different sampling sites at monthly interval from November- 2014 to October- 2015. Several instruments and standard methods were employed for determination of the physicochemical parameters and trace metals in the UGC water. Further, the most important 15 physicochemical parameters (pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, $HCO3^{-}$, $CO3^{2-}$, Cl^{-}, $SO4^{2-}$, $NO3^{-}N$, DO, COD and B), and 11 trace metals (Al, As, Cd, Cr, Co, Cu, Fe, Hg, Pb, Mn and Zn) were analyzed on seasonal time-scale. Numerous irrigation water quality metrics i.e. Sodium Adsorption Ratio (SAR), Residual Sodium Content (RSC), Residual Sodium Bicarbonate (RSBC), Sodium Soluble Percentage (SSP), Magnesium Adsorption Ratio (MR), Permeability Index (PI) and Kelley`s Index Ratio (KR) were studied and evaluated for suitability of UGC water. The arithmetic weightage based Water Quality Index (WQI) values were computed to evaluate the water quality for irrigation, livestock drinking, human drinking. Further, a three-dimensional geometry has been developed, from old canal bridge to Ganeshpur bridge, Roorkee, for numerical modelling of pollutant dispersion at five different locations by varying density and size of the solid particles.

For irrigation, only the concentration of Mg^{2+} was higher than the prescribed standard range. On seasonal basis, Boron value was within the permissible limits at all sites, except at sites S4, S5 and S7 in summer, and at site S5 in winter. However, the other physicochemical parameters are within permissible limit at all sites of the UGC, Roorkee and hence, the UGC water is suitable for irrigation purpose. In case of toxic trace metals, concentrations of the Mn during winter, the Zn during winter as well as summer, and the Co during all three seasons were beyond the allowable limits for irrigation at only three sites. The water quality metrics namely SAR, SSP, EC and TDS were ‘excellent’; RSC and RSBC were ‘safe’, and KR was ‘good’ for irrigation. The WQI values of the UGC water ranged from 18.78 to 89.31 (mean of 45.56 and

SD of 29.79) in winter**;** from 25.99 to 84.94 (mean of 53.84 and SD of 18.99) in summer; and from 15.58 to 57.76 (mean of 34.02 and SD value of 12.91) in monsoon seasons, revealing suitability of the UGC water for irrigation purpose. Furthermore, inter-relationship analysis depicted that the sensitivity of trace metals varies with the seasonal changes. High sensitivity amongst all metals was observed in monsoon season, followed by winter and summer seasons.

For livestock drinking, all the physicochemical parameters considered in this study were within the permissible limits. Also, most of the toxic trace metals in the UGC water at all the sites, except at S4, S5 and S7, were within the permissible limits. The WQI values of the UGC water sites ranged from 22.79 to 190.46 (mean of 66.30 and SD of 55.37) in winter**,** from 36.12 to 170.52 (mean of 72.95 and SD of 45.77) in summer, and from 15.36 to 172.99 (mean of 62.17 and SD value of 49.39) in monsoon seasons. However, the WQI values were more than 100 for sites S4, S5 and S7 during all the seasons, whereas for other sites it was within permissible limit. Therefore, UGC water can be used for livestock drinking purpose.

For human drinking, the physicochemical parameters viz., Ca, K, B, DO and COD were beyond the permissible limits. Most of the toxic trace metals in the UGC water have higher concentration compared to the authentic standards. The WQI values of the UGC water sites ranged from 104.64 to 1485.64 (mean of 443.48 and SD of 459.28) in winter; from 127.65 to 1518.1 (mean of 458.51 and SD of 463.52) in summer; and from 104.24 to 1484.66 (mean of 434.71 and SD value of 455.38) in monsoon seasons. Therefore, UGC water is not suitable for human drinking.

Numerical modelling of the UGC water showed that the rate of sewage pollutant dispersion and mass fraction increases with high sewage inlet velocity. Result shows that the inlet of sewage pollutant in canal water leads to maximum change in concentration near the canal banks, and have minimal effect at the center. The mass fraction of sewage pollutant increased from 0.006 to 0.018 in flow time of 50 minutes, when velocity of sewage was increased from 0.2 m/s to 0.4 m/s. The study of solid particle insertion along with the sewage pollutant revealed that the solid particles of large size (diameter of the order of 80 μm to 150 μm) and high density have high affinity to get settle down at the canal base, whereas the particles of small size (below 25 μm diameter) and less density floats with the canal water and travel large distance to settle down.

This study will explore the suitability of the UGC water considering physicochemical parameters and toxic trace metals, and provide numerical modelling framework for pollutant dispersion study which would be a value addition for water quality assessment.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation / symbol	Description
%	Percentage
%Na	Percentage Sodium
$U^{\rightarrow}$	Average velocity of fluid flow
*	Asterisk
∑	Summation of all
µeff	effective viscosity
µg	Microgram
µm	Viscosity of the mixture
µS/cm	microhom Simien per centimeter
µt	Stands for eddy viscosity
1D	One Dimensional
2D	Two Dimensional
3D	Three dimensional
a.m.	ante meridiem (before midday)
AAS	Atomic Adsorption Spectrophotometer
ADCP	Acoustic Doppler current profiler
AgNO3	Silver Nitrate
Al	Aluminum
ANSYS	Analytical System Fluent 15.0
ANZECC	Australian and New Zealand Environment and Conservation Council
APHA	American Public Health Association
AR	Analytical Reagent
As	Arsenic
Avg.	Average
B	Boron
BaCl2	Barium Chloride
BIS	Bureau of Indian Standards
BOD	Biochemical Oxygen Demand
℃	Degree Celsius
Ca	Calcium

CaCO3	Calcium Carbonate
CCME	Canadian Council of Ministers of the Environment
Cd	Cadmium
CFD	Computational Fluid Dynamics
CH3COONa.3H2O	Sodium Acetate Trihydrate
Cl	Chloride
Co	Cobalt
CO_2	Free carbon dioxide
CO_3	Carbonate
COD	Chemical Oxygen Demand
Cr	Chromium
Cu	Copper
Di, m	Mass diffusion coefficient
DO	Dissolved Oxygen
dS/m	decisemien per meter
DT, i	Thermal diffusion coefficient
DWAF	Department of Water Affair and Forestry
E	East
EBT	Eriochrome Black-Titrant
EC	Electrical Conductivity
EDTA	Ethylene Diamine Tetra Acetic Acid (Ethylenediaminetetraaceticacid)
Eij	Stands for the component of rate of deformation
EPA	Environmental Protection Agency
F	Force
FAO	Food and Agricultural Organization
FC	Fecal Coli form
Fe	Iron
g	gram
$H2SO_4$	Hydrogen Sulfate
HCl	Hydrogen Chloride
HCO_3	Bicarbonate
Hg	Mercury
HNO_3	Hydrogen Nitrate

ICMR	Indian Council Medical Research
IS	Indian Standards
Ji	Diffusion flux
K	Potassium
K	Proportionality constant of the “Weights” for various water quality characteristics
K2Cr2O7	Potassium Di-Chromate
K2CrO4	Potassium Chromate
KCl	Potassium chloride
kg/m^3	kilogram per cubic meter
KHP	Potassium hydrogen Phthalate (CHOOC-C6H4-COOK)
KNO3	Potassium Nitrate
KR	Kelly`s Ratio
LHS	Right hand Side
m	Mass transfer due to cavitation or user-defined sources of mass
m	Meter
M	Mole
m/s	meter per second
m^2/s	square meter per second
MAR	Magnesium Adsorption Ratio
Max.	Maximum
meq/L	milli equivalent per litre
Mg	Magnesium
mg	milligram
mg/L	milligram per litre
$MgCl_2.6H_2O$	Magnesium Chloride Hexahydrate
Min.	Minimum
ml	milliliter
Mn	Manganese
N	Normality
n	Number
N	North
N. R.	No Relaxation
Na	Sodium

NaOH	Sodium hydroxide
NH_4Cl	Ammonium Chloride
Ni	Nickel
nm	nanometer
NO_2	Nitrite
NO_3	Nitrate
NO_3-N	Nitrate Nitrogen
NRCD	National River Conservation Directorate New Delhi
OH	Hydroxide
OTIS	One-Dimensional Transport with influx and Storage
p	Phase
P	Phenolphthalein
p.m	post meridiem (after midday)
pa	applying/operating pressure
Pb	Lead
pH	Concentration of hydrogen ion (Acidity/ Alkalify
PI	Permeability
PO4	Phosphate
ppm	parts per million
Qi	Quality rating of ith parameter for a total of n water quality parameters
r	Correlation Coefficient rho
RANS	Reynolds Averaged Navier-Stokes
RHS	Right hand side
RSBC	Residual Sodium Bi-Carbonate
RSC	Residual Sodium Content
S	Site of a study area
SAR	Sodium Adsorption Ratio
SD	Standard Deviation
Si	Rate of creation by addition from the dispersed phase and user-defined sources
Si	Standard higher permissible parameter for nth parameter
SO4	Sulfate
SSP	Sodium Soluble Percentage

T	Titrant volume
TA	Total Alkalinity
TDS	Total Dissolved Solids
TH	Total Hardness
TSS	Total suspended solids
Tw	Water Temperature
UGC	Upper Ganga Canal
USDA	United States Department of Agriculture
V	Volume of water sample
$v_{(dr,p)}$	drift velocity of phase
V_{actual}	Actual value of water quality parameter obtained from laboratory
v_i	Velocity component in 'ith' direction
V_{ideal}	Ideal value of water parameter obtained from the
Vm	Mass-averaged velocity
$V_{standard}$	Standard Values recommended for irrigation purpose or human or livestock drinking
WHO	World Health Organization
Wi	Relative (unit) for nth parameter
WQI	Water Quality Index
xy	x and y representing two numbers
$Y_{i.}$	Rate of production by chemical reaction
Z_n	Zinc
α_k	volume fraction of secondary
ϵ	Dissipation of energy
ρm	Mixture density

CHAPTER 1

INTRODUCTION

1.1 General background of the study

Water is essential for all forms of lives from microorganism to complex systems of plants, animals and human beings (Matta, 2014). Globally, fresh water to the tune of 3240 million cubic kilometer is being utilized. Among this, about 69 percent is being used in agricultural sector, 8 percent in domestic, 23 percent in industrial and other sectors (Singh, 2017). The availability of freshwater is already a thought provoking concern in various parts of globe. It is extensively involved in many of the daily human activities such as agriculture, drinking, domestic purposes, industrial activities, transport, power generation and recreation, which show water is an integral part of life (Choudhary et al., 2014). Water is a key input for plant growth and is instrument in the upkeep of environment. Especially, availability of water at optimum quality is essential for irrigation purpose (Ayers & Westcott, 1985, 1994). Quality drinking water is a preliminary requirement for good health. It is a sensitive issue for mankind and a cause of deaths and diseases worldwide (Kaur and Kaur, 2015). The quality of water is a very important aspect for successful livestock production. Poor quality of water may cause livestock health deterioration and consequential inferiority in livestock products. As a result, the producer may incur monetary losses. Cattles need quality water because loss of body water occurs through milk production, fecal excretion, urine excretion, sweet and vapor loss. It means, availability of good quality irrigation water is an indispensable feature for preventing crop and livestock diseases, and for rising and improving the quality of agriculture and crop production.

According to Kundu (2012) and Tomar (1999), utilization of water for various activities depends on its physical, chemical and biological characteristics. All the water uses require a definite threshold water quality regarding biological, physical and chemical characteristics of the suspended or dissolved constituents, which should ascertain no harmful effects to the user (Geol, 2006; Bhattarai et al., 2008; Shinde et al., 2017; Shakya & Ghosh, 2018a). Nowadays, the surface water as well as groundwater is under threat due to undesired alterations in the biological as well as physicochemical nature of water, air and soil. According to Goel (2006), increasing water pollution has become a global challenge in recent times due to industrialization, intensive agriculture fertilization and human activities. The situation is predicted to be further detrimental in the future driven by urbanization, population explosion and climate change (Suthar et al., 2009; Mohsin et al., 2013).

Water is regarded as ‘polluted’ when its quality or composition alters by either natural or anthropogenic activities, and becomes less suitable for domestic, agricultural or industrial applications. Especially, the high toxicity of heavy metals can be dangerous even at very –little contamination (Yahaya et al., 2012). Due to non-biodegradability, these get accumulated in plants and animals, there by persistently causing harmful impacts on human health (Bhaskar et al., 2010). The wide range of industries and point source discharges from mining activities are the primary sources of these heavy metals causing water pollution. The toxin of trace metals (copper, chrome, cyanide, mercury, strong base, strong acid, radiation materials etc.) in water causes crop damage and reduce agricultural yield (Nazif et al., 2006).

The canal and river waters of many countries are in danger due to undesirable changes in the biological and physiochemical nature of water (Jensen et al., 2001; Shortt et al., 2003; Horn et al., 2004; Jha and Singh, 2008). Buccolieri et al. (2010) analyzed the flow behavior in a portion of the Canal Grande (Grand Canal) in Venice (Italy). Previously, experimental investigation of water quality has been done for irrigation purposes at different canals and river. Numerical investigations can be also carried out to study the canal water flow behavior with pollutant dispersion. Drolc and Koncan (1996) applied a surface water quality model, QUAL2E, developed by United States Environmental Protection Agency, to estimate the impact of discharged wastewater on quality of the river Sava and model was used to determine the most important factors which affect the dissolved oxygen concentration in river water. The reported studies shows an importance of the mathematical modelling to study the flow behavior of water pollutant dispersion, which is needed in present days.

Mathematical modelling of water quality is capable of identification, formulation, parameter estimation, and sensitivity testing of pollutant transport and dispersion in streams, lakes, and reservoirs. It manifests the behavior of water pollutants, and become a helpful tool in the water management. Numerical model can enable and identify the pathways towards superior solutions of real-world problems. It depends on hydrology and hydromechanics of water movement, and mechanism of pollution mixing. Mathematical model deals with the dilute solutions, chemical kinetics, and biochemistry for determination of the fate of substances dissolved or suspended in water (Orlob, 1983; Ji, 2017). Thus, this kind of models conceptualize the practical problems in digital model form, and the use of such model can aids in decision making.

1.2 Water quality and pollution in India

Water resources are polluted so much that 70 % rivers and streams not only of India but also of all the countries contain polluted waters (Goel, 2006; Jain et al., 2007). Many water bodies of India has become polluted due to discharge of domestic sewage, municipal waste drains, urban agricultural waste, and large scale industrial effluents (Kaur and Kaur, 2015). In India, the population increase, exponential growth of urbanization as well as industrialization and rise in living standards of people, have revealed the several forms of degradation in Indian water resources, particularly in the river systems (NRCD, 2009; Srivastava et. al., 2011). In India, irrigation is one of the significant applications of surface waters. Canal waters are originated from rivers, dams, lakes etc. (Michael, 1978). However, majority of the Indian rivers are polluted due to discharge of industrial and domestic wastes into them (Kaur, 2014). As canals are meant for optimum utilization of river water by irrigating the remote areas, the water quality and pollution of river waters are important (Semwal and Akolkar, 2011).

The perennial flow of water in the irrigation canal diverted from the main Ganga River makes it possible to have all year agricultural production. Indian rivers, the source of many canal waters, are polluted by discharge of industrial effluents and untreated sewage into it. Thus, canal water qualities are generally the same as the water of their parent rivers, unless it is contaminated while passing through salt affected area and river from which it originates (Michael, 1978; Tomar, 1999).

The Ganga River has regrettably become the receiving waste bin for untreated waste; industries withdrawal of water for their consumptive use and discharge the untreated used water in the water bodies (Goel, 2006). There is evidence from other canals in the Indian subcontinent that the water quality of river systems has been degrading. Sardar et al. (2013) discussed that heavy metals pollution have adverse effects on soil, atmosphere and water resources. Kumar and Chopra (2012) studied the hydrological characteristics i.e. physicochemical and microbiological of abandoned Old Ganga Canal at Haridwar (Uttrakhand), India. They concluded that it has high contaminants in terms of physicochemical and microbiological parameters and metal contents deteriorated the canal water. They observed that the canal water quality changed badly after drainage and discharge of domestic wastewater and agricultural runoff.

The Ganga River provides water for drinking purpose and irrigation in agriculture to about 40% of India's population in 11 states. Despite the fact that Ganga River is a major source of water for drinking and agriculture, and has significant environmental values in India. This precious asset is getting degraded due to effluent discharge from different organizations and communities. The Ganga River was ranked among the five most polluted rivers of the World in 2007 (Jain et al., 2007; Munawar, 2013). The pollution can also be seen in the Upper Ganga Canal (UGC), which crucially affecting the water quality of canal water at Roorkee for irrigation and drinking purpose. The increase in population, food production demand, rising standard of living, growth of industrialization and urbanization increases the demand of clean and safe water. Moreover, disposal of sewages are the major source of pollutant (waste water) and contamination specifically in the UGC.

1.3 Canal water quality and pollution in Northern India

In India, the canal system plays a vital role in optimal use of available water in rivers, dams, lakes, groundwater and other sources. The quality of canal water for irrigation has to be good in order to prevent the crops and livestock diseases, and for rising and improving the quality of agriculture and crop production (Chowdary et al., 2005). Whereas, the use of poor quality or contaminated water for long time can make the soil less productive (Hanson et al., 1993; Samani et al., 1998; Chowdary et al., 2004) or even barren depending on the amount and type of constituents present in the canal water (Majumdar, 2001), and unsuitability of water at an acceptable quality can be detrimental to crops (Wattoo et al., 2004). Therefore, evaluation of the canal water quality is important for environmental management as well as human health (Butler & Srivastava, 2007). Canals are meant for optimum utilization of river water by irrigating the remote areas, thus the water quality monitoring, and pollution of rivers waters must be significantly studied (Yu et al., 1991; Ozkul et al., 2000; Joshi and Srivastava, 2006; Schmalz et al., 2008; Wang et al., 2009). Toxic trace and heavy metals are also critical as they damage crop, pollute water causing persistent poisoning to aquatic animals, livestock and human health (Samani et al., 1995; Basha et al., 2008; Shakya and Ghosh, 2018b). Thus, the study on water quality of canal is important to preserve and maintain the natural ecosystem (Kumar et al., 2016). In India, Paliwal et al. (2007) used QUAL2Q-UNCAS model, and Sharma et al. (2017) used QUAL2Kw for numerical modelling of water quality in the Yamuna River. Sarkar and Pandey (2015) used artificial neural network technique for water quality modelling. Recently, the distribution of phytoplankton in Sundarbans Estuarine System was examined using mathematical modelling (Das et al., 2018). Thus, advancement of numerical modelling to study the water pollution dispersion is progressively utilized for Indian regions. However, the canal water quality modelling is rarely done so far in the literature, especially for Northern Indian region where dense Ganga canal network uses efficiently. Therefore, importance of numerical modelling for water quality and pollution dispersion is increasing day by day. The Upper Ganga Canal (UGC) water is being polluted due to mass bathing (canal is frequently used for human bathing), washing clothes and buffalo, and disposal of sewage, industrial waste and other human activities. Besides, trace metals may enter directly from the river either due to natural causes such as geological erosion, due to atmospheric deposition, or anthropogenic activities i.e. dumping of industrial effluents, domestic sewages, and mining. The human activities such as swimming, dipping, dumping of idols, washing clothes, defecating, cattle wadding, domestic sewages and disposing solid materials are common and could be the sources of pollution and the UGC water may be unfit for livestock drinking use around Roorkee and in the downstream area of the UGC.

1.4 Motivation of the study

The Upper Ganga Canal (UGC) water plays an important role in the Northern India for irrigation, drinking, navigation and spiritual beliefs. NRCD (2009) reported that the Ganga River is the most polluted river today. Thus, the water quality of UGC should be assessed before uses for agriculture and humans.

Matta (2014) carried out assessment of water quality of Ganga canal system at Haridwar and studied the physicochemical parameters in different seasons. He found that results exceeded the permissible limit during rainy season and summer season at Bahadrabad when the results were compared by Bhimgoda Barrage water. The main source of contamination was from domestic, human and industries. Sewage, solids and liquid contaminants or organic nature were found to be the prime source of pollution. As the untreated effluents are continuously discharged to the canal, the water was found to be unfit for drinking or irrigation.

From the literature, it is found that very less attention were paid towards the numerical assessment of water quality on inclusion of sewage as well as the velocity at which sewage pollutant are discharged into the canal. No study has been found to conduct numerical investigation of change in water quality/concentration due sewage liquid pollutants and/or solid particle pollutants for the UGC.

Looking to the aforementioned, the main objective of this study is to assess the UGC water quality and pollution in terms physicochemical parameters and trace metals for agricultural and drinking purposes, as well as the numerical modelling for sewage pollutant dispersions in the UGC water.

1.5 Objectives

The present study has been planned with the following specific objectives:

1. To assess the UGC water quality for irrigation purpose.
2. To assess the UGC water quality for livestock drinking.
3. To assess the UGC water quality for human drinking.
4. Numerical modelling of sewage pollutant dispersion in the UGC water.

1.6 Organization of thesis

The thesis is organized in eight chapters as follows:

Chapter 1: This chapter briefly describes the general subject background, and the present state-of-the-art knowledge of water quality and pollution in Indian River basin and northern canal network. It helps to motivate our study and to decide the specific research objectives. Also, thesis organization is summarized.

Chapter 2: This chapter deals with the literature review on water quality and pollution status in India, including critics in the literature review.

Chapter 3: This chapter includes details of the study area, data measurement and analysis, and methodology used for water quality and pollution assessment.

Chapter 4: This chapter deals with the analysis of the UGC water for irrigation purpose. The physicochemical as well as trace metals are assessed to study canal water quality and pollution status.

Chapter 5: This chapter deals with the analysis of physicochemical and trace metals in the UGC water for livestock drinking purpose.

Chapter 6: This chapter deals with the analysis of physicochemical and trace metals in the UGC water for human drinking purpose.

Chapter 7: This chapter emphasizes the numerical modelling of sewage pollution dispersion in the UGC water.

Chapter 8: This chapter deals with the summary and conclusion of the study. It discusses major research contribution as well as future research scope of the present work.

CHAPTER 2

REVIEW OF LITERATURE

Water is the fundamental need of life, as it is consumed by all forms of living beings. Thus, quality of water is an important aspect, which requires continuous monitoring. For this, it is needed to evaluate the quality of water, which requires a precise quantification of various constituents and the corresponding deviation from ideal or acceptable conditions. In the past, several researchers have attempted to evaluate the water quality based on their specific utilities viz., irrigation, human drinking, livestock drinking, etc. The general background of water quality analysis and applications in different countries are also included in this chapter. The various parameters (physicochemical and toxic trace metal) that are considered to be a measure of water quality and their effects are also derived from literatures. The remarkable prior studies pertinent to assessment of water quality for irrigation, livestock drinking and human drinking purposes reported in different countries are also presented. This chapter also enlists some of the past studies related to application of Water quality index (WQI) to determine suitability of water for specified uses. Further, the relevant literatures regarding correlation analysis among different water quality parameters to estimate their inter-dependencies are also cited. Some of the prior works regarding numerical modeling of sewage transport and its influence on quality of surface water are also reviewed. Lastly, the critiques on the literatures reviewed in all the above sections are presented, which will help to frame specific objectives and explicit methodologies to achieve them.

2.1 General Background

Water is an essential resource for existence of life on earth. The human existence predominantly depends on quality water; food and air; while food is tied to water. Water is necessary to all living organisms i.e. from microorganism to huge plants, animals and human beings (Matta, 2014). According to Majumdar (2001), irrigation is the key input in crop production. The canal and river waters of many countries are in danger due to undesirable changes in the biological and physiochemical nature of soil, air and water. Water pollution is said to have occurred, when untreated wastes from industries and other human activities are put in to water bodies. Water pollution causes harm to all types of natural communities. The canal water is usually preferred for irrigation applications because requisite water temperature is a vital factor for the growth of many plants. In India, irrigation is one of the significant applications of surface waters. Canal waters are originated from rivers, dams, lakes etc. (Michael, 1978, 2007). However, majority of the Indian rivers are polluted due to discharge of industrial and domestic wastes into them (Kaur and Kaur, 2014). As canals are meant for optimum utilization of river water by irrigating the remote areas, the water quality and pollution of river waters are significant (Semwal and Akolkar, 2011). All uses of water require a definite threshold water quality regarding the biological and chemical characteristics of the suspended or dissolved constituents, which should ascertain no harmful effects to the user (Goel, 2006). Ayers and Westcott (1985, 1994), FAO (1985, 1992) have provided guidelines for the basic assessment of quality for irrigation water. Similarly, Standards of BIS, World Health Organization and others are also considering an improved approach to evaluate the quality of water for human drinking. These Standards have been implemented successfully to evaluate the various components available in water to determine the overall quality. However, the guidelines are the elementary steps in identifying the quality constraints of water supply. This is because, quality of the water for irrigation has to be good in order to prevent the crops and livestock diseases and for rising and improving the quality of agriculture and crop production. Whereas, use of poor quality or contaminated water for long time can make the soil less productive or even barren depending on the amount and type of constituents present on the canal water (Majumdar, 2001) and unavailability of water at an acceptable quality will be detrimental to crops. (Wattoo et al., 2004). This chapter encompasses review of water quality parameters relevant to irrigation, livestock drinking and human drinking. The studies from different countries viz., India, Ethiopia, Greece, China, Egypt, Pakistan, Bangladesh, Morocco, Nigeria, Ghana, Uganda, Kenya, United states of America, United Kingdom, Italy, Canada, Argentina, Brazil, Ecuador, Jordan, Iraq, Turkey, Iran, Croatia, Georgia etc. are reported.

2.2 Water Quality Assessment for Irrigation

This section deals with the various researches related to assessment of water quality for irrigation suitability across different parts of the globe. This includes the studies on effects of physicochemical as well as biological parameters and the toxic trace metals on quality of water for agricultural applications. Moreover, the studies on irrigation water quality metrics viz., SAR, SSP, TRSBC, MAR, PI, KR are also discussed. Some of the remarkable prior works in this context are presented in **Table. 2.1.**

Table 2.1: Review of water quality assessment for irrigation suitability in different countries

Sl. No.	Author (Year)	Work Done	Remarks
1	Wattoo et al. (2004)	Studied the quality characterization of Phulali canal water (Hyderabad city) for agriculture purposes and to monitor the pollution by studying the physicochemical parameters and some essential elements from the impact of sewage and industrial effluents on the canal water quality.	pH, EC, TDS, and fecal coliforms values were found to be higher with marginal to unsafe hazards status and Ca, Mg and Na were found to be higher than K. Water was found to be poorly suitable for irrigation in the long run. The untreated wastewater being discharged to the canal is the main reason for unsuitability of water for drinking or irrigation uses.
2	Chaturvedi and Pandey (2006)	Evaluated the pollution status by analyzing some physicochemical parameters and heavy metals during Navaratri festival over Ganga river at Vindhyanchal Ghat.	Owing to the huge gathering of people, the study site gets highly polluted during the festival. The water is not suitable for irrigation or domestic purposes. water of Ganga River before entering the Vindhyachal Ghat (Mirzapur district, U.P.) is already polluted by industrial and sewage pollutant and at site it becomes more polluted by the accumulation of a huge pilgrim of populations during the Navratri Mela in the month of April & October.
3	Nazif et al. (2006)	Evaluated irrigation water sources (canal and Bara River) for heavy metal contents in Akbarpura area of the Nowshera district, Pakistan.	Comparing with water from Bara river, the trace metal concentrations in the irrigation canal water were too less, except only Mn and Zn, which were found to be similar for both. However, from the irrigation perspectives, both the sources water (Bara River and its canal) were found suitable.
4	Islam and Shamsad (2009)	Evaluated the irrigation water quality of Bogra District, Bangladesh through important physicochemical parameters of surface (canal and river) water as	Water temperature, pH, EC, TDS, SAR, SSP, RSC and KR of the water were within the permissible limits for irrigation purposes but only B and Cl contents were within the maximum allowable concentration. Surface and ground waters of Borga has no salinity problem.

		well as groundwater.	
5	Nahid et al. (2009)	Carried out assessment of water quality for irrigation in Muktagacha, Bangladesh. The samples of water collected from 19 sites of surface water bodies (canal, river, pond, khal, beel, etc.) were checked for physicochemical and trace metal concentrations.	The salinity (or EC) and Boron were found to be in excellent condition for all the sites. SAR and pH were normal for agricultural perspectives at all the sites. The nitrate concentration at some sites were high and water from those sites should be used for irrigation with utmost care.
6	Olowu et al. (2010)	Studied assessment of Pollution Trend of Oke Afa Canal (Lagos), Nigeria. The collected water samples from five different sites were analyzed for the physicochemical parameters and toxic trace metals.	The BOD and COD concentration were found to be high due to domestic sewages discharged into the canal. However, all the heavy metals were within the limits barring Lead, thereby indicating no serious pollution.
7	Sivakumar et al. (2010)	Carried out assessment of the contamination from the Tanneries and Dying Industries on to Kalingarayan Canal of Tamilnadu for the major physicochemical water quality parameters. They studied assessment of the quality of the canal water and the impact/ evaluation of rate of dumping of effluent water in terms of irrigation and the impacts onto the environment.	The water was found to be contaminated by discharge of effluents from the industries. Results showed a constant variation in different parameters in different locations and there was a recommendation to take periodical monitoring of the canal water quality in its region for future sustainability.
8	Aftab et al. (2011)	Studied the physicochemical properties, contamination status (metal constituents)	All physical and chemical parameters were within standards limit but the metal concentrations were found in variable quantities in canal samples with Cd, Cu and

		and suitability of canal water for irrigation in Lahore. The average result of each physical, chemical and metal parameter of the canal was compared with FAO.	Cr concentrations were found higher than the permissible limits. Pollution level in the canal was not high except high turbidity and cadmium. The rain in monsoon season dilutes the more critical contamination of the canal water, thus decreases the pollution effect.
9	Jayalakshmi et al. (2011)	Assessed the physicochemical parameters of water in canals (from Krishna River) and wastewaters in and around Vijayawada, India.	Some of the water quality samples from canals around the city were slightly polluted while wastewaters of other canal samples were highly polluted as a result of contamination with industrial, agricultural and domestic wastes.
10	Semwal and Akolkar (2011)	Assessed suitability of four canals (Agra, Hindu, west Yamuna and Ganga) in NCR Delhi for irrigation in terms of critical pollutants such as SAR, TDS, pH, EC and B identified for Class-E of primary water quality criteria were studied. Water samples were analyzed for Na, K, Ca, Mg, TDS and Cl parameters. Previously utilized annual averages of the biological and physicochemical water quality data for different years were included in the study.	The results reveal that the canals were not suitable for irrigation purposes, considering the effects of the critical pollutants SAR, TDS, pH, EC and B altogether. The maximum levels of critical pollutants as per primary water quality criteria may not be suitable for irrigation to various sensitive, semi-tolerant and tolerant groups of crops and there was need to classify surface waters to various classes of irrigation waters specific to crops.
11	Augoustis et al. (2012)	Assessed an irrigation canal ecosystem by checking the physicochemical parameters and heavy metals in sediment of Asmaki canal, Greece.	EC (salinity) and SAR were very high and found unsuitable for irrigation. % Na was suitable for irrigation. The ions like Cl, SO_4, Ca, and Mg were unfit for irrigation and the heavy metals like Cd, Cr, Cu, Pb, and Ni concentration in sediment were unsuitable for agricultural applications.

12	Verma et al. (2012)	Assessed water quality in terms of the physicochemical variables for a canal at Allahabad, India.	All the parameters were found to be within the desirable limit and thus, water from the canal is suitable for agricultural utilities in Allahabad. Most of them were also within the permissible limit to be considered potable.
13	Barakat et al. (2013).	Assessed the water quality in open channels of Beni-Mellal City, Morocco, in terms of physicochemical, bacteriological parameters and trace metals before reaching the irrigation areas.	Comparing with Food and Agricultural Organization (FAO, 1994) Standards, the results indicated that the channels water was suitable for irrigation purpose. Various determinants such as electrical conductivity, residual sodium carbonate, total dissolved solids and total hardness were in the desirable range.
14	Huang (2013)	Tested and analyzed the water quality of Yue-Guan Canal, China, based on the quality parameters viz., pH, TDS, Cu, NH_3-N and Cr (VI). He modeled the water quality of the whole canal based on LULC.	The main pollutant was NH3-N, pH was higher in the upstream than the downstream, where more rural industries involving metal processing were located. Cu concentration was higher in the downstream due to industrial effluent. TDS exhibited an increasing trend from the upstream to downstream due to the increasing salinity as it got closer to the ocean. Cr (VI) was not found except at one site suggesting possible illegal discharge of industrial wastewater.
15	Mohamed (2013)	Carried out water quality assessment through chemical properties of the El-Salam canal (Egypt) in three seasons i.e. winter, spring and summer, for irrigation suitability. The irrigation water quality metrics were also computed. The results were compared with FAO (1994) standards.	Based on FAO (1994) guidelines, there are no problems with chemical properties of irrigation quality like ESP, SSP, SAR, RSC, PI, KR, EC and thus, all the samples were found suitable for irrigation. However, EC, cations and anions have increased in summer season as compared to other seasons. Further, SAR, Na and Cl in waters of different locations increased progressively with increasing salinity.
16	Rama et al. (2013)	Studied the environmental quality of Damodar River and its two canal systems to assess their suitability	Concentration of major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, NO_3^-, PO_4^{2-}, and SO_4^{2-}) of the analyzed physicochemical parameters were within the prescribed standards and

		for irrigation using SAR, % Na and Permeability Index.	thus, suitable for irrigation. But a severe organic pollution load was noted at all the sampling sites, thereby demanding regular monitoring.
17	Bassuony et al. (2014)	Studied evaluation of irrigation water quality in different regions of North East Delta in Egypt. Different tests were conducted to determine the salinity, sodicity and permeability.	Canal water was considered suitable for irrigation in terms of salinity (EC, TDS, and TH); sodicity as well as permeability (pH, SSP, SAR, RSC and MR). However, water wells in some locations were considered unsuitable. Also, water drains in El-Gabel El-Asfar were unsuitable, because of their high EC, Cl^-, SAR and RSC.
18	Elhaddad (2014)	Assessed effects of pollution on hydro-chemical and water quality assessment of the Ismailia Canal water, Egypt.	The computed values of SAR, %Na, MAR, RSC along with the physicochemical variables and heavy metals showed that all of the Ismailia Canal water is of acceptable irrigation quality limits.
19	Matta (2014)	Evaluated water quality of Ganga canal system at Haridwar, India, by focusing on the physicochemical parameters of water samples at two sites (Bhimgoda Barage and Bahadrabad) in monsoon, summer and rainy seasons.	Results were more during rainy and summer seasons at Bahadrabad site as compared to at Bhimgoda Barrage site. The water was suitable for domestic purposes. But, the source of contamination was from domestic, human and industrial sewages and the quality of water is depleting rapidly with the change in human practices. Sewages, solid and liquid contaminants of organic nature were found to be the prime source of pollution. Phytoplankton diversity was high.
20	Atta-Darkwa et al. (2016)	Assessed the irrigation suitability of water in Oda river basin, Ghana using irrigation quality metrics viz., SAR, % Na, TDS, EC, MAR and KR.	All the values of the indices used were within the maximum allowable limits and thus, the water is suitable for irrigation purposes.
21	Husien et al. (2017)	Carried out assessment of water quality for irrigation in lowlands of the Bale Zone (South Eastern Oromia), Ethiopia.	In their study surface irrigation water has less salinity, sodium hazard and residual sodium carbonate hazard in the irrigated canals and canals along the farms. EC, RSC, Na concentration within the permissible limits. The salinity indicator parameters

			such as all cations and anions, total dissolved solid, adjusted sodium ratio, residual sodium carbonates in the irrigated rivers were low. The river in both districts was normal for agricultural production for all types of crops which are grown in the low lands of Bale.
22	Manohar et al. (2017)	Conducted water quality assessment of Yatta Canal, Kenya, for Irrigation. Water samples were collected once in a month during the wet and dry seasons to monitor its suitability for irrigation.	Most of the physical and chemical levels are within the permissible limits as recommended by FAO and also by Kenya's National Environment Management Authority with the exception of Turbidity (100.2 NTU) and Nitrate concentration (13.1 mg/L) only during the wet season. Based on the results, the canal water is safe for irrigation during dry season.

2.3 Water Quality Assessment for Livestock Drinking

This section deals with the various researches related to assessment of water quality for livestock drinking purposes across different parts of the globe. This includes the studies on effects of physicochemical as well as biological parameters and the toxic trace metals on quality of water for livestock drinking. This is a very crucial concern as it directly affects their health and thereby, propagate to human beings through food chain, livestock products etc. Some of the remarkable prior works in this context are presented in **Table 2.2**

Table 2.2: Review of water quality assessment relevant to livestock drinking

Sl. No.	**Author (Year)**	**Work Done**	**Remarks**
1	Ayers and Westcott (1985)	Emphasized on the harmful effects of water contamination for livestock drinking.	Undesirable quality of water adversely affects growth and reproduction ability of animals. Consumption of water with excessive salts may be detrimental to livestock and some ions can cause specific problems, even leading to death. Thus, the livestock drinking water should be free of contaminants in terms of physicochemical parameters and organism load.

2	Hooda et al. (2000)	Reviewed water quality issues in livestock farming for UK. Several best management practices were suggested for the control of pollutants from diverse sources.	Increased losses of nutrients, farm effluents, particularly livestock wastes, pesticides such as sheep-dipping chemicals, bacterial and protozoan contamination of soil and water are some of the main concerns regarding water quality degradation. Results from several field studies indicate that a rational use of manure and mineral fertilisers can help reduce the pollution problems arising from livestock farming practices.
3	LeJeune et al. (2001)	Carried out an assessment of microbial water quality parameters relevant to livestock drinking water for 98 dairy farms within the states of Washington, Oregon, and Idaho.	The results demonstrate that drinking water offered to cattle is often of poor microbiological quality. The association between the water quality parameters and the ecological factors measured suggest that many of the same factors that influence the survival and proliferation of bacteria in natural aquatic ecosystems have parallels in cattle water troughs.
4	Abbas et al. (2008)	Focused on the importance of water quality specific to poultry farms.	Water constitutes almost 65 percent of the weight of a chicken and its eggs. Moreover, it also constitutes almost 70 percent of the cells and about 30 percent of the fluids around the cells. Thus, water consumed by poultry should be of good quality.
5	Abd-El-Kader et al. (2009)	Studied the effect of poor quality of water on eggs.	Comparison of different cases confirmed that water of low quality affects layer production performance which was indicated by decreased egg production and egg quality.
6	Looper (2012)	Described the importance of water quality on livestock drinking.	Water constitutes 60 to 70 percent of the body of livestock. It is also a vital nutrient, involved in many aspects of poultry metabolism and other animals. It has a significant role in metabolic processes such as digestion, food absorption, nutrient transport and waste products elimination.
7	Sardar et al. (2013)	Investigated the heavy pollution in a canal and its detrimental effects on	The heavy metals are harmful when their accumulation rate is more than the discharge. These may also enter the food

		livestock health.	chain causing damaging effects to plants and animals. These are non-degradable and can accumulate in the body system of animals, causing damage to internal organs and nervous system. They are toxic and thus, cause growth reductions in animals.
8	Pandey and Madhuri (2014)	Emphasized on the nature and harmful effects of heavy metals viz., Zinc (Zn), Selenium (Se), Copper (Cu), Thallium (Tl), Chromium (Cr), Cadmium (Cd), Mercury (Hg), Manganese (Mn), Lead (Pb) and Arsenic (As), on livestock health.	The metals like Chromium show carcinogenic effect due to its unusual oxidation phases and hence, may cause toxicity. The heavy metals are normally non-toxic in their metallic and insoluble compound forms. The toxicity in metals is imparted mainly by the ligands. The elementary researches in this context are based on study of several animal species. Due to their poor biodegradability and environmental stability, these pollutants amass and persist in the animal bodies.
9	Korgaonkar et al. (2014)	Assessed the effects of poor quality water on livestock bodies and products.	Poor quality of water may cause livestock health deterioration and consequential inferiority in livestock products. As a result, the producer may incur monetary losses. Moreover, the contaminated water may propagate to human beings through consumption of livestock products and thereby, affect adversely to human health.
10	El Mahdy et al. (2016)	Described the necessary conditions of water quality relevant to health sustenance and reproduction ability of domestic animals.	Water quality administered to livestock must meet the requirements for potability, prerequisite to maintaining the health, externalization full productive potential and sustaining breeding. Its degradation above permissible limits may result in decrease of milk production, decreased feed conversion rate and average daily gain, degradation of health status by reducing the local resistance, decreased overall body resistance, metabolic, decreasing fertility, digestive, skeletal disorders etc.

2.4 Water Quality Assessment for Human Drinking

This section deals with the various researches related to assessment of water quality for human drinking suitability across different parts of the globe. This includes the studies on effects of physicochemical as well as biological parameters and the toxic metals on quality of water for human health. Some of the remarkable prior works in this context are presented in **Table 2.3.**

Table 2.3: Water quality assessment studies for suitability of human drinking in different countries

Sl. No.	Author (Year)	Work Done	Remarks
1	Alam et al. (2007)	Water samples were collected and analyzed for various water quality parameters of Surma River, Bangladesh (within the Chattak to Sunamganj portion), which is significant due to the presence of two major industries- a paper mill and a cement factory. The effects of industrial wastes, municipal sewage, and agricultural runoff on river water quality have also been investigated.	The river was highly turbid in the monsoon season whereas, the BOD and Faecal Coliform concentration was higher in the dry season. The water was slightly acidic. It was concluded that the water was certainly unfit for drinking purposes without any form of treatment. However, for various other surface water usage purposes, it still could be considered quite acceptable.
2	Kar et al. (2008)	Studied different surface water samples collected from river Ganga in West Bengal during 2004-05 and analysed for pH, EC, Fe, Mn, Zn, Cu, Cd, Cr, Pb and Ni.	They observed values of pH and EC were within the limits for drinking (WHO, 1973), but not the heavy metals. The dominance of various heavy metals in the surface water of the river Ganga followed the sequence: Fe > Mn > Ni > Cr > Pb > Zn > Cu > Cd. The river water as such is not suitable for drinking purpose due to the excess concentrations of Fe, Mn, Pb and Ni.
3	Venkatesharaju et al. (2010)	Investigated the water quality of River Cauvery in Kollegal stretch, Karnataka. Different physicochemical and bacteriological parameters were considered at seasonal and	The pH, EC and hardness levels were moderate. The values of DO, BOD and COD indicated the absence of major organic pollution sources. Seasonal and annual averages of plant nutrients like Phosphate, Nitrates,

		annual level for assessing suitability for drinking purposes.	Potassium and Sulphates had no significant variation in their concentration. The major source of organic pollutants is only the domestic source. Population density spread over sparsely located villages like Dasanapura and Harle certainly contributes towards Faecal Coliforms. Thus, the river water was not suitable for drinking purposes from the point of view of bacteriological parameters.
4	Kundu (2012)	Determine the concentrations of different ions present in the surface water of Ghaggar River system, to assess its suitability for drinking purposes. Different physicochemical parameters pertinent to water quality were estimated.	River water at most of the sites was highly influenced by the point source pollutants at the joining points. These point sources generally carried wastewaters due to industrial and municipal sectors and agricultural runoff. Some anthropogenic activities like river bed mining, disposal of untreated effluents from industries along with agricultural wastes may result in deterioration of water quality of Ghaggar River system. Concentration of the physicochemical parameters revealed the water at the sampling sites to be unsuitable for human drinking.
5	Ombaka and Gichumbi (2012)	Carried out physicochemical and microbiological analyses on water and sediment samples from Ruguti River in Meru South, Kenya, to ascertain the water quality. They compared the mean of the obtained results with WHO (2011) standards for drinking water.	The physicochemical parameters such as T_W, EC, TDS, TA, TH, sulphates, chlorides and fluorides were in compliance with the WHO (2011) standards whereas, turbidity, nitrite and nitrates levels were higher. The mean values for all trace metals at all the sampling sites of the water samples were below the standards for drinking water except Fe, Mn and Al. Sediments have lower carbonaceous matter and higher mineral contents. Overall, the Ruguti River is

			contaminated and use of the water for domestic purposes by the inhabitants could lead to hazardous side effects.
6	Seerja and Pillai (2012)	Collected water samples from Kodayar River to assess the quality in terms of the physicochemical parameters across few stations of the river. They compared the results with the standards prescribed by WHO (1973) and BIS (10500: 1991).	The water samples were not much contaminated and fit for domestic purposes. The physicochemical parameters were within the water quality standards. But, in some sites, SO_4^{2-}, NO_3^-, PO_4^{3-} were found to be increasing, which is due to the discharge of domestic wastes, animal wastes, hospital wastes and also effluents from small cottage industries. Thus, reliable monitoring measures are essential for keeping a close watch on water quality.
7	Yahaya et al. (2012)	Evaluated the heavy metal contents in the surface water of Oke-Afa Canal (Isolo Lagos), Nigeria, and also determined their pollution trends.	Cd, Ni and Pb in most of the samples were above the WHO Standards for drinking limits, except only Zn values were below the standard. The canal water was grossly polluted with heavy metals and their toxicity effects, which exceeded the WHO Standard limits. Thus, it was not suitable for human drinking without prior treatment.
8	Gupta et al. (2013)	Evaluated water quality of Yamuna River from different sampling sites in Agra City. The water samples were collected and analyzed for different physicochemical parameters. The results were compared with WHO standards.	Yamuna River water was found to be alkaline in nature. The turbidity and TDS were also above the WHO permissible limits. Most of the parameters investigated were at the level of pollution except total hardness and Chlorides. Thus, Yamuna River in the Agra city was highly polluted and unsafe for human use during the study period.
9	Dash et al. (2015)	Evaluated water quality of local streams and Baitarani river in Joda region (Odisha), India, for drinking purposes.	The values of most of the parameters were high in post- monsoon period. The pH, EC, TDS, TH, the major cations and anions in all samples and DO values in most of the samples

			were well within the BIS and WHO limits. But turbidity, TSS, total and faecal coliform units and in some cases BOD values were beyond the limits. Thus, the water is not suitable for drinking purposes.
10	Frimpong et al. (2015)	Evaluated the physicochemical and microbiological quality of water in streams of Brong Ahafo region (Ghana) for human drinking.	Most of the physicochemical parameters were within WHO guidelines recommended for potable water with the exception of Turbidity. However, the water was unsuitable for drinking purposes due to microbial contamination, which was beyond the WHO permissible limits.
11	Kaur and Kaur (2015)	Studied the seasonal variations in oxygen demanding parameters (DO, BOD, COD), and drinking water suitability for Sirhind Canal passing through Moga (Punjab), India.	DO was found to be decreased in summers but has shown elevated values during monsoon. Decreased The DO level in summers can be attributed to increased temperature in summer. BOD and COD values were high during summer following by winter & monsoon. A high BOD value indicated the presence of a large number of microorganisms, which showed a high level of pollution. The water was found unsuitable for drinking in summer season.
12	Lukubye and Andama (2017)	Assessed the physicochemical quality of selected drinking water sources (springs, boreholes and shallow wells) in Mbarara municipality, Uganda with respect to WHO drinking water guidelines.	The parameters like pH, DO, BOD and hardness in water were not permissible and hence, the water was not suitable for drinking. The water have been compromised mainly by the increased human activities especially improper sanitation.
13	Oboh and Agbala (2017)	Carried out water quality assessment of the Siluko River, Southern Nigeria, for human drinking. Water samples were collected from three sites at monthly level for six months.	Out of thirteen physicochemical parameters, turbidity, dissolved oxygen and phosphate were above the permissible limits by WHO guidelines, for some months. However, from the WQI analysis, the

			water quality was found to be excellent for human drinking.
14	García-Ávila et al. (2018)	Evaluated water quality of the drinking water distribution network in the Azogues city, Ecuador. Thirty samples were collected at monthly basis for six months.	The assessment of physicochemical parameters viz., turbidity, T_w, EC, pH, TDS, TH, calcium, magnesium, alkalinity, chlorides, nitrates, sulfates and phosphates, revealed all of them to be within permissible limits during all the months.

2.5 Water Quality Index (WQI)

WQI is a mathematical technique which gives a single number that expresses the overall water quality at a definite location and time, based on numerous water quality parameters. It assimilates all the physicochemical parameters and toxic trace metals into a single numerical value thereby, making it easy for decision-making. The applications of WQI across different countries of the world are presented in the **Table 2.4**.

Table 2.4: Review of WQI applications for water quality assessment in different countries

Sl. No.	Author (Year)	Work Done	Remarks
1	Štambuk-Giljanović (1999)	Applied WQI for evaluation of water quality in Dalmatia County (Southern Croatia) for a three year period (1995, 1996, 1997), considering nine parameters.	The increase of sulphate as well as chloride in springs, rivers and underground waters decreases the WQI value. The surface waters are not in 'Excellent' condition for drinking purposes.
2	Banerjee and Srivastava (2009)	Applied WQI for assessment of surface water quality in IIE-Pantnagar, India, during winter, summer, monsoon and post-monsoon seasons.	During summer season, WQI inside IIE-Pantnagar varied from 47.4 to 66.6, revealing moderate to good surface water quality. However, in monsoon and post-monsoon seasons, WQI demonstrated a modest increase in quality for all sampling points, with a few exceptions due to dilution caused by monsoonal rainfall.
3	Kumar and Dua (2009)	Assessed the pollution status of the River Ravi, India by using Water Quality Index.	The WQI values for the River Ravi ranged from 54.8 to 97.88. Thus, although it is within the limit, the water

			may become unsuitable as WQI is on verge of unsuitability at some sites. The anthropogenic activities were adjudged to be the main reasons for the pollution.
4	Chauhan and Singh (2010)	Calculated water quality index for the Ganga River, India at Rishikesh for drinking, recreation and other purposes by using the relevant water quality parameters.	They concluded that the river Ganga water at Rishikesh is completely unsuitable for drinking purpose of human beings, wild animals and cattle.
5	Srivastava et al. (2011)	Collected water samples from six different locations along with the route of Ramganga River and analysed for some physico-chemical parameters levels at pre-monsoon period and post-monsoon period following standard methods of sampling and testing. The WHO standards were adopted for calculation of water quality index.	The WQI values revealed that river water quality at almost all the locations were found to be contaminated for pre-monsoon as well as post-monsoon period. A comparison of data for two seasons clearly indicates improvement in the river water quality in post-monsoon period. The main source of contamination in Ramganga river water is from domestic, human & industrial waste discharges. The quality of water has depleted rapidly with the change in human life style i.e., massive industrialization, construction activities, utilization of agricultural land and forest land for other developmental purposes.
6	Akkoyunlu and Akiner (2012)	Investigated the stream water quality in Sapanca Lake Basin (Turkey) by WQI. Fifteen physicochemical parameters were considered for calculating WQI, whose limits were obtained from Canadian Council of Ministers of the Environment (CCME) and National Sanitation Foundation (NSF).	WQI scores were found to be effective for designating the pollution in streams feeding into Sapanca Lake. The weightage factors play a major role in deciding the overall quality of water.
7	Khwakaram et al. (2012)	Studied the results obtained on Water Quality Index for the different sampling sites in Qalyasan stream, Sulaimani city,	The results indicated heavy pollution at some of the sites which hints at a number of sewage outlets and industries around. The water quality

		Kurdistan, considering the important physiochemical parameters in order to evaluate the suitability of water for various purposes.	rating at most of the sampling sites clearly showed that the status of the water body in Qalyasan stream was degraded and unsuitable for the human uses during the period of study because it was not within the WHO standards. They concluded that discharging of domestic and industrial wastewater and also other anthropogenic activities were the main factors for contaminating the stream.
8	Kumar and Chopra (2012)	Investigated the water quality aspects of abandoned Old Ganga Canal at Haridwar. Water Quality Index was computed considering the chemical as well as biological contaminants and trace metals.	The microbiological and physicochemical parameters revealed for a high contamination level. The Water Quality Index showed that canal water quality changed bad after drainage and discharge of domestic wastewater and agricultural runoff which considerably increased the physicochemical, microbiological and metal contents, which deteriorate the water quality of Old Ganga Canal.
9	Kankal et al. (2012)	Studied the physicochemical parameters; WQI of surface water bodies (river, lake and canal) of Gujarat, India. Results were compared with standard values given by World Health Organization (WHO) and United State Salinity Laboratory for drinking and irrigation purposes.	Results show that the WQI is observed in the range of 44 to 61 and expected in the range of 45 to 64 which shows marginal water quality for drinking purposes. Results show that quality for irrigation purpose is quite good
10	Rama et al. (2013)	Assessed pollution status of the Damodar river and its two canal systems by WQI.	The WQI values were found within the limits to be considered suitable for agricultural applications.
11	Goher, et al. (2014)	Evaluated surface water quality in terms of heavy metal contents for Ismailia Canal, Egypt. The weighted arithmetic method of WQI was used to evaluate the canal for drinking, irrigation and aquatic life.	The WQI for drinking and aquatic life were from ‘Good’ to ‘Poor’ across various sites. But, WQI was ‘Excellent’ for irrigation utilization for all the sampling sites.

12	Kaur and Kaur (2014)	Studied various parameters and their seasonal variations through water quality index (WQI) of Sirhind Canal passing through Moga (Punjab), India. The parameters were compared among various seasons.	WQI values were highest for summer season. The parameters have shown increased concentration during summer in comparison to monsoon and winter except nitrate and phosphate that have shown maximum concentration during monsoon by accelerating the process of eutrophication and due to flushing out of the agricultural runoff from adjacent agricultural fields. Parameters have shown significant variations at ($p<0.005$) level.
13	Sharma et al. (2014)	Assessed WQI of post-monsoon water samples of Ganges river at various locations in Allahabad stretch including that from the confluence with river Yamuna. Physicochemical parameters such as T_W, pH, EC, DO, TDS, alkalinity, major cations and anions were considered for WQI determination.	Based on the permissible limits by WHO and BIS, WQI of Ganges river water at Allahabad ranged from 86.20 to 157.69 which falls in the range of poor quality of water. WQI may be a useful tool for assessing water quality and predicting trend of variation in water quality at different locations in the Ganges river.
14	Al-Mashagbah (2015)	Assessed the water quality of King Abdulla canal, Jordan, using physicochemical characteristics and water quality index (WQI) in four different seasons.	Water quality status was from ‘Excellent’ to ‘Good’ in the upper part of the canal and from ‘Poor’ to ‘Very poor’ in the lower part of the canal. Results were compared with the WHO and Jordan standards. Lower part of the canal was polluted from different contaminations and it was not safe for domestic use.
15	Sun et al. (2016)	Calculated WQI to assess the spatiotemporal variability and identify the classification of water quality in the Dongjiang river, China. Based on correlation analyses, the six most influential parameters were selected to calculate WQI.	The results showed an excellent water quality in the tributary site near the reservoir, a good water quality in the upstream of the river, and medium water quality in the downstream of the river, which suggested that the urban wastewater originated from increasing population size and industry development in the downstream mainly led to the deterioration of water quality

			along the river.
16	Zahedi (2017)	Applied WQI to evaluate groundwater quality and its suitability for irrigation and human drinking purposes, over semi-arid regions of Karaj plain, Iran.	Out of 109 wells, 106 were in ‘Good’ and only 3 were in ‘Excellent’ category for irrigation. For drinking purposes, 63 wells were classified in the ‘Excellent’ class, 36 wells were classified in the ‘Good’ class, 10 wells were placed in the ‘Poor’ class.

2.6 Correlation Matrix for Analysis of Water Quality Parameters

The correlation coefficient ‘r’ is a measure of the strength of linear relation between two variables. Therefore, ‘r’ is computed to obtain dependence existing among the variables so that it can be helpful to compensate the data unavailability, if required. This will also be helpful to decide the most influential variables for monitoring the water quality. Some of the previous works carried out in this context are presented in **Table 2.5.**

Table 2.5: Literature review on correlation-based analysis of water quality parameters

Sl. No.	Author (Year)	Work Done	Remarks
1	Ibrahim and Saseetharan (2007)	Collected Ground water samples from 18 wards of Coimbatore city north zone, where 2 samples were collected from 2 different locations for each ward, i.e. total 36 samples were collected. Correlation coefficients were determined to identify the highly correlated and interrelated water quality parameters.	Comparison of observed and estimated values of the different parameters reveals that the regression equations developed in the study can be very well used for making water quality monitoring by observing only the parameters viz., like temperature, turbidity, pH, electrical conductivity, total dissolved solids, chlorides, hardness, alkalinity, calcium, sodium and potassium only. This provides an easy and rapid method of monitoring of water quality.
2	Kar et al. (2008)	Carried out correlation analysis of the toxic trace metals and physicochemical parameters for water samples collected from river Ganga in West Bengal for a	A significant positive correlation was exhibited for electrical conductivity (EC) with Cadmium and Chromium in water. But Manganese exhibited a negative correlation with EC.

		year.	
3	Sinha et al. (2009)	Developed an approach for water quality management through correlation and regression studies between various water quality parameters for six data points of underground drinking water of different hand pumps at J.P. Nagar, India.	Regression analysis suggests that conductivity of underground water is found to be significantly correlated with eight out of twelve water quality parameters studied. It may be suggested that the underground drinking water quality at J. P. Nagar can be checked very effectively by controlling the conductivity of water.
4	Jothivenkatachalam et al. (2010)	Correlation and regression amongst various physicochemical and biological parameters such as pH, Electrical Conductivity, TDS, TH, total acidity, total alkalinity, Calcium, Magnesium, Chloride, Sulphate and DO was determined for Perur block (Tamil Nadu), India.	A significant linear relationship among different pairs of water quality parameters was obtained. Distribution of TDS, TH, Calcium, Magnesium and Chloride were significantly correlated ($r > 0.5$) with Electrical conductivity in most of the study areas. Highest positive correlation is observed between EC and TDS (0.9780) while highest negative correlation coefficient is seen among pH and TA (-0.0796)
5	Verma et al. (2012)	Analyzed the physicochemical characteristics of the water to know the present status of the canal water quality of Allahabad. He computed correlation amongst these physicochemical parameters to find any inter-dependencies.	The correlation between chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were found highly significant.
6	Gupta et al. (2013)	The correlation analysis was done for the parameters like Turbidity, pH, Total Dissolved Solids, Electrical Conductivity, Total Hardness, Total Alkalinity, Chloride, Calcium and Magnesium, were carried	Only significant correlation was found for total hardness and total dissolved solids with respect to Chlorides. There was no significant correlation for the other parameters.

		out for Yamuna River in Agra city.	
7	Rama et al. (2013)	Calculated correlation between physicochemical parameters of water quality over Damodar river and its two canal systems.	All the parameters excluding pH, phosphate and BOD, were exquisitely correlated. The sulfate was found to possess maximum positive correlation with all other parameters.
8	Islam et al. (2014)	Assessed the correlation amongst the trace metals related to contamination of water and sediment of some rivers in Bangladesh.	Very significant correlation was found for most of the metals in water with respect to their corresponding contents in sediment.
9	Al Obaidy et al. (2014)	Assessed correlation amongst 8 toxic trace metals for surface water samples collected from Mahrut River in Diyala City, Iraq.	Although all the correlation values were positive, only a few of them were significant. Maximum correlation was observed between Mn and Pb (r = 89) while that of minimum between Cr and Zn (0.09).
10	Brraich and Jangu (2015)	Calculated correlation amongst 10 heavy metals to assess the contamination status Harike wetland (Ramsar site), India. Water samples were collected from March 2013 to February 2014 in four different seasons of the year from five sites.	Both positive and negative correlations were found, but only a few of them were significant. Highest positive correlation was observed between Manganese and Nickel (0.949), whereas the highest negative correlation was observed between Copper and Lead (-0.967).
11	Matta et al. (2015)	Carried out correlation analysis amongst six phytoplankton species and 12 physicochemical variables over two sites for Ganga canal in Haridwar.	A significant positive correlation was recorded for all the phytoplankton species with Na, NO_2, NO_3^-, SiO_3, HCO_3, PO_4, Ca, Mg, and, a negative correlation with DO at both the sites.
12	Song et al. (2015)	Assessed the correlations between the heavy metal (Cu, Zn, Pb and Cd) concentrations with organic matter, total nitrogen and total phosphorous in Weihe River of Shaanxi Province,	Significant correlations were found between the heavy metal concentrations. Total phosphorous and total nitrogen possessed insignificant correlations with all the parameters. Organic matter had a significant positive correlation with

		China.	Cd and Zn only.
13	Adewuyi et al. (2017)	Analyzed physicochemical parameters for dependencies through correlation matrix over Yewa river in Badagry Creek Lagos, Nigeria.	The parameters were positively correlated, though not significant for all the cases. The highest correlation was observed between EC and TDS (r = 0.999), whereas both of them had lowest correlation with pH (r = 0.05).
14	Mohanty and Nayak (2017)	Computed correlation amongst 15 physicochemical parameters over Brahmani River, India, during winter, summer and monsoon seasons.	Both positive and negative correlations were observed amongst the parameters. The correlation was poor during monsoon season compared to the winter and summer seasons. During all the three seasons, Na^+ and Cl^- were highly correlated.
15	Tajmunnaher and Chowdhury (2017)	Performed correlation analysis of water quality parameters over Kushiyara River at Sylhet division, Bangladesh, for winter and rainy seasons.	The results revealed pH to be significantly correlated with water temperature, BOD, COD, total solids and TDS, during rainy season. The correlations were comparatively weaker in winter season.

2.7 Numerical Modeling

The numerical investigation of pollutant dispersion in surface water sources is crucial as it enables to understand the influence of pollutants in particular sections of a channel. The alterations in water quality due to discharge of sewage i.e. the effects of sewage inflow velocity as well as the size of sewage particles on water quality can be assessed by numerical modeling. Some of the previous works carried out in this context are presented in **Table 2.6.**

Table 2.6: Literature review on numerical modeling for pollutant dispersion

Sl. No.	Author (Year)	Work Done	Remarks
1	Runkel (1995)	Presented two numerical models OTIS (One-Dimensional Transport with Inflow and Storage) and OTEQ (one Dimensional transport with equilibrium chemistry) that simulate conservative and non-conservative solute transport in streams	OTIS may be used in conjunction with tracer-dilution methods to quantify hydrology transport processes (advection, dispersion, lateral inflow and transient storage), whereas OTEQ may be used to quantify chemical

		respectively.	processes within the background of hydrology transport.
2	Adamsson et al. (2003)	Implemented a boundary condition based on bed shear stress in FLUENT CFD tool and evaluated against laboratory data. A particle is trapped if the local bed shear stress is below the critical bed shear stress; otherwise, the particle is resuspended.	The approach gave satisfactory agreement with measured sedimentation efficiency data, and the simulated spatial distribution is very similar to the sediment distribution observed in a laboratory tank.
3	Modenesi et al. (2004)	Developed a three-dimensional model based on CFD techniques for pollutant dispersion in Atibaia River in São Paulo, Brazil. The model was specifically designed to be fast, providing a significant improvement in performance of CFD models, which were used to take a huge computational time.	The new CFD model was capable of giving detailed information on the dispersion of inert soluble particles in a river, despite the simplifications considered. The comparison between experimental data and model results indicates that the model is suitable for predicting particle dispersion. The model is very fast, making it a powerful tool for risk assessment.
4	Kachiashvili et al. (2007)	Simulated transport and diffusion of chemicals substances for two rivers in Western Georgia flowing into the Black Sea, using transient convection–diffusion–reaction partial differential equations. The diffusion and transport of chemicals (NO_3 and PO_4) were verified.	By analyzing the difference between the measured and the simulated values of controlled chemicals in the rivers, the effect of agricultural events along the banks of the river (in the interval between two sections) on the pollution degree of the Khobistskali River was estimated.
5	Di Sabatino et al. (2008)	Studied the flow within a small building arrangement and pollutant dispersion in street canyons opening from the simplest case of dispersion from a simple traffic source. Waft outcome from the commercial computational fluid dynamics (CFD) code FLUENT are validated against wind tunnel data (CEDVAL). Dispersion results from FLUENT are analyzed using the good-validated atmospheric dispersion mannequin	The analysis indicates that the CFD mannequin well reproduce the wind tunnel glide measurements and compares adequately with ADMS-urban dispersion predictions. The analysis suggests that utilizing a CFD mannequin equivalent to FLUENT for atmospheric dispersion requires a number of concerns regarding the grid decision, floor roughness, inlet

		ADMS-urban. Sensitivity of dispersion outcome to wind path within road canyons of facet ratio equal to 1 is investigated.	stipulations, discretization ways and the selection of the right turbulence and dispersion units.
6	Hossain and Naser (2009)	Developed a 2-D turbulence dispersion analytical model for particle diffusion and deposition for altered heights at crossways of the flow in the pipe and peripheral accumulation. This settling was found to be dependent on diameter of particle, its density and velocity of fluid. Also, this accumulation was examined along with the circumferential wall and also at different depths.	It was found that the settling of bulky particles at the bottom was obtained more at low velocities and minimal at higher ones. The lighter particles were observed suspended homogeneously.
7	Buccoliri et al. (2010)	Studied the flow field and dispersion of pollutant in a particular section of canal Grande (Venice), both experimentally as well as numerically. Numerical study was carried out to evaluate the consequence of water surface on flow of air and atmospheric mass fractions of pollutant.	Initial results showed that due to the water at the bottom altered airflow and turbulence scale with straight impact on distribution of mass fraction inside the field.
8	Martínez-Solano et al. (2010)	Applied a CFD tool called FLUENT to model flow as well as concentration field within 3-D rectangular storage tank. In numerical analysis, using RANS equation and turbulence viscosity concept, the closer problems were solved.	When simulation was done for transport of tracer by use of advection equation inside the storage tank, the final result demonstrated that around 82% tank was completely under mixing condition.
9	Etemad-Shahidi and Taghipour (2012)	Used M5′ model tree to develop a new model for predicting the longitudinal dispersion coefficient. Extensive field data sets consisting of hydraulic and geometrical characteristics of different rivers were used. By using error measures, the performance of the model was also compared with the performance of other existing equations.	The results showed that the developed model outperforms the existing formulas and can serve as a valuable tool for predicting of the longitudinal dispersion coefficient. The main advantages of the model trees are that, they provide transparent formulas and offer more insight into the obtained formulas. Also, they are

			more convenient to develop and employ compared with other soft computing methods.
10	Chen et al. (2013)	Explored the characteristics of anisotropic diffusion of the unstable pollutants at the air-water interface. The connection between speed gradient and mass switch cost was once situated to calculate the turbulent mass diffusivity. Simulations and experiments were carried out to gain knowledge of the trichloroethylene (C_2HCl_3) liberate. By means of comparing the anisotropic coupling diffusion model, isotropic coupling diffusion mannequin, and non-coupling diffusion model, the aspects of the transport of unstable pollution at the air-water interface were determined.	The results exhibit that the anisotropic coupling diffusion mannequin is more accurate than the isotropic coupling diffusion model and non-coupling diffusion model. Mass transfer tremendously increases with the development of the air-water relative velocity at a low relative speed. However, at a higher relative pace, broadening within the relative velocity has no influence on mass transfer.
11	Marusic (2013)	Discussed the methods for predicting the pollution and determining the water quality parameters. The problems related to mathematical modeling of hydrodynamics and dispersion of pollutants in the river systems were also addressed.	There are many factors upon which the behavior of pollutant in the aquatic environment depends: physical chemical biological and hydrodynamic. Pollution is termed as ‘pressure’ that can influence the state of aquatic ecosystem.
12	Piller and Tavard (2014)	Introduced a new numerical technique in order to transform the water quality equations into a water transport equation. In order to model the water temperature in the network, an advection convection reaction was introduced using incompressible Navier-Stokes equation.	The method was able to calculate single species water quality indicator. The algorithm for solution comprised of time splitting method which combined an exact step by a characteristics method with an upwind Crank-Nicolson scheme.
13	Meddah et al. (2015)	Introduced a model of contaminant dispersion in the streams which are at far distances where dispersion is longitudinal as well as 1-D flow, using Transmission line matrix (TLM). In	The result showed quite good agreement with observed data and thus, the introduced model could be used to predict spatio-temporal evaluation of contaminant in

		order to validate the model, the result were compared with experimental data and observation collected from river Severn (UK).	natural stream for rapid and effective decision making.
14	Marusic et al. (2016)	Studied the usage of CFD tool in analyzing river type system in order to address the water quality problems. The spatial-temporal evolution of transport as well as dispersion of contaminant using this technique was analyzed. This also included a case study of accidental pollution of Prut River.	On the basis of bibliographical study, CFD was inferred to act as a power tool for determining water quality parameters and predicting emergency situations. From numerical simulations, it was concluded that the derived numerical model can be directly used for any case of pollution in the studied zones.

2.8 Critiques on Review of Literature

From the literatures reported, it is evident that deterioration of water quality has become a major issue in many countries. In India, with rapid increase in population, the available water resources per capita get reduced drastically. In such a scenario, contamination of water further aggravates the problem. This is crucial for canal water since these are the artificial water channels diverted from rivers to fulfill specific utilities. Consumption of water with a compromised quality is harmful to plants, animals and human beings, as evident from several prior studies. The Upper Ganga Canal (UGC) serves the purposes of irrigation, livestock drinking and human drinking in most of its riparian districts, for which, quality of water is a vital concern. A few investigations have been carried in this context. However, most of them have just quantified either physicochemical parameters or trace metal constituents. But comparison of individual parameters with authentic national and international standards/guidelines is imperative to assess the quality of water. There is hardly any study which has evaluated the suitability of UGC water for irrigation by considering physicochemical parameters, toxic trace metals and irrigation water quality metrics, altogether. A very few studies around the entire globe have been conducted to assess the quality of water for livestock drinking. Not many studies regarding water quality assessment for human drinking are executed too. In most of the studies reported, the parameters taken into consideration for evaluating water quality are less in number. This may be due to unavailability of sophisticated instruments or facilities for carrying out measurements. Even the allowable limits for all the parameters for a specific purpose may not be obtained from a single reliable standard. This is a key factor for Water Quality Index (WQI) and correlation analysis. Thus, it is necessary to assess the combined effects of all the influential physicochemical parameters and toxic trace metals, considering their permissible limits that can be obtained from multiple authentic standards. This will help to assign proper weightage to each parameter, ultimately leading to a robust WQI computation for determining the overall water quality. Moreover, most of the literatures found for water quality analysis at different canals and rivers worldwide are based on experimental investigations. However, numerical investigation of flow of water in Ganga River and its canals are rare in literature. Although a few studies are reported in which the flow behavior of water by mathematical modeling has been carried out. No study has been found on numerical investigation of water quality alterations due to inclusion of pollutants in river or canal. Thus, very little attention was paid towards the numerical assessment of water quality on inclusion of sewage as well as the velocity at which pollutants/sewages are discharged into the canal. Considering the above factors, an extensive study of water quality, accounting all the above gaps, has not been performed for any canal in India, in general and Upper Ganga Canal at Roorkee in particular. Therefore, it is essential to conduct a comprehensive water quality assessment for UGC, through experimental and numerical investigations.

CHAPTER 3

MATERIALS AND METHODS

This chapter presents the materials and methods used to accomplish this work. This encompasses about the study area, wherein the details of location as well as description of the sampling sites, about the collection of water samples, the analytical methods along with the instruments employed for determination of various parameters, relevant to the study. Further, the brief description of all these parameters (physicochemical and toxic trace metals) used to assess the quality of water is also presented in this chapter. This also covers the observed data and statistical summary for all the parameters, which are to be referred subsequently. The irrigation water quality metrics, which are widely used to evaluate the irrigation suitability of a water source, are discussed too. Details of the various national and international standards/guidelines which can be used to draw comparative conclusions for irrigation, livestock drinking and human drinking purposes are also included. Further, this chapter covers Water Quality Index (WQI) and its calculation procedure, which is to be used for evaluation of water quality of the Upper Ganga Canal. It provides a comprehensive view of the water quality by incorporating numerous parameters. The methodology to obtain association or dependency amongst different variables using correlation matrix is also presented. A detailed methodology for numerical modeling for pollutant dispersion through ANSYS Fluent, based on computational fluid dynamics is also covered in this chapter.

3.1 Description of the Study Area

The Ganges or Ganga Canal is a canal system intended to irrigate the Doab region i.e. the land lying between the two confluent rivers, namely Ganges and Yamuna (Bharati and Jayakody, 2010; Matta et al., 2015). The necessity of an effective irrigation system was discerned after the disastrous Agra famine of 1837-38 and subsequently, the Ganges canal system was commissioned in the year 1854-55. The canal has its origin from the mythological Ganga River and is basically an irrigation canal, though some of its parts are also used for navigation too (Singh, 2007; Lokgariwar et al., 2014). The canal is administratively divided into two parts i.e. the Upper Ganges Canal from Haridwar to Aligarh (Singh and Sirohi, 1977), with some branches, and the Lower Ganges Canal which constitutes several branches below Aligarh. The present study was carried out for the Upper Ganga Canal (UGC) around Roorkee, India which is located at 29° 87′ N Latitude and 77° 88' E Longitude in the district of Haridwar, Uttarakhand. The average elevation of UGC is

268 meters. The UGC starts at Bhimgoda Barrage near Har Ki Puri at Haridwar, flows from north to south through the center of Roorkee, then through Bulandshahr and Meerut, moves to Nanu in Aligarh district. From there, it bifurcates into Kanpur and Etawah branches, which are regarded as the parts of the lower Ganges Canal. The head discharge of UGC is 295 cumecs, which facilitates irrigation to an area of 20 lakh ha (Amarasinghe et al., 2013). The UGC system traverses for 6582 kilometers, including a main canal of 292 km, branch canals of 562 kilometers and long distribution channels. The agricultural lands of 9000 km^2 spread over Haridwar district in Uttarakhand; and the districts viz., Saharanpur, Muzaffarnager, Meerut, Ghaziabad, Bullandshahr, Gautam Budh Nagar, Aligarh, Hathras, Mathura, Agra, Etawah and Firozabad, in Uttar Pradesh, are benefitted by irrigation through this canal system. The maximum capacity of the canal in head reaches is proposed to be 370 cumecs (Mishra et al., 2013; Sharma and Singh, 2011; NRCD, 2009).

The locations of water sampling points in the UGC for the purpose of this study were selected based on reconnaissance survey. There were a total of 18 sites from which water samples were collected (**Figure 3.1).** All the 18 sites are within the district of Haridwar in Uttarakhand. Out of these, 12 sites are in main canal and 6 sites are in branch canals of the UGC. The details of location (latitude, longitude, elevation) of the sites and if they are in main canal/ branch canal, are presented in **Table 3.1**.

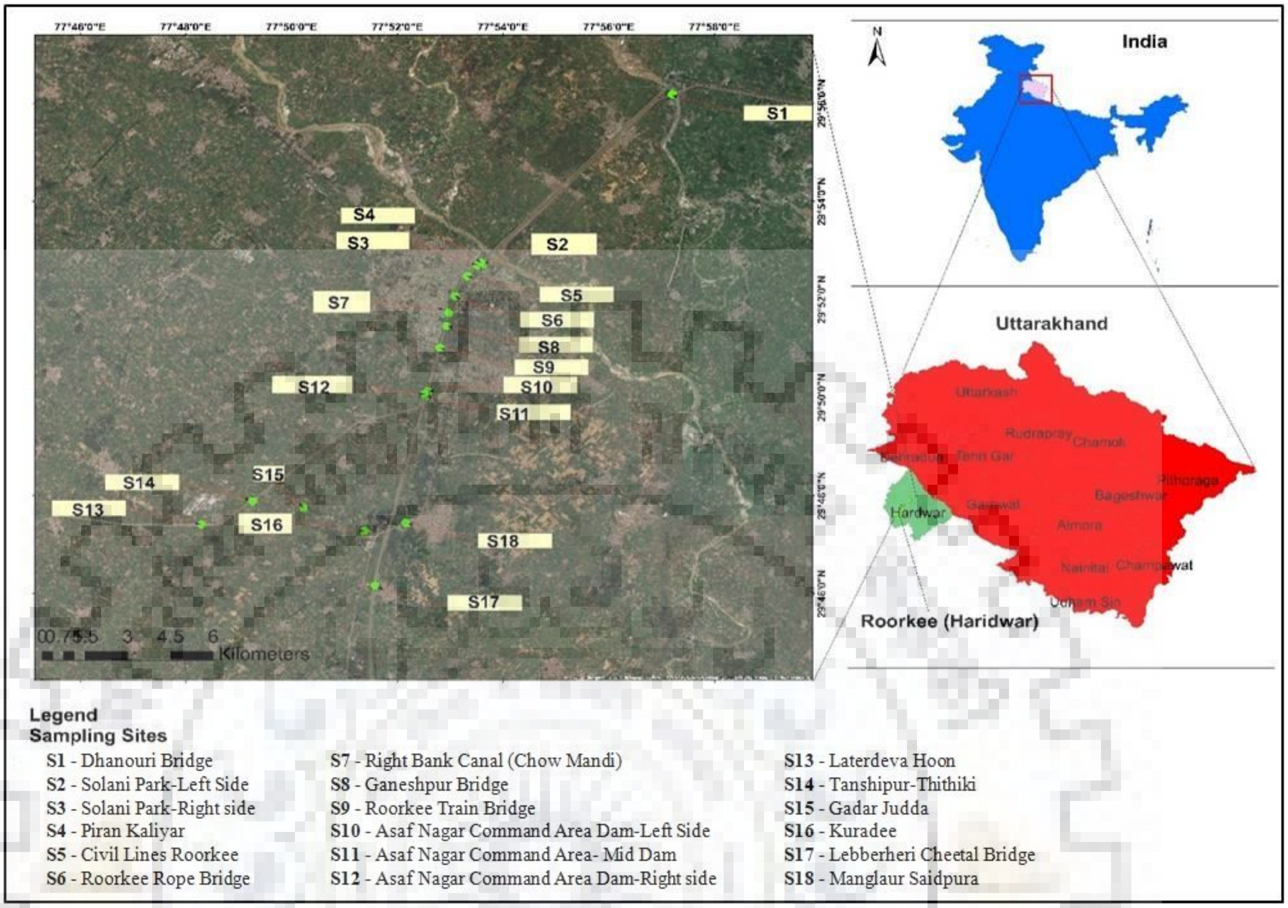


Figure 3.1 Locations of sampling sites in the study area (Source: Google Earth)

Table 3.1: Description of the sampling Sites of UGC

Description	Site Code	Latitude	Longitude	Elevation (m)	Type of water sample
Dhanouri Bridge	**S1**	29°56’ 0.70’’N	77°57’12.25’’E	261	Main Canal
Solani Park-Left Side	**S2**	29°52’42.55’’N	77°53’36.74’’E	261	Main Canal
Solani Park-Right side	**S3**	29°52’41.44’’N	77°53’30.75’’E	263	Main Canal
Piran Kaliyar	**S4**	29°55’15.72’’N	77°56’1.20’’E	261	Main Canal
Civil Lines Roorkee	**S5**	29°52’26.39’’N	77°53’20.20’’E	267	Main Canal
Roorkee Rope Bridge	**S6**	29°52’4.34’’N	77°53’5.33’’E	271	Main Canal
Right Bank Canal (Chow Mandi)	**S7**	29°51’43.68’’N	77°52’57.95’’E	269	Main Canal
Ganeshpur Bridge	**S8**	29°51’27.4’’N	77°52’56.18’’E	266	Main Canal
Roorkee Train Bridge	**S9**	29°51’1.15’’N	77°52’48.34’’E	267	Main Canal
Asaf Nagar Command Area Dam-Left Side	**S10**	29°50’6.66’’N	77°52’35.50’’E	265	Main Canal
Asaf Nagar Command Area- Mid Dam	**S11**	29°50’1.10’’N	77°52’32.63’’E	267	Main Canal
Asaf Nagar Command Area Dam-Right side	**S12**	29°50’2.74’’N	77°52’35.19’’E	263	Main Canal
Laterdeva Hoon	**S13**	29°47’24.55’’N	77°48’17.36’’E	259	Branch Canal
Tanshipur-Thithiki	**S14**	29°47’53.24’’N	77°49’15.60’’E	262	Branch Canal
Gadar Judda	**S15**	29°47’32.36’’N	77°51’5.58’’E	263	Branch Canal
Kuradee	**S16**	29°47’16.7’’N	77°51’22.53’’E	262	Branch Canal
Lebberheri Cheetal Bridge	**S17**	29°46’10.04’’N	77°51’34.64’’E	262	Branch Canal
Manglaur Saidpura	**S18**	29°47’26.35’’N	77° 52’ 9.41’’E	265	Branch Canal

3.2 Collection and Analysis of Water Samples

In this study, water samples were collected from eighteen sites i.e., S1, S2, S3,…, S17 and S18 (**Figure 3.1**) in the study area from a depth of 20-30 cm. The time of collection was between 6 A.M. to 12 A.M. in the morning and 1 P.M. to 5 P.M. in the afternoon hours. The one-liter polyethylene plastic bottles were thoroughly cleaned by 8M HNO_3, followed by repeated washing with de-ionized water, before collecting the samples. The samples were collected at monthly interval for a period of one year (from November, 2014 to October, 2015) with the aim of understanding the seasonal (winter, summer, and monsoon) variation (Bharati et al., 2011; Sapkota et al., 2013). The water samples were preserved in deep refrigerator (ice box) at 4^0C to prevent the possible alteration of parameters. The water samples preserved in ice box were then analyzed in the Department of Chemistry, Institute Instrumentation Centre, and Environmental Engineering Laboratory in the Department of Civil Engineering, IIT Roorkee. To remove the suspended particles, the samples were filtered through 0.45 micro-membrane filters. The procedures and methods of analysis were as per guidelines of American Public Health Association (APHA), 2005.

3.2.1 Physicochemical Parameters

From each monitoring station, water samples were collected monthly by applying the procedures of the APHA (2005), for the period of October 2014 to November 2015. Water samples were collected using 1000 milliliter acid-leached plastic (polythene) bottles. The physicochemical parameters namely pH, water temperature, electrical conductivity, Dissolved Oxygen and Total Dissolved Solids of the water were measured *In-Situ* at every monitoring station using portable measuring equipment, and chemical parameters like total alkalinity, total hardness, carbonate and bicarbonate, Boron, Sodium, Magnesium, Potassium, Calcium, Chloride, Nitrate, Sulfate, Zinc, Lead, Manganese, Mercury, Iron, Copper, Chromium, Cadmium, cobalt, Arsenic and Aluminum were analyzed in the environmental laboratory of the Civil Engineering Department, IIT Roorkee. Boron was measured by the carmine method using UV-VIS Spectrophotometer (DN 5000 HACH model). The methods and instruments adopted in the analysis of various physicochemical parameters are presented in Table **3.2**, followed by a brief description of these parameters (Matta et al., 2017). The detailed methodology adopted in the determination of these physicochemical parameters is given in Annexure A.

Table 3.2: Instruments and methods used for determination of the physicochemical parameters

Sl. No.	Parameter	units	Instrument used for Determination	Analytical Method
1.	Acidty/Alkalinity, pH	-	Electronic	Portable Single-multi-parameters water quality meters (Model OR900P)
2.	Electrical Conductivity, EC at 25°C	(µS/cm)*		
3.	Total Dissolved Solids, TDS	(mg/L)**		
4.	Calcium, Ca^{2+}	mg/L	Burette	Titration by EDTA
5.	Magnesium, Mg^{2+}	mg/L	Burette	Difference
6.	Sodium, Na^{+}	mg/L	Flame Photometer (Mode eL-378)	Calibration

7.	Potassium, K^+	mg/L	Flame Photometer (Mode eL-378)	Calibration
8.	Bicarbonate, HCO_3^-	mg/L	Burette Titration	Titration by standard H_2SO_4, 0.02N
9.	Carbonate, CO_3^{2-}	mg/L	Burette Titration	Titration by Standard H_2SO_4, 0.02N
10.	Chlorides, Cl^-	mg/L	Burette Titration	Argentometric Titration using standard $AgNO_3$, 0.0141N
11.	Sulfates, SO_4^{2-}	mg/L	Model HACH 2100AN	Turbidimetric
12.	Nitrate-Nitrogen, NO_3^- N	mg/L	UV-VIS Spectrophotometer (Model DN5000 HACH)	UV-VIS Spectrophotometric
13.	Dissolved Oxygen (DO)	mg/L	Electronic	Portable Single-multi-parameters water quality meters
14.	Chemical Oxygen Demand (COD)	mg/L	UV-Spectrophotometric using COD digester	UV-VIS Spectrophotometer (DN 5000 HACH
15.	Boron, B	mg/L	UV-VIS Spectrophotometer (Model DN5000 HACH)	Carmine

°C = degree Celsius; *µS/cm = microhm Simien per centimeter, **mg/L = milligram per litre

The crucial physicochemical parameters that were analyzed for various samples collected from the UGC water are discussed as follows:

Water Temperature (T_w)

The temperature of canal water (T_w) fluctuates in accordance with the season and climate. Measurement of T_w is helpful in identifying the trend of different biological, biochemical, physical and chemical activities. Water temperature is known to influence the growth and death of micro-organisms, kinetics of biochemical oxygen demand, pH, alkalinity, and dissolved oxygen concentration in the water (Jayalakshmi et al., 2011; Semwal and Akolkar, 2011; Verma et al., 2012; Wattoo, 2004). A biological activity is enhanced by higher temperature up to 60℃. Temperature is crucial as it possess an inverse variation with the portion of dissolved oxygen (DO) in water i.e., the total DO in water increases with a decrease in T_w. The concentration of the oxygen dissolved in water at 0^0C and 30^0C can be up to 14.6 mg/L and 7.6 mg/L respectively.

Acidity/ Alkalinity (pH)

The pH is regarded as the negative logarithm of hydrogen ion concentration in water. It is used to decide whether a solution is acid or alkaline. The range of pH is 0 to 14, with an ideal value of 7, which is regarded as perfectly neutral. This is used to draw a line between the acidity and alkalinity nature of the solution, in the sense, pH value in the range of (0, 7) is called as acid solution whereas, a range of (7, 14) denotes alkaline solution. The pH for water normally ranges between 6.5 and 8.4, which is generally considered suitable for several purposes, although the upper and lower limits may vary for specific practices. A pH outside this normal range may be harmful as they cause toxicity or nutritional imbalance to plants/animals (Semwal and Akolkar, 2011; Sundaray et al., 2009). In water, pH correlates with electrical conductance and total alkalinity (Al-Mashagbah, 2015).

Electrical Conductivity (EC)

The electrical conductivity (EC) is used to diagnose and classify the total concentration of soluble salts in water. It accounts for ability of water to carry out an electric current, which is directly linked with quantity of dissolved solids (Al-Mashagbah, 2015). Hence, EC is a robust tool to recognize the salinity problems (Kundu, 2012). The prominent factors controlling EC are concentration of constituent ions, type of substances dissolved, valence, mobility and temperature (Islam and Shamsad, 2009; Sultana et al., 2009; Verma et al., 2012; Augoustis et al., 2012; Mohamed, 2013). A high EC adversely affects plants, in the sense; they have to compete with constituent ions for water (Semwal and Akolkar, 2011).

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) is the usual measure of water salinity. TDS is a crucial parameter for water quality indices, as many of the toxic solid materials may be imbedded in water and thereby causing harm to the plants/animals. The inter-link between EC and TDS makes both of them potent to characterize water salinity in absence of the non-ionic dissolved constituents (Shainberg and Oster, 1978). It accounts for all inorganic salts present in water in dissolved form along with the dissolved organic compounds. The TDS concentration possesses remarkable variation in natural waters. In rainwater (which is taken as purest form of natural water), TDS values are less than 1 mg/L whereas in seawater, it reaches up to 35000 mg/L and maybe even higher in brines. The TDS also reflects the geology of the regions, as the weathering of rocks, minerals and soil affects its concentration (Weber-Scannell and Duffy, 2007). The TDS is mainly contributed by the cations such as sodium, magnesium, potassium and calcium; and the anions such as chloride, carbonate, bicarbonate, sulfate and nitrate. Highly mineralized waters can cause physiological upset and sometimes death in terrestrial animals, including humans.

Dissolved Oxygen (DO)

Dissolved Oxygen is a natural characteristic of clean water. The prime requirements for DO arise in connection with fish life (Kramer, 1987; Breitburg, 1994), and it is generally true that if water quality is suitable for fish it will also meet the criteria for most if not all other beneficial uses and be of good ecological status. The cardinal point about the solubility of oxygen in water is that it has an inverse relationship with temperature (Murthi et al., 2004). The consequence is that the actual concentrations of DO in a river will be lowest in summertime when it is usually the case that the risk of damage to a water supply source or of environmental pollution is greatest. The effects of eutrophication are closely related to the DO regime in both rivers and lakes. Where there are dense growths of phytoplankton, photosynthesis will take place during the extended daylight periods of summertime, resulting in the production of oxygen which may lead to water DO levels far in excess of 100 per cent saturation (Matta, 2015). An excess of DO is not a problem in itself but it indicates that the daytime conditions may be mirrored by an equally large under saturation of oxygen at night-time when photosynthesis ceases and plant respiration supervenes with the consumption of oxygen.

Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as Ammonia and nitrite (Rezania et al., 2015). COD measurements are commonly made on samples of waste waters or of natural waters contaminated by domestic or industrial wastes. Chemical oxygen demand is measured as a standardized laboratory assay in which a closed water sample is incubated with a strong chemical oxidant under specific conditions of temperature and for a particular period of time. Chemical oxygen demand is related to biochemical oxygen demand (BOD), another standard test for evaluating the oxygen-demanding strength of waste waters (Jouanneau et al., 2014). However, biochemical oxygen demand only measures the amount of oxygen consumed by microbial oxidation and is most relevant to waters rich in organic matter. For COD assay, both organic and inorganic sources of oxygen demand are considered.

Calcium (Ca^{2+})

Calcium is a necessary element for plants and animals including human beings; however, excessive amount may lead to detrimental effects on health (Wattoo, 2004). The calcium content in water has close relation with geology of the source regions, as it is contributed by weathering of rocks and minerals. Calcium is also a major component of hardness in water. It is present in the form of a bivalent cation (Ca^{2+}). This cation (Ca^{2+}) combining with carbonates (CO_3^{2-}) or bicarbonates (HCO_3^-) may cause the water to be extremely hard and saline (EPA, 2001). The concentration of Calcium possesses a wide range of variation in natural waters. In aquatic systems, although it is naturally present, but substantial addition of effluents or sewage increases its concentration, which is undesirable (Kumar et al., 2015).

Magnesium (Mg^{2+})

Naturally, Magnesium occurs at almost half of calcium concentration, but higher amount of it may cause serious effect on soil, and consequently plants and animals (Wattoo, 2004). The magnesium concentration varies significantly in natural water. Based on the geology of catchment, concentration of Mg may range from less than 1 mg/L to nearly 1000 mg/L or above. The concentration of Magnesium in water has a close association with that of TDS and thus, complications arising due to high Mg concentration may be attributed to high TDS levels. Similar to Calcium, Magnesium also exists as a bivalent cation (Mg^{2+}) in water, which is a main constituent of water responsible for hardness and this may combine with carbonates and bicarbonates to result in lime deposits, very hard water and salinity. The source of Magnesium is Dolomite salts and soil, surfactants, anionic and emulsifiers (EPA, 2001).

Sodium (Na^+)

Sodium is abundant constituent of rocks and soils. It is always present in natural waters. Sodium is an essential dietary requirement for human beings and the normal intake is as common salt (sodium chloride) in food. It is also required for plants, though in very small quantities, to promote the metabolism. Natural component of water, salts and weathering of sodium bearing minerals, rocks, industrial brine, reclaimed effluent water and sea water etc. are sources of occurrence for sodium. The concentration of sodium ranges from very low in the surface waters and relatively high in deep ground waters and highest in the marine waters (EPA, 2001). It is very difficult to diagnose Sodium toxicity, but many cases are observed with high sodium concentrations in the water. The toxicity due to excessive Sodium has damaging effects on soil, plants and animals including human beings (Ayers and Westcott, 1994). Water with high sodium concentration is regarded as ‘Soft water’ (Wattoo, 2004).

Potassium (K^+)

Potassium ranks seventh among the elements in order of abundance. However, it is found in small quantities in natural waters. Rivers generally contains about 2-3 ppm potassium. But, seawater contains about 400 ppm potassium. It tends to settle, and consequently ends up in sediment mostly. This difference in seawater and rivers is mainly caused by a large potassium concentration in oceanic basalts. It behaves similar to sodium and also a monovalent cation (K^+) in its ionic form. Potassium plays a vital role in the metabolism of plants and animals (Hashemabadi et al., 2015). It is usually originated from geological formations. Potassium is an essential constituent of many artificial fertilizer formulations, and hence its determination is often carried out on lake waters when an assessment of nutrient input is being made. However, potassium tends to be fixed in soils and is not that easily leached out. There is hardly any implication of toxicity from potassium. The toxicity is usually caused by other components in a compound, for example cyanide in potassium cyanide (EPA, 2001). Very often potassium is measured on samples solely to permit the calculation of ion balance for the verification of the analysis.

Chloride (Cl^-)

Chloride is required in smaller amount to plants and animals. However, if it is used at amply high concentrations, it gets accumulated in the body and cause toxic effects. In ionic form, it occurs as a monovalent anion (Cl^-). The sources of chlorides are dissolving minerals, surface water from septic tank effluents and animal feeds, road salt, fertilizers, industrial wastes or sewages, water additive used to control microbes, disinfectants etc. Sodium chloride dissolves in water from soil and rocks; and it occurs in all natural waters in widely varying concentrations. Chloride normally increases as the mineral contents increase. Water with 250mg/L of Cl^- ion or higher possesses a salty taste (Kundu, 2012). Natural levels of chloride in rivers and other fresh waters are usually in the range of 15-35 mg/l, which is much below the allowable limits. An increase of even 5 mg/l at one station may give rise to suspicions of a sewage discharge, especially if the free ammonia levels are also elevated (EPA, 2001). In coastal areas, however, elevated chloride values may be due to sea spray, or sea water infiltration, and not necessarily to discharges (Sundaray et al., 2009).

Sulfate (SO_4^{2-})

Sulphates (SO_4^{2-}) exist in nearly all natural waters, the concentrations varying according to the nature of the terrain through which they flow. They are originated from rocks, geological formations, discharges, etc. They are often derived from the sulphides of heavy metals (iron, nickel, copper and lead). Iron sulphides are present in sedimentary rocks from which they can be oxidized to sulphate in humid climates; the latter may then leach into water courses so that ground waters are often excessively high in sulphates (Caraco et al., 1989). Excess sulphate has a laxative effect, especially in combination with magnesium and/or sodium. As magnesium and sodium are present in many waters their combination with sulphate will have an enhanced laxative effect of greater or lesser magnitude depending on concentration (Sun et al., 2016). The utility of water for domestic purposes will therefore be severely limited by high sulphate concentrations (< 250 mg/l). The polluted water in which the dissolved oxygen is zero, sulphate is very readily reduced to sulphide causing noxious odours. Waters containing sulphates in excess will also attack the fabric of concrete sewer pipes (EPA, 2001).

Nitrate-Nitrogen (NO_3-N^-)

The source of Nitrate is runoff from fertilizer, leaking septic tanks, sewages disposal systems and soil erosion, natural deposits. Relatively little of the nitrate found in natural waters is of mineral origin, most coming from organic and inorganic sources, the former including waste discharges and the latter comprising chiefly artificial fertilizers. However, both bacterial oxidation and fixing of nitrogen by plants can both produce nitrate. This may lead to the problem of eutrophication in lakes. The nitrate itself is not a direct toxicant but is a health hazard because of its conversion to nitrite. High nitrite levels would indicate more recent pollution as nitrite, which is an intermediate stage in the ammonia-to-nitrate oxidation (EPA, 2001). However, it should be noted that there is a general tendency for nitrate concentrations in rivers to increase as a result of enhanced nutrient run-off (Pacheco and Fernandes, 2016). Nitrite concentration in rivers are rarely more than 1 - 2 per cent of the nitrate level so that it may therefore be acceptable to carry out the analytically convenient determination of nitrate + nitrite at the same time. This determination is correctly referred to as total oxidized nitrogen.

Bicarbonate (HCO_3^-) and Carbonate (CO_3^{2-})

Carbonates and bicarbonates have an indirect influence on the water quality by precipitating calcium and magnesium and resulting to increased sodium percentage and sodium hazards of water (Majumdar, 2001).The source of Carbonates is dissolution of CO_2. Al-Mashagbah (2015) assured that the amount of CO_3^{2-}, HCO_3^- and H_2CO_3 (carbonic acid) in water are having a relation with the hydrogen ion concentration. The CO_3^{2-} concentration predominates in surface water with pH < 9. The concentration of CO_3^{2-} in natural waters possesses remarkable variation i.e. from < 25 mg/L in non-carbonate-rocks areas to > 400 mg/L in carbonate-rocks areas. The pH touching 8.3 is an indicative for presence of carbonates. The CO_3^{2-} converts to an equivalent amount of HCO_3^- below the pH threshold of 8.3 (Augoustis et al., 2012).

Boron (B)

Boron is essential for plant growth, though in traces. Boron is toxic at higher concentration in irrigation waters. Boron may become toxic (1-2 mg/L) to some plants when its concentration is more than the required amount. Boron content in irrigation water is usually more in arid and semi-arid regions. Usually, the irrigation water contains less than 1 ppm (Majumdar, 2001). Even at a concentration less than 1.0 ppm, it can cause toxicity to sensitive crops and affect the plant metabolism. Boron is recognized for class ‘‘E’’ of primary water quality criteria (IS: 2296;2002). For irrigation canal and river waters, Boron levels less than 0.33 ppm, between 0.33-0.67 ppm and above 0.67 ppm were used to categorize the crops as sensitive, semi-tolerant and tolerant ones respectively (Provin and Pitt, 2002; Semwal and Akolkar, 2011)**.**

In this study, water samples were collected every month from November 2014 to October 2015. The duration from November 2014 to February 2015 were considered as winter season, March to June 2015 as summer season and July to October 2015 as monsoon season. The physicochemical parameters mentioned above were determined at monthly level, which were then converted to seasonal level by taking the average value of all months in that particular season. The monthly averaged seasonal observations of these physicochemical parameters are presented in Annexure B (Tables B1 to B8). The seasonal data for these parameters are presented in **Tables 3.3, 3.4 and 3.5** for the winter, summer and monsoon seasons respectively.

Table 3.3: Observed values of physicochemical parameters for winter season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
T_w	17.300	16.500	17.100	18.800	17.400	17.800	17.100	17.000	17.600	16.700	16.700	17.300	18.200	17.100	18.700	16.700	16.700	17.300	16.500	18.800	17.333	0.670
pH	8.300	8.400	8.400	7.100	6.800	8.300	6.900	8.300	8.300	8.300	8.200	8.300	8.300	8.300	8.400	8.300	8.300	8.300	6.800	8.400	8.083	0.534
EC	200.000	187.000	181.000	1316.000	984.000	193.000	985.000	199.000	185.000	182.000	183.000	195.000	186.000	238.000	243.000	242.000	241.000	195.000	181.000	1316.000	351.944	348.878
TDS	128.000	120.000	121.000	826.000	637.000	124.000	636.000	127.000	118.000	116.000	117.000	125.000	119.000	152.000	156.000	155.000	154.000	125.000	116.000	826.000	225.333	221.914
TA	76.250	76.250	83.500	257.500	260.500	79.750	215.250	75.250	73.000	78.500	89.750	83.750	84.750	82.750	81.500	86.500	86.250	86.750	73.000	260.500	108.764	63.185
TH	57.800	64.000	67.500	219.000	364.300	64.300	220.800	60.300	61.800	63.300	60.800	64.000	58.800	56.500	66.800	55.500	58.500	59.800	55.500	364.300	95.767	84.338
Ca	42.000	46.000	41.500	121.000	335.250	43.250	137.500	37.750	39.000	41.000	44.250	36.250	36.000	35.500	44.000	33.000	33.000	34.250	33.000	335.250	65.583	73.458
Mg	15.750	21.500	22.500	98.000	29.000	21.000	83.250	22.500	22.750	22.250	22.250	24.500	25.250	21.000	22.750	28.250	27.500	28.000	15.750	98.000	31.000	22.074
Na	2.825	3.200	2.850	42.300	54.800	4.450	43.000	3.950	2.775	3.175	3.350	3.175	3.175	3.250	3.500	3.525	3.275	3.550	2.775	54.800	10.563	16.808
K	1.400	1.550	1.500	14.650	31.175	2.425	22.250	1.450	1.550	2.550	1.875	1.800	1.975	1.900	2.675	1.950	1.950	2.875	1.400	31.175	5.417	8.451
Cl	16.000	10.750	14.250	117.500	345.000	14.250	148.000	11.500	16.250	15.000	15.250	14.000	18.000	15.750	24.000	11.750	14.750	14.750	10.750	345.000	46.486	83.802
SO_4	94.500	96.750	97.250	89.000	93.500	100.750	176.250	98.000	101.250	102.000	100.000	104.500	100.000	103.250	115.000	103.750	103.000	116.000	89.000	176.250	105.264	18.899
NO_3	4.300	3.875	4.650	1.687	2.360	5.825	2.625	5.975	3.900	3.775	4.150	4.025	2.975	3.350	4.900	3.075	3.000	3.000	1.687	5.975	3.747	1.131
DO	9.720	9.690	9.670	2.160	1.540	9.750	2.110	9.870	9.770	9.690	9.640	9.700	9.510	9.740	9.640	9.850	9.680	9.500	1.540	9.870	8.402	2.979
COD	25.17	39.01	32.98	202.06	491.09	260.88	28.89	22.39	31.59	16.74	26.30	18.48	22.42	16.10	48.53	27.49	22.14	30.49	16.10	491.09	75.71	123.45
B	0.453	0.568	0.665	0.936	0.988	0.688	0.947	0.828	0.831	0.831	0.832	0.831	0.836	0.946	1.531	0.836	0.833	0.884	0.453	1.531	0.848	0.218

Table 3.4: Observed values of physicochemical parameters for summer season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
T_w	22.300	22.700	23.200	22.000	23.100	21.300	24.700	22.200	21.700	21.200	21.800	21.900	23.000	23.300	25.300	23.600	22.700	22.800	21.200	25.300	22.711	1.085
pH	7.800	7.700	7.800	7.400	7.100	7.600	7.300	7.800	7.800	7.800	7.700	7.700	7.600	7.700	7.700	8.000	7.800	7.700	7.100	8.000	7.667	0.211
EC	198.000	201.000	202.000	1226.000	1237.000	209.000	1029.000	208.000	180.000	195.000	164.000	180.000	243.000	161.000	249.000	168.000	196.000	170.000	161.000	1237.000	356.444	374.537
TDS	127.000	129.000	129.000	653.000	713.000	134.000	679.000	133.000	115.000	124.000	105.000	115.000	155.000	103.000	160.000	108.000	125.000	108.000	103.000	713.000	217.500	214.394
TA	52.750	62.530	72.500	100.850	177.250	66.500	110.500	65.250	67.750	69.750	71.250	70.250	74.250	70.750	90.250	88.550	72.500	70.250	52.750	177.250	80.760	27.856
TH	64.500	67.800	71.500	202.300	247.800	67.800	224.500	65.800	65.000	66.300	65.300	65.300	66.300	65.500	76.000	66.800	64.800	65.500	64.500	247.800	93.267	61.123
Ca	43.000	43.500	44.200	132.500	173.750	42.500	136.250	42.000	45.500	42.250	42.000	42.250	43.750	44.250	53.750	41.750	43.250	42.000	41.750	173.750	61.025	40.645
Mg	21.500	28.000	23.500	69.750	74.000	25.250	88.250	23.750	19.500	24.000	23.250	23.000	22.500	21.250	22.250	25.000	21.500	22.500	19.500	88.250	32.153	21.134
Na	1.175	1.900	2.800	12.400	16.800	2.450	13.320	1.050	1.475	2.900	3.250	3.325	1.975	2.450	1.900	2.075	2.075	2.075	1.050	16.800	4.189	4.704
K	1.650	2.225	1.675	20.250	13.000	1.475	28.075	1.225	1.400	1.850	1.225	1.500	1.650	1.925	4.750	1.450	1.450	1.650	1.225	28.075	4.913	7.639
Cl	15.750	16.750	17.000	119.000	169.000	16.750	141.250	16.500	16.250	17.000	17.500	17.500	17.500	17.750	22.750	19.750	18.000	16.200	15.750	169.000	38.456	48.933
SO_4	219.750	143.750	126.000	209.500	205.250	86.500	193.750	105.250	117.000	92.000	85.500	82.250	85.500	79.750	94.250	84.000	76.250	87.000	76.250	219.750	120.736	50.746
NO_3	4.500	6.250	4.150	4.692	5.062	3.625	6.542	3.725	3.875	3.900	4.075	3.500	3.850	3.600	9.875	3.800	4.050	4.150	3.500	9.875	4.623	1.566
DO	8.770	9.050	9.020	2.510	1.520	8.950	2.240	9.020	9.120	9.260	9.220	9.280	9.280	9.120	9.380	8.760	8.760	8.900	1.520	9.380	7.898	2.685
COD	2.98	3.09	3.55	218.73	295.98	170.75	18.86	3.00	8.73	20.88	21.21	16.61	29.26	6.98	15.85	4.55	6.15	5.24	2.98	295.98	47.35	86.47
B	0.525	0.612	0.652	1.252	1.352	0.663	1.253	0.664	0.725	0.828	0.827	0.828	0.872	0.923	0.846	0.854	0.835	0.845	0.525	1.352	0.853	0.226

Table 3.5: Observed values of physicochemical parameters for Monsoon season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
T_w	21.800	22.100	21.800	27.000	26.900	27.800	23.000	23.100	23.600	21.500	21.500	22.700	23.000	22.300	24.100	24.600	25.000	23.200	21.500	27.800	23.611	1.948
pH	7.300	7.200	7.000	7.100	7.300	7.300	7.500	7.200	7.100	7.400	7.300	7.400	7.300	7.200	7.100	7.400	7.500	7.400	7.000	7.500	7.278	0.144
EC	166.000	198.000	153.000	1020.000	667.000	205.000	1064.000	224.000	209.000	213.000	256.000	215.000	246.000	250.000	240.000	200.000	213.000	219.000	153.000	1064.000	331.000	281.008
TDS	106.000	127.000	98.000	734.000	427.000	131.000	681.000	143.000	133.000	136.000	168.000	142.000	158.000	160.000	153.000	127.000	136.000	140.000	98.000	734.000	216.667	192.078
TA	58.750	63.000	63.000	335.000	179.250	62.750	208.750	63.250	61.750	62.250	61.750	62.250	61.750	61.750	138.250	78.750	63.350	64.250	58.750	335.000	97.214	74.205
TH	78.000	78.300	77.000	184.000	178.700	70.300	157.800	73.000	77.300	86.800	82.500	86.000	78.800	72.500	118.800	92.300	87.500	83.800	70.300	184.000	97.967	36.654
Ca	49.750	50.750	51.750	124.450	113.750	52.000	111.750	53.250	54.000	54.250	55.500	54.750	56.000	55.000	68.000	57.000	57.210	55.250	49.750	124.450	65.245	24.077
Mg	28.250	27.550	25.250	59.550	64.900	18.300	46.050	19.750	23.300	32.550	27.000	31.250	22.800	17.500	50.800	35.300	30.290	28.550	17.500	64.900	32.719	13.768
Na	2.200	2.625	2.350	49.125	57.675	3.175	48.200	3.025	2.850	3.275	3.175	3.300	3.400	3.450	10.950	3.050	3.600	3.575	2.200	57.675	11.611	18.615
K	2.850	2.750	2.550	16.350	10.475	2.950	18.150	2.925	3.025	3.300	3.600	3.275	3.300	3.375	11.050	3.400	3.400	3.525	2.550	18.150	5.569	4.918
Cl	22.250	22.550	23.500	103.500	95.750	23.650	120.750	24.750	24.800	24.850	24.950	23.750	25.250	24.950	39.500	27.250	26.250	24.950	22.250	120.750	39.067	31.633
SO_4	110.500	114.750	118.250	139.750	136.750	119.250	144.550	120.750	122.250	127.250	130.250	128.250	132.750	131.750	136.200	136.000	138.750	129.250	110.500	144.550	128.736	9.420
NO_3	1.075	1.500	1.625	3.200	3.825	1.100	5.325	1.325	1.325	1.175	1.175	1.150	1.025	1.200	1.425	1.000	1.075	1.075	1.000	5.325	1.700	1.185
DO	8.560	8.560	8.520	2.510	1.880	8.400	2.190	8.560	8.520	8.440	8.610	8.520	8.280	8.440	8.180	8.520	8.360	8.480	1.880	8.610	7.418	2.409
COD	12.97	12.81	20.88	96.00	272.54	205.19	19.23	24.50	11.54	12.80	30.94	11.22	41.16	48.26	58.66	13.02	7.80	38.47	7.80	272.54	52.11	72.36
B	0.671	0.727	0.707	0.911	0.912	0.708	0.952	0.735	0.747	0.818	0.816	0.816	0.815	0.837	0.867	0.925	0.814	0.827	0.671	0.952	0.811	0.082

3.2.2 Toxic Trace (Heavy) Metals

The total heavy metals like Zn, Pb, Mn, Hg, Fe, Cu, Cr, Co, Cd, As and Al, which are important parameters for water quality, were measured after digestion with a concentrated HCO_3 using the GBC-AVANTA flame atomic adsorption spectrophotometer (AAS) model (Tüzen, 2013). This method of estimating trace metal concentration is called 'Flame Atomic Absorption Spectrophotometry'. The details of the analytical methods and instruments used to determine the toxic trace metals are presented in **Table 3.6**. Before measuring the parameters, the instrument GBC AVANTA A.A.S needs to be calibrated at the specified wavelengths for each of the parameters. This is referred as working wavelength, which is also mentioned in **Table 3.6**. It can be observed that, there are a total of 11 parameters, which are regarded as the toxic trace metals. Although the heavy metal and trace metal seems contrasting, they are not very different. The 'heavy metal' is attributed to specific gravity of the metals. The metals that are having a density greater than 5 g/cm^3 in their elemental form are called heavy metals (Tomar, 1999). On the other hand, 'trace' indicates that they are present in very tiny concentrations (generally in parts per million). So, the trace elements are small units of presence of heavy metals in a water sample. These metals possess toxicity in higher than desirable concentration, which may be imparted to the water (Gambrell, 1994). Hence, these are generally termed as toxic trace metals. A brief description of these toxic trace metals is presented below. The detailed methods and procedure to determine these toxic metals is given in Annexure A.

Table 3.6: Analytical methods and Instruments used to determine the toxic trace metals

Sl. No.	Parameters	Instrument	Working wave length (nm)⌂
1	Al	GBC AVANTA A.A.S	396.2
2	As	GBC AVANTA A.A.S	193.7
3	Cd	GBC AVANTA A.A.S	228.8
4	Cr	GBC AVANTA A.A.S	357.9
5	Co	GBC AVANTA A.A.S	240.7
6	Cu	GBC AVANTA A.A.S	324.7
7	Fe	GBC AVANTA A.A.S	248.3
8	Hg	GBC AVANTA A.A.S	253.7
9	Pb	GBC AVANTA A.A.S	217
10	Mn	GBC AVANTA A.A.S	279.5
12	Zn	GBC AVANTA A.A.S	213.9

Note: Analysis of the above parameters was in accordance with the APHA (2005) Methods and Guide Manual: Water and Wastewater Analysis (Gautam, 2008); ppm = parts per million, 1ppm = 1mg/L, mg/L = milligram per litre and 1 ppm = 1mg/L; ⌂nm = nanometer. The instrument of GBC AVANTA Atomic Absorption Spectrometer was used for estimation of all these parameters.

Aluminium

Aluminum is one of the most abundant elements in the earth's crust. The amount of aluminum in seawater varies between approximately 0.013 and 5 ppb. River water generally contains about 400 ppb of aluminum. Aluminum mainly occurs as Al^{3+} (aq) under acidic conditions, and as $Al(OH)_4^-$ (aq) under neutral to alkaline conditions. Other forms include $Al(OH)_2^+$ (aq) en $Al(OH)_3$ (aq). Aluminum may negatively affect terrestrial and aquatic life in different ways (Roy et al., 1988). Regular aluminum concentrations in groundwater are about 0.4 ppm, because it is present in soils as water insoluble hydroxide. At pH values below 4.5, solubility rapidly increases, causing aluminum concentrations to rise above 5 ppm. This may also occur at very high pH values (EPA, 2001).

Arsenic (As)

Arsenic is widely distributed throughout the earth's crust. It occurs in many minerals, usually in combination with sulfur and metals, but also as a pure elemental crystal. According to world Health Organization (WHO, 2004) and EPA (2001), it is introduced into water through the dissolution of minerals and ores, from industrial effluents, and from atmospheric deposition. The concentrations in ground water in some areas are sometimes elevated as a result of erosion from natural sources. Generally, Arsenic is present in earth crust (2 ppm), sea water (5 ppb) and soils (1 to 40 ppm), in human body tissues (18 mg) and blood (25 mg). The white arsenic (or arsenic oxide) is formed as a by-product in smelting of copper, lead and silver ores. Owing to its toxic effects, it is used as an insecticide. Moreover, Arsenic is a general protoplasmic poison and its presence in water above permissible limits affects plants and animals adversely (Jain and Ali, 2000; Buschmann et al., 2008). The inorganic arsenic is a documented human carcinogen. The order of toxicity of Arsenic compound is: Arsines [As(III)] > Arsenite [As(III)] > Arsenate [As (V)] > Arsenic organic acids [As (V)].

Cadmium (Cd)

Cadmium, a toxic heavy metal, occurs in nature in association with zinc, lead, copper and other ores which can serve as sources to ground and surface waters, especially when in contact with soft, acidic waters. It is present in natural water in traces. Cadmium possesses high toxicity i.e., even at a concentration of parts per billion (ppb), it can be very harmful. Major industrial releases of cadmium are due to waste streams and leaching of landfills, mining and smelting, and from a variety of operations that involve cadmium or zinc. In particular, cadmium can be released to water from the corrosion of some galvanized plumbing and pipe materials. Cadmium metal is very strongly adsorbed on muds, humus and organic matter, leading to the possibility of entry to the water and food chain (via fish and fish food) which subsequently accumulates in plant and animal tissues (EPA, 2001; Perfus-Barbeoch et al., 2002).

Chromium (Cr)

Chromium occurs naturally in ore, but chromium arises in surface waters from discharges from electroplating, tanning, textile, paint and dyeing plants. Chromium is toxic, to a degree which varies with the form in which it occurs, whether as the trivalent Cr (III) or the hexavalent Cr (VI) form. The latter is considered the more hazardous because it is difficult to distinguish. Chromium element is an essential dietary requirement - in limited amounts - and a deficiency can lead to disruption of glucose metabolism. Indeed, it has been reported that chromium deficiency is of greater nutritional concern than overexposure (Taylor et al., 1985). However, it is considered that the element is carcinogenic (at high concentrations), though much more evidence of this is needed, and it can act as a skin irritant. Hence, strict limitations are imposed in domestic water supplies. The deaths of livestock resulting from watering in chromium-contaminated water have been reported from time to time (EPA, 2001).

Cobalt (Co)

Cobalt occurs naturally in ores. But the presence Cobalt in surface water is primarily due to discharges dumped into them. Owing to its low level of occurrence, there is little health/sanitary significance for its presence in water (Diamond et al., 1992). But, the metal and its compounds are hazardous as solids or strong solutions (Rötting et al., 2006). Cobalt is contained in the Vitamin B12 molecule and is an important dietary requirement, being provided by green vegetables, in particular. It is rarely found in natural waters and, accordingly, there are few recommendations for its limitations. The lack of standards for Cobalt in drinking water also reflects the minimal risk (EPA, 2001).

Copper (Cu)

Copper, as a necessary trace element, is required by plants and animals for activation of some enzymes. Mining, metallurgy and industrial applications are the major sources of copper exposure in the environment (Davis et al., 2003). Copper is not particularly toxic to humans (indeed, it is an essential dietary requirement and medicinal doses up to 20 mg/l are not unknown). However, astringent tastes in water can be caused by levels above 1 mg/l Cu. This element is present naturally in metalliferous areas, but more often its presence in waters is due to attack on copper piping. Rarely, its occurrence may be due to its use as an algicide. Unless used with great care for algal control there is a grave risk of fish kills, as it is as a toxicant to fish that copper is of greatest interest. Copper is an element the toxicity of which to fish varies widely with the hardness of the water (Taylor et al., 1985). A problem associated with high levels of copper in water is galvanic corrosion of tanks (EPA, 2001).

Iron (Fe)

Iron occurs or gets originated through geological formations (especially under reducing conditions), acid drainage, effluent discharges etc. Iron is present in significant amounts in soils and rocks, principally in insoluble forms. However, many complex reactions which occur naturally in ground formations can give rise to more soluble forms of iron which will therefore be present in water passing through such formations (Chapelle and Lovley, 1992). Appreciable amounts of iron may therefore be present in ground waters. Normally no harmful effect on persons consuming waters with significant amounts of iron is reported, but it should not be ignored. Rather, the problems are primarily aesthetic, as the soluble (reduced) ferrous (Fe^{2+}) iron is oxidized in air to the insoluble ferric (Fe^{3+}) form, resulting in color or turbidity (or, in severe cases, precipitate formation). Laundry becomes stained if washed in water with excessive iron, and vegetables likewise become discolored on cooking. Taste problems may also occur. The metal is quite harmful to aquatic life, as evidenced by laboratory studies, but in nature the degree of toxicity may be lessened by the interaction of the iron with other constituents of water (EPA, 2001).

Lead (Pb)

The sources of lead are mainly leaching from ores, effluent discharges and attack on water pipes. Lead is one of the most commonly determined heavy metals, as it accumulates in body tissue and may be very harmful (Taylor et al., 1985; Davis et al., 2003). Thus, very strict limits on its presence in raw and finished drinking waters must be imposed. Particular attention is paid to this element as in many older houses extensive use is made of lead piping and there is a danger of lead being brought into solution. The waters which are in prolonged contact with old lead pipes are liable to dissolve possibly significant amounts of the metal, which is regarded as 'plumbosolvency'. So the drinking water pipes should be monitored regularly (EPA, 2001).

Manganese (Mn)

Manganese occurs naturally as a widely distributed constituent of ores and rocks. There are no particular toxicological implications from only Manganese. Rather, similar to iron, the objections to manganese are aesthetic. Along with iron, it is found widely in soils and is a constituent of many ground waters (Ellis et al., 2000; Roccaro et al., 2007). Manganese may be brought into solution in reducing conditions and the excess metal will be later deposited as the water is reaerated. The general remarks for iron apply to manganese but the staining problems with this metal may be even more severe, hence quite stringent limits should be imposed. Presence of manganese much above the limits also leads to unacceptable taste problem. Toxicity is not a factor, as waters with high levels of manganese will be rejected by the consumer long before any danger threshold is reached (EPA, 2001).

Mercury (Hg)

The presence of Mercury (Hg) in surface water is mainly contributed by industrial waste discharges. It is generally industrial in origin (dental amalgams, anti-fouling paints, plastics manufacture, battery making, paper-making etc.) though some comes from the natural environment. The natural sources of mercury are volcanic eruption, weathering of rocks and soils. This is a very toxic element, the hazards of which are magnified by the accumulation of organo-mercury compounds in fish. There have been some major pollution incidents where both death and severe damage to health has been caused to many people consuming fish and shellfish contaminated by heavy industrial discharges of mercury (Suns and Hitchin, 1990). Among all species of Mercury, Methyl Mercury is the most toxic form (EPA, 2001).

Zinc (Zn)

The origin of zinc is natural geological occurrence as well as from wastes. Zinc occurs as zinc blende (ZnS), zincite (ZnO), willemite (Zn_2SO_4) and smithsonite ($ZnCO_3$). It occurs as 0.004% in earth crust and 320 ppb in oceans. Zinc is an essential micronutrient to plants and animals. But, inhalation of zinc-containing fumes can cause a variety of harmful physiological effects. The principal significance of excessive amounts in water is that, it imparts emetic effects (causes vomiting). However, the concern in water supply arises in regard to taste and not toxicity, and thus, quite high levels are also permissible (Davis et al., 2003). On the contrary, in fishery water, the toxic action is much more important and very much lower limits have been imposed (Taylor et al., 1985). The toxicity of zinc to aquatic life is (as with copper) dependent on the hardness of the water i.e., it decreases with rising hardness. Smelting of ores and agricultural use of pesticides are the main pollution sources of zinc (EPA, 2001).

The trace metals were determined for every month (during November 2014 to October 2015), which were categorized into observations for winter, summer and monsoon season, for analyzing in seasonal scale. These seasonal observations and the statistical summary for winter, summer and monsoon seasons are given in **Tables 3.7, 3.8 and 3.9** respectively.

Table 3.7: Observed values the toxic trace metals for winter season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.532	0.134	0.131	0.152	0.165	0.236	0.153	0.136	0.136	0.166	2.327	0.166	0.136	0.186	0.186	1.184	1.168	2.157	0.131	2.327	0.525	0.707
As	0.002	0.003	0.003	0.014	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.014	0.0045	0.0038
Cd	0.001	0.001	0.002	0.005	0.009	0.001	0.003	0.002	0.002	0.002	0.006	0.001	0.019	0.003	0.005	0.002	0.001	0.006	0.001	0.019	0.004	0.004
Co	0.035	0.035	0.036	0.056	0.085	0.037	0.064	0.038	0.039	0.039	0.040	0.040	0.041	0.041	0.042	0.042	0.042	0.042	0.035	0.085	0.044	0.012
Cr	0.021	0.027	0.028	0.042	0.030	0.028	0.037	0.029	0.029	0.029	0.041	0.025	0.032	0.087	0.081	0.080	0.030	0.039	0.021	0.087	0.040	0.020
Cu	0.047	0.037	0.031	0.037	0.020	0.067	0.063	0.051	0.036	0.059	0.051	0.059	0.057	0.061	0.071	0.064	0.077	0.092	0.020	0.092	0.054	0.018
Fe	1.151	1.973	2.962	3.922	3.911	2.972	3.918	2.978	2.971	2.973	2.973	2.974	2.983	2.982	2.983	2.983	2.976	2.986	1.151	3.922	2.976	0.641
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0211	0.0022	0.0011	0.0028	0.0034	0.0039	0.0021	0.0022	0.0011	0.0012	0.0023	0.0021	0.0011	0.0211	0.0052	0.0066
Mn	0.035	0.043	0.056	0.213	0.214	0.045	0.213	0.070	0.055	0.097	0.098	0.097	0.102	0.102	0.105	0.106	0.102	0.106	0.035	0.214	0.103	0.056
Pb	0.012	0.020	0.021	0.057	0.050	0.021	0.055	0.024	0.024	0.024	0.024	0.024	0.029	0.029	0.030	0.029	0.024	0.029	0.012	0.057	0.029	0.012
Zn	0.567	0.621	0.072	2.054	2.064	0.801	2.074	0.822	0.861	0.986	1.013	1.013	1.023	1.023	1.034	1.034	1.012	1.021	0.072	2.074	1.061	0.521

Table 3.8: Observed values of the toxic trace metals for summer season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.134	0.234	0.335	1.152	1.165	0.336	1.153	0.446	0.456	0.548	0.547	0.548	0.766	0.757	0.859	0.735	0.548	0.843	0.134	1.165	0.642	0.311
As	0.002	0.003	0.003	0.013	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.013	0.0041	0.0035
Cd	0.002	0.002	0.003	0.008	0.008	0.003	0.008	0.003	0.004	0.004	0.004	0.004	0.007	0.007	0.007	0.007	0.004	0.006	0.002	0.008	0.005	0.002
Co	0.035	0.040	0.041	0.078	0.085	0.043	0.085	0.046	0.046	0.051	0.051	0.051	0.052	0.052	0.051	0.050	0.051	0.051	0.035	0.085	0.053	0.014
Cr	0.021	0.024	0.024	0.092	0.086	0.026	0.098	0.028	0.038	0.038	0.038	0.046	0.048	0.049	0.047	0.046	0.039	0.048	0.021	0.098	0.046	0.023
Cu	0.023	0.035	0.065	0.073	0.036	0.176	0.040	0.051	0.049	0.049	0.092	0.053	0.042	0.045	0.044	0.052	0.052	0.053	0.023	0.176	0.057	0.033
Fe	1.151	2.329	2.337	2.429	2.336	2.556	2.922	2.322	2.416	2.416	2.413	2.413	2.414	3.007	3.016	2.413	2.412	2.414	1.151	3.016	2.429	0.392
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0199	0.0022	0.0012	0.0028	0.0034	0.0039	0.0021	0.0022	0.0012	0.0012	0.0023	0.0021	0.0012	0.0199	0.0049	0.0061
Mn	0.103	0.083	0.116	0.179	0.172	0.171	0.113	0.106	0.104	0.127	0.157	0.138	0.108	0.132	0.133	0.131	0.137	0.154	0.083	0.179	0.131	0.027
Pb	0.022	0.024	0.024	0.042	0.099	0.026	0.048	0.029	0.030	0.030	0.030	0.030	0.033	0.034	0.035	0.034	0.030	0.034	0.022	0.099	0.035	0.017
Zn	0.570	0.762	0.788	2.986	3.141	0.798	2.606	0.888	0.888	0.988	0.988	0.988	0.889	1.122	1.122	1.223	1.111	1.121	0.570	3.141	1.277	0.775

Table 3.9: Observed values the toxic trace metals for monsoon season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.131	0.142	0.142	1.106	1.142	0.152	1.175	0.204	0.205	0.324	0.324	0.324	0.326	0.329	0.329	0.326	0.326	0.326	0.131	1.175	0.407	0.347
As	0.002	0.003	0.003	0.017	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.017	0.0051	0.0042
Cd	0.001	0.001	0.001	0.004	0.005	0.002	0.004	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.005	0.005	0.004	0.004	0.001	0.005	0.003	0.001
Co	0.025	0.020	0.021	0.064	0.065	0.021	0.065	0.021	0.021	0.021	0.021	0.022	0.031	0.031	0.032	0.032	0.023	0.026	0.020	0.065	0.031	0.016
Cr	0.020	0.024	0.025	0.055	0.054	0.026	0.053	0.026	0.026	0.029	0.029	0.029	0.035	0.037	0.037	0.036	0.030	0.034	0.020	0.055	0.033	0.011
Cu	0.020	0.022	0.023	0.056	0.069	0.027	0.063	0.028	0.030	0.038	0.041	0.040	0.035	0.035	0.038	0.039	0.043	0.039	0.020	0.069	0.038	0.013
Fe	1.299	1.363	1.377	2.424	2.244	1.387	2.438	1.767	1.777	1.823	1.815	1.828	2.019	2.088	2.142	2.089	1.839	2.158	1.299	2.438	1.882	0.354
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0222	0.0022	0.0011	0.0028	0.0034	0.0039	0.0021	0.0022	0.0011	0.0012	0.0023	0.0021	0.0011	0.0222	0.0062	0.0071
Mn	0.062	0.086	0.115	0.149	0.135	0.088	0.145	0.112	0.114	0.115	0.116	0.115	0.020	0.021	0.022	0.021	0.119	0.115	0.020	0.149	0.093	0.044
Pb	0.011	0.015	0.016	0.042	0.041	0.015	0.045	0.017	0.019	0.021	0.021	0.021	0.023	0.024	0.024	0.022	0.016	0.024	0.011	0.045	0.023	0.010
Zn	0.370	0.551	0.588	1.873	1.834	0.592	1.954	0.677	0.678	0.688	0.688	0.688	0.776	0.756	0.777	0.738	0.688	0.758	0.370	1.954	0.871	0.478

3.3 Water Quality Standards

Water is an essential resource for all living organisms, i.e. from microorganisms to huge plants, animals and human beings (Matta, 2014). However, an increased industrialization, urbanization and other anthropogenic activities have aggravated the problem of water pollution (Suthar et al., 2009). The various sources of pollutants and the way they get into the surface water bodies, as discussed in the previous subsections, have become very common and hence, the quality of water in rivers or canals needs continuous monitoring. This will help to determine the suitability of water for specified utilities. The Upper Ganga Canal (UGC) water plays an important role in the Northern India for fulfilling various purposes. Thus, the perennial flow of the main Ganga River is diverted into the UGC to have agricultural production all over the year. As the Ganga River is one of the most polluted river in the country (NRCD, 2009), consequently, there is a high possibility that the water in canals associated with River Ganga to be adversely affected by pollution. The aforementioned issues necessitate a thorough examination of water quality of UGC. It must be noted that all the water uses require a definite threshold water quality regarding biological, physical and chemical characteristics of the suspended or dissolved constituents, which should ascertain no harmful effects to the user (Goel, 2006; Bhattarai et al., 2008). Thus, this study is envisaged with an objective to examine the UGC water at Roorkee for physicochemical parameters and trace metals for different uses, viz., agricultural (irrigation), livestock drinking and human drinking purposes. In order to assess the suitability, these quality parameters should be compared with the reliable standards/guidelines of water quality for specified uses. The water quality guidelines and Standards of analyzed parameters for Irrigation water, livestock drinking and human drinking purposes are presented in **Tables 3.10, 3.11 and 3.12** respectively.

Table 3.10: Guidelines and Standards used for irrigation water

Parameter	**Units**	**Usual range for irrigation water**	
		FAO* (1985)	**IS 2296:1992 (Class E)**
T_w	°C	-	-
pH	-	6.0 – 8.5	6.0-8.5
EC	µmhos/cm	0 - 3000	2,250
TDS	mg/L	0 - 2000	2,100
TA	mg/L	-	-
TH	mg/L	-	-
Ca^{2+}	(meq/L)	0 - 20	-
Mg2+	meq/L	0 - 5	-
Na^+	meq/L	0 - 40	-
K^+	meq/L	0 - 2	-
Cl^-	meq/L	0 - 30	17 (600 mg/L)#
SO_4^{2-}	meq/L	0 - 20	20.8 (1000 mg/L)#
NO_3^-	meq/L	0 - 10	-
HCO_3^-	meq/L	0 - 10	-
CO_3^{2-}	meq/L	0 - 1	-
DO	mg/L	-	-
COD	mg/L	-	-
B	mg/L	0 - 2	2
Al	mg/L	5.00	-
As	mg/L	0.1	-
Cd	mg/L	0.01	-
Co	mg/L	0.05	-
Cr	mg/L	0.10	-
Cu	mg/L	0.20	-
Fe	mg/L	5.00	-
Mn	mg/L	0.20	-
Pb	mg/L	5.00	-
Zn	mg/L	2.00	-

***Sources**: For Irrigation: Ayers & Westcott (1985)

Original standards are in mg/L

Table 3.11: Guidelines and Standards used for livestock drinking water

Parameter	Units	Permissible limit for livestock drinking	
		CCME (2005)	**FAO (1985)**
EC	µS/cm	1500	-
TDS	mg/L	1000	-
Ca	mg/L	1000	-
Mg	mg/L	-	-
Na	mg/L	-	-
HCO_3	mg/L	-	-
CO_3	mg/L	-	-
Cl	mg/L	-	-
SO_4	mg/L	1000	-
K	mg/L	-	-
NO_3	mg/L	100	-
DO	mg/L	-	-
COD	mg/L	-	-
pH	-	-	-
B	mg/L	5.0	-
Al	mg/L	5.0	5.00
As	mg/L	0.5	0.2
Cd	mg/L	0.02	0.05
Co	mg/L	0.05	1.00
Cr	mg/L	1.0	1.00
Cu	mg/L	1.0	0.50
Fe	mg/L	-	Not Needed
Hg	mg/L	0.003	0.01
Mn	mg/L	-	0.05
Pb	mg/L	0.1	0.10
Zn	mg/L	50	24

Table 3.12: Guidelines and standards used for human drinking water

Parameter	Unit	Guidelines for Human drinking water (IS: 10500 (2012))	
		Acceptable Limit	Permissible limit in the absence of alternate source
pH	-	6.5 - 8.5	No relaxation
EC	µS/cm	-	-
TDS	mg/L	500	2000
TA	mg/L	200	600
TH	mg/L	200	600
Ca	mg/L	75	200
Mg	mg/L	30	No relaxation
Na	mg/L	200 (WHO)	-
Cl	mg/L	250	1000
SO_4	mg/L	200	400
NO_3	mg/L	45	No relaxation
DO	mg/L	4	6
COD	mg/L	10	-
B	mg/L	0.5	1
Al	mg/L	0.03	0.2
As	mg/L	0.01	0.05
Cd	mg/L	0.003	No relaxation
Cr	mg/L	0.05	No relaxation
Cu	mg/L	0.05	1.5
Fe	mg/L	0.3	No relaxation
Hg	mg/L	0.001	No relaxation
Mn	mg/L	0.1	0.3
Pb	mg/L	0.01	No relaxation
Zn	mg/L	5	15

3.4 Irrigation Water Quality Metrics

For evaluating the suitability of water quality of the UGC for irrigation, indices or metrics i.e. Sodium Adsorption Ratio (SAR), Residual Sodium Content (RSC), Residual Sodium Bicarbonate (RSBC), Sodium Soluble Percentage (SSP), Magnesium Adsorption Ratio (MR), Permeability Index (PI) and Kelley's Index Ratio (KR) were studied and evaluated using established equations (Ayers and Westcott, 1985; Doneen 1964; Eaton 1950; Joshi et al., 2009; Kelley 1951; Richard 1954; Sharma et al., 2014; Todd 1980; Wilcox 1955). For agronomical aspects, major parameters of water have been clustered in to classes namely salinity and sodicity that may affect soil, plant and human directly and indirectly (Kundu, 2012). The water quality indices were calculated by the following formulas:

$$\text{SAR} = \frac{\text{Na+}}{(\sqrt{\text{Ca2+ + Mg2+}})/2} \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3.1)}$$

$$\text{SSP, Na\%} = \left[\frac{(\text{Na+ + K+})}{(Na+ + Ca2+ + Mg2+ + K+)}\right] x\ 100 \ldots\ldots\ldots\ldots \textbf{(3.2)}$$

$$\text{RSC} = (\text{HCO3}^{-} + \text{CO3}^{2-}) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \ldots\ldots\ldots\ldots \textbf{(3.3)}$$

$$\text{RSBC} = \text{HCO}_3^{-} - \text{Ca}^{++} \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3.4)}$$

$$\text{MAR} = \frac{\text{Mg2+}}{(\text{Ca2+ + Mg2+})} \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3.5)}$$

$$\text{PI} = \left[\frac{(Na+ + \sqrt{HCO3-})}{(Ca2+ + Mg2+ + Na+)}\right] \times 100 \ldots\ldots\ldots\ldots \textbf{(3.6)}$$

$$\text{KR} = \frac{\text{Na+}}{(\text{Ca2+ + Mg2})} \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3.7)}$$

Where all the ionic concentrations contained in equations 1-7 are expressed in meq/L.

Sodium Adsorption Ratio (SAR)

The SAR accounts for sodium absorption by soil. The SAR was also expressed as sodium hazard, higher values of sodium in irrigation water resulting in poor drainage. Increase in SAR will cause replacement of Calcium and Magnesium content of soil by sodium, and consequently damage the soil structure (Asiwaju-Bello, 2013). Continued application of water with high SAR causes breakdown of soil aggregates. This makes soil compact and hard, which impedes water penetration (Samantray et al., 2009). The sodium hazard of high carbonate waters can be predicted using SAR, especially in the absence of residual alkali (Gopal and Joseph, 2015). Irrigation water containing large amounts of sodium has ill effects on soil as it changes soil properties and reduces permeability (Asiwaju-Bello, 2013). The sodium adsorption ratio is calculated using equation (**3.1)**. The water having SAR (< 10) is excellent, SAR (10-18) is good, SAR (18-26) is doubtful and SAR >26 is unsuitable for irrigation (Ayers and Westcott, 1985; Eaton, 1950; Richard, 1954).

Sodium Soluble Percentage (SSP)

Sodium soluble percentage is an important factor to study the sodium hazard. It is used for adjusting the quality of water for the use of agricultural purposes. Sodium reacts with soil to reduce its permeability. Higher SSP is unsuitable for irrigation as it inhibits growth of plants. The higher organic content and finer soil texture increases the impact of sodium on aeration and water infiltration (Joshi, et al., 2009). The formula for calculating SSP is presented in equation (**3.2)**. SSP values less than 20 as excellent, 20-40 as good, 40-60 as permissible, 60-80 as doubtful and above 80 is unsuitable for irrigation (Wilcox, 1955).

Residual Sodium Carbonate (RSC)

RSC is commonly used to express bicarbonate hazards. In the context of agriculture, RSC is computed to determine the ill effects of carbonate as well as bicarbonate on quality of water for irrigation. It is determined using the formula given in equation (**3.3)**. RSC account for the excessive alkalinity caused by quantity of carbonate and bicarbonate, which influences the usability of irrigation water. A high RSC content in water will lead to higher pH, causing soil infertility due to deposition of calcium and magnesium in the soil, when applied for irrigation (Asiwaju-Bello, 2013; Eton, 1950; Omotoso and Ojo, 2012). Further, continued usage of high RSC waters affects crop yields (UCCC, 1974). The value of RSC < 1.25meq/L is safe for irrigation as class I (USEDA, 1954), a value between 1.25 and 2.5 meq/L is of marginal quality and a value > 2.5meq/L is alkali water and unsuitable for irrigation (Dhembare, 2012; Majumdar, 2001; Richard, 1954). Further, continued usage of high RSC waters affects crop yields (UCCC, 1974).

Residual Sodium Bicarbonate Content (RSBC)

Considering the less frequent occurrence of carbonate in appreciable concentrations, and property of bicarbonate not to precipitate magnesium ions, Gupta and Gupta (1987) suggested that alkalinity hazard should be determined through the RSBC index. This is calculated using the formula in equation (**3.4**). The value of RSBC < 5meq/L is safe for irrigation as class I (Gupta et al., 2013), a value between 5-10 meq/L is of marginal quality and a value > 10 meq/L is unsuitable for irrigation.

Magnesium Adsorption Ratio (MAR)

Magnesium content plays a vital role in determining the water quality, especially for irrigation purposes. More magnesium in irrigation water will adversely affect soil potential, soil become more alkaline and reduce crop yield (Asiwaju-Bello et al., 2013; Gopal and Joseph, 2015; Joshi et al., 2009). The measure of the effect of magnesium in irrigation water is expressed as magnesium ratio. MAR is calculated using the formula in equation (**3.5)**. According to the guidelines of Food and Agriculture Organization (FAO), the value of MAR (%) < 50 indicates suitability for irrigation, whereas MR (%) > 50 is regarded as unsuitable (Ayers & Westcott, 1985).

Permeability Index (PI)

The permeability of soil is influenced by several factors like, continual application of irrigation, the contents of Na, Ca, Mg, CO_3^{2-}, HCO_3^- etc., in water and the soil type (Asiwaju-Bello et al., 2013). Permeability Index (PI) was formulated by Doneen (1964) to evaluate the suitability of water for irrigation. PI is computed using the formula given in equation (**3.6)**. PI values can be used to categorize water into three classes i.e. I, II and III, where Class I is regarded favorable for irrigation with maximum permeability of 75% or more. On the contrary, Class III is considered unsuitable for irrigation with 25% of maximum permeability.

Kelly Ratio (KR)

Suitability of water for irrigation purposes (Asiwaju-Bello et al., 2013) is also examined based on Kelly's ratio (Kelly, 1951). According to Dhemebare (2012), the concentration of Sodium (Na), Calcium (Ca) and Magnesium (Mg) in water are representing the alkali hazard. Sodium measured against calcium and magnesium was considered for calculating Kelly index (Khan, 2013). KR is calculated using the equation (**3.7)**; where, all the ions are expressed in meq/L. The values of KR < 1 for surface water indicate its suitability for irrigation and KR > 1 indicates water unsuitable (not good quality) for irrigation (Kelly, 1951).

3.5 Water Quality Index (WQI)

The WQI represents the state of complex water quality data in a simple numerical value, which can be easily understood and used by public. According to Tiwari and Mishra (1985), Water Quality Index expresses overall water quality based on several water quality parameters. In the present study, the weighted Arithmetic Index method suggested by Amadi et al. (2010), Khwakaram (2015) and Mukhtar et al. (2014), has been used to compute WQI.

Calculation of the WQI involves the following four steps: The quality rating scale (Q_i) for each parameter was calculated by the formula given below in equation (**3.8**):

$$Q_i = [(V_{actual} - V_{ideal}) / (V_{standard} - V_{ideal})] \times 100 \ldots\ldots\ldots\ldots\ldots \ (3.8)$$

Where,

Q_i = Quality rating of ith parameter for a total of n water quality parameters

V_{actual} = Actual value of water quality parameter obtained from the laboratory analysis

$V_{standard}$ = Recommended by standards for irrigation, livestock and human drinking.

V_{ideal} = Ideal value of that water quality parameter can be obtained from the Guidelines or standard tables.

V_{ideal} = for pH = 7 and for other parameters it is equivalent to zero, but for DO the V_{ideal} = 14.6 mg/L.

After obtaining Q_i, the relative (unit) weight (W_i) was computed by the following expression (equation **3.9**):

$$W_i \propto \frac{1}{Si}, \text{ or } W_i = \frac{K}{Si} \ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

Where,

W_i= Relative (unit) for nth parameter, S_i = Standard higher permissible value for nth parameter. K= proportionality constant of the “weights” for various water quality characteristics and is given by equation (**3.10**).

$$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{Si}} \ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

It implies, W_i for different quality parameters is inversely proportional to their corresponding recommended standards. Finally, the overall WQI was computed by the weighted Arithmetic Index as given below in equation (**3.11**):

Overall, $\mathbf{WQI} = \sum_{i=1}^{n} Q_i W_i \,/\, \sum_{i=1}^{n} W_i$ ……………………………………………..**(3.11)**

Where,

Q_i = Quality rating scale of each parameter;

W_i = Relative weight unit of each parameter, and n = number of parameters.

The WQI calculation method was developed by Harton (1965), which was modified by Brown (1970) by providing weights to influential parameters. WQI has been used by numerous researchers to evaluate the surface water quality across several parts of the globe, mostly for irrigation and human drinking purposes. According to Pandey et al. (2014), WQI is defined for a specified and purposive water use. In general, the allowable limit of WQI is considered as 100, which is the critical pollution index value (Reza and Singh, 2010). A WQI score beyond 100 is regarded unsuitable for irrigation and drinking uses. According to Al-Mashagbah (2015), Amadi et al. (2010), and Goher et al. (2014) water quality rating as per weight arithmetic water quality of canal is shown in **Table 3.13.**

Table 3.13: Water quality rating as per weighted arithmetic method for canal surface water

WQI value	Range of water Supply	Grading
0-25	Excellent	A
26-50	Good	B
51-75	Poor	C
76-100	Very Poor	D
Above 100	Unsuitable for drinking purpose	E

In the present study, the water quality index is calculated considering physicochemical variables and toxic trace metals, which are crucial parameters for specified purposes. For the evaluation of the pollution status of the UGC water using the weighted arithmetic Water Quality Index method, different water quality components were multiplied by weighting factor and then were aggregated using the simple arithmetic mean. It is evident from equation 3.9 that the permissible limits of different parameters are imperative for calculation of WQI. However, these permissible limits possess variation amongst standards/guidelines by different organizations or policy making bodies.

Moreover, the allowable limits for all the parameters for a specific purpose may not be obtained from a single standard. In this study, WQI is computed to assess the suitability of water from UGC for irrigation, livestock drinking and human drinking purposes. Hence, the guidelines imposed by Food and Agricultural Organization (FAO, 1985) and Bureau of Indian Standards (IS 11624: 2009) for irrigation; Canadian Council of Ministers of the Environment (CCME, 2005) and FAO (1985) for livestock drinking; and BIS (IS 10500: 2012) for human drinking have been considered for obtaining permissible limits of different parameters, for computing WQI. These standards are considered authentic and are well acknowledged in scientific literatures of water quality analyses.

3.6 Correlation Matrix

The correlation coefficient ‘r’ is a measure of the strength of linear relation between x and y variables. Therefore, ‘r’ was computed to obtain dependence existing among the indices by using the equation 3.12.

$$r = \frac{N\Sigma(xy) - (\Sigma x)(\Sigma y)}{\sqrt{[Nx2 - (\Sigma xy2][N\Sigma y2 - (\Sigma y2)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \mathbf{(3.12)}$$

Where, x and y represents two different parameters, N = number of total observation.

The value of r ranges from -1 to 1, where 1 represents a perfect match and -1 represents an inverse linear variation among the variables. A zero value of *r* represents no relation among the concerned variables (Gupta et al., 2013; Matta, 2015; Jothi Venkatachalam et al., 2010).

A correlation matrix is a table showing correlation coefficients between sets of variables (Table 3.15). Each random variable (X_i) in the table is correlated with each of the other values in the table (X_j). This allows you to see which pairs have the highest correlation.

Table 3.14: An example of correlation matrix for 5 variables (B1 to B5)

	B1	**B2**	**B3**	**B4**	**B5**
B1	1				
B2	0.53	1			
B3	0.73	0.44	1		
B4	0.87	0.96	0.41	1	
B5	0.43	0.71	0.72	0.56	1

The **Table 3.14** represented above is a correlation matrix which shows a correlation amongst different parameters (B1, B2, B3, B4 and B5) used. It may be noted that, the correlation of any parameter with itself is 1, as correlation accounts for the degree of agreement between variables. Generally, the correlation matrix is presented as an upper triangular or lower triangular matrix. This is due to the fact that, correlation (B1:B2) is equal to correlation (B2:B1). So mentioning the same value at both places is not necessary. From this table, the robust inter-dependencies amongst the parameters can be visualized.

3.7 Numerical Modeling for Pollutant Dispersion

This section is about application of a numerical modeling approach to study the pollutant dispersion. The influence of opening of various sewage as well as sewage velocities on the change in concentration of canal water can be investigated. The study is augmented by analyzing the insertion of solid particle pollutants from the sewage inflow. The model description and its mathematical formulation (Governing equation for fluid flow and solid particle trajectory calculation) are presented in the following sub-sections.

3.7.1 Model Description

The study has been performed by considering UGC, Roorkee, which is affected by pollution, mainly contributed by the surrounding urban area. The intervention of non-biodegradable waste, dumping of sewage and industrial pollutant in the river are the primary reasons for the increasing pollution in the canal (Kazmi and Hansen, 1997). Thus, a three dimensional model geometry has been developed from old canal bridge to Ganeshpur Bridge, Roorkee. In this region, five sewages have been observed along both side of the canal, which have also been considered while modeling the geometry. **Figure 3.2** shows the model geometry developed based on geometrical data obtained Upper Ganga Canal between old canal bridge to Ganeshpur bridge, Roorkee.

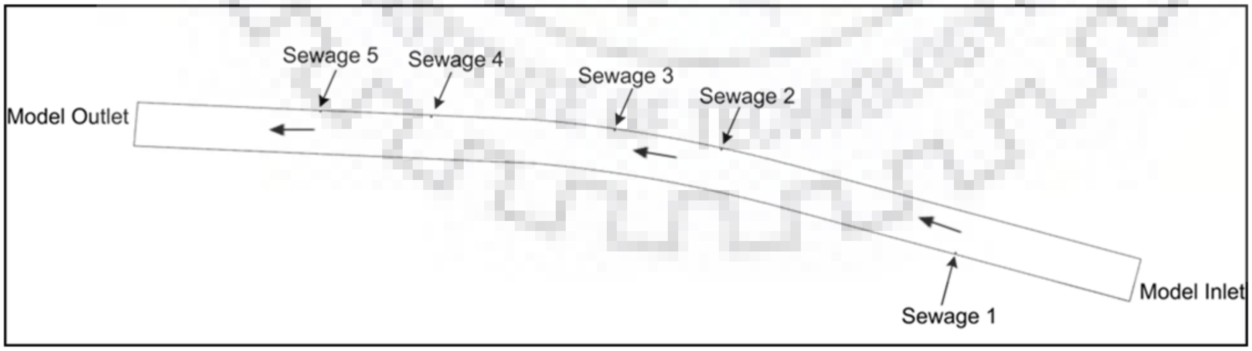


Figure 3.2: Model geometry of canal

The geometrical data such as distance from old canal bridge to Ganeshpur bridge, depth and width of the canal, and sewage positions are obtained physically from the canal site. Moreover, the parameters such as water flow velocity and sewage discharge velocity have been measured manually and executed in the numerical model. The dimensions of the canal modelled are length 1397.715 m, depth 8 m and width 60 m. The inlet of the each sewage is taken as circular inlet of diameter 0.4 m, 0.5 m away from the canal wall. Other process parameters used for the development of model and simulations are given in **Table 3.15**. The geometry has been subdivided into 85440 elements with structured hexahedron meshing. **Figure 3.3** shows the mesh developed into the geometry. The computation has been performed by using the commercial tool ANSYS Fluent 15.0.

Further to simplify the calculation few assumptions have made during the computation. All the fluids have been assumed as Newtonian and incompressible. The velocities at all the inlets are assumed to be constant throughout the calculation. The solid particles were assumed to be inert in nature and have spherical shape. The movement of particles in the canal was assumed not to affect the flow streamlines. Ideal absorption of solid particle to the canal base was assumed i.e. any solid particle reaching to the canal base will not revert back into the system at a later time.

Table 3.15: Boundary condition and process parameters applied

Boundary condition /Process parameters	**Value**
Length of canal modelled (m)	1397.715
Width of canal (m)	60
Depth of canal (m)	8
Sewage inlet diameter (m)	0.4
Velocity at old canal bridge near civil line (m/s)	0.981
Average Sewage velocity (m/s)	0.2, 0.4 and 0.6
Density of water (kg/m3)	998.2
Density of sewage pollutant (kg/m^3)	1300
Mass diffusivity of mixture (m^2/s)	2.88×10^{-9}
Density of solid particle (kg/m^3)	1200, 1500, 2000
Diameter of solid particle (m)	0.00015, 0.00008, 0.000023, 0.000008, 0.0000023

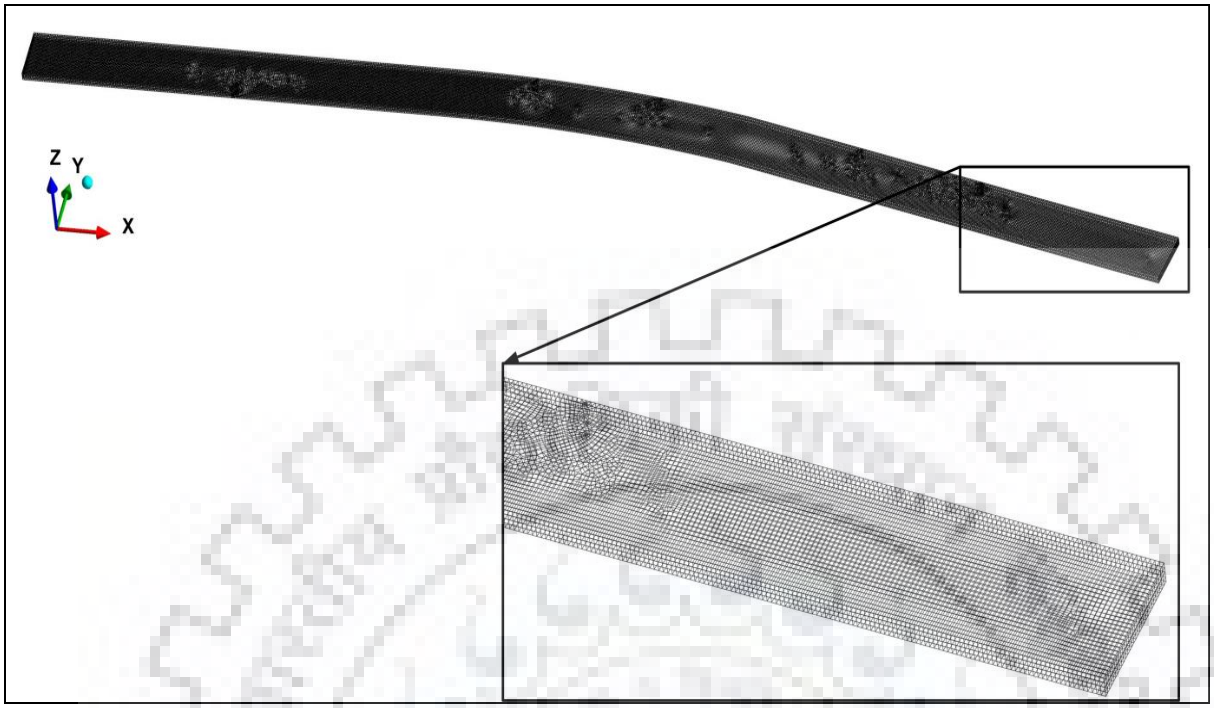


Figure 3.3: Meshing used for the computation

3.7.2 Governing equation for fluid flow

The continuity equation and transient Navier-Stokes equation for momentum conservation can be expressed as

$$\nabla.\vec{U} = 0 \tag{3.13}$$

$$\frac{\partial}{\partial t}(\rho\vec{U}) + \rho\nabla.(\vec{U}\vec{U}) = -\nabla P + \nabla.\left[\mu_{eff}(\nabla.\vec{U})\right] + \rho\vec{g} \tag{3.14}$$

Where, $\mu_{eff} = \mu_l + \mu_t$ is the effective viscosity, μ_l is the dynamic viscosity and μ_t is the turbulent viscosity.

The partial differential equations for turbulent kinetic energy (k) and dissipation rate (ε) are given by Equations ~~3~~ 3.15 and ~~4~~ 3.16 respectively as:

$$\rho\frac{\partial k}{\partial t} + \nabla.(\rho k\vec{U}) = \nabla.[(\mu_l + \alpha_k\mu_t)\nabla k] + G + \rho\varepsilon + S_k \tag{3.15}$$

$$\rho\frac{\partial \varepsilon}{\partial t} + \nabla.(\rho\varepsilon\vec{U}) = \nabla.[(\mu_l + \alpha_\varepsilon\mu_t)\nabla\varepsilon] + C_{1\varepsilon}\frac{\varepsilon}{k}G - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}} + S_\varepsilon \tag{3.16}$$

Where, α_k and α_ε are the inverse effective Prandtl numbers, $C_{1\varepsilon}$ =1.44 and $C_{2\varepsilon}$ =1.92 are the model parameters, G is the generation of the turbulence kinetic energy due to mean velocity gradients.

Sink terms S_k and S_ε are added to the turbulence kinetic energy and dissipation equations respectively.

The governing equation solved to calculate the mass fraction of sewage pollutant can be expressed as:

$$\frac{\partial(\rho C)}{\partial t} + \nabla.\rho u C = \nabla.(\partial D \nabla C) \tag{3.17}$$

Where, C is the mass fraction and D the mass diffusivity.

3.7.3 Solid Particle Trajectory Calculation

In a quiescent fluid, solid particle pollutants are small enough and obeys Stokes law, the terminal rising velocity of the particles, V_s may be given by Stokes relation.

$$V_s = \frac{g(\rho - \rho_p)d^2}{18\mu} \tag{3.18}$$

However, when the liquid have motion, the velocity V_s becomes an additional vertical component to the fluid velocity. The particles that reaches to bottom surface of the canal by settling down were assumed to be trapped at the base. Solid particle pollutant trajectories have been calculated using Lagrangian particle tracking method, which solves a transport equation for each particle as it travels through. The mean local particle velocity component, μ_p needed to obtain the particle path. These have been obtained by balancing force from Equation ~~7~~3.19.

$$\frac{du_p}{dt} = F_D\left(u - u_p\right) + \frac{g_x\left(\rho_p - \rho\right)}{\rho_p} + F_x \tag{3.19}$$

Where, $F_D\left(u - u_p\right)$ is the drag force per unit mass of the particle and

$$F_D = \frac{18\mu}{\rho_p {d_p}^2}\frac{C_D R_e}{24}, \tag{3.20}$$

u is the fluid phase velocity, u_p is the particle velocity, μ is the molecular viscosity of the fluid, ρ is the fluid density, ρ_p is the density of the particle, and d_p is the particle diameter. Re is the relative Reynolds number, which is defined as

$$R_e = \frac{\rho d_p \left| u_p - u \right|}{\mu} \tag{3.21}$$

C_D is dimensionless drag coefficient and can be defined as:

$$C_D = \frac{24}{R_e}\left(1 + 0.186 {R_e}^{0.6529}\right) \tag{3.22}$$

CHAPTER 4

WATER QUALITY ASSESSMENT OF UPPER GANGA CANAL FOR IRRIGATION

This chapter presents a detailed analysis of the Upper Ganga Canal (UGC) water quality for assessing its suitability specific to irrigation purpose. The effects of physicochemical variables and toxic trace metals in UGC water pertaining to irrigation are discussed. Various irrigation water quality metrics are computed and compared with authentic Standards as well as with the previous literatures. The intra-correlation amongst the irrigation water quality metrics along with EC and TDS, which are prominent factors for salinity, are also calculated to obtain the dependencies. Water Quality Index, which is acclaimed as a robust indicator of overall water quality, is also computed for all three seasons (winter, summer and monsoon) for the period of November 2014 to October 2015, considering the effects of physicochemical parameters and toxic trace metals, separately as well as in combined form.

4.1 Introduction

Water is essential for all forms of lives i.e. from microorganism to complex systems of plants, animals and human beings. It is essential natural resource for the survival of life, a key input for plant growth and instrumental in the upkeep of environment. Especially, availability of water at optimum quality is essential for agriculture (Ayers & Westcott, 1985, 1994; and FAO, 1985, 1992). Globally, fresh water to the tune of 3240 million cubic kilometer is being utilized. Of this, 69 percent is being used in agricultural sector, 8 percent in domestic, 23 percent in industrial and other sectors (Pandey, 2014). Availability of good quality irrigation water is an indispensable feature for preventing crop and livestock diseases and for rising and improving the quality of agriculture and crop production. Use of poor quality or contaminated water for long time can make the soil less productive or even barren land depending on the amount and type of constituents present on the canal water (Majumdar, 2001, Wattoo, 2004). According to Wilcox (1955) and Ayers and Westcott (1985), the application of inferior quality water in irrigation has remained the major cause for the deterioration of soils, agricultural crops and various health problems confronting human being. Moreover, rapidly increasing population, rising standards of living and exponential growth of industrialization and urbanization (Srivastava et al., 2011) have exposed the water resources, in general, and rivers, in particular, to various forms of degradation.

In India, the major water sources are rivers, lakes, canals, reservoirs, tanks, and ground water. The Upper Ganga Canal (UGC) water is used for mainly irrigation purposes in the districts of Utter Pradesh and Uttarakhand. Thus, the perennial flow of water in the irrigation canal diverted from the main Ganga River makes it possible to have year-round agricultural production. Indian rivers, the source of many canal waters, are polluted by discharge of industrial effluents and untreated sewage. That means canal water qualities are generally the same as the water of their parent rivers, unless it is contaminated while passing through as salt affected area and quality of canal water depends mainly on the river from which it originates (Michael, 1978; Tomar, 1999). This quality should be suitable for agricultural purposes. The agricultural water quality parameter includes numerous properties of water relevant to the quality and yield of crops, conservation of soil fertility, environmental protection, effects on livestock health and human health etc. Various studies have already been carried out by different researchers to study the irrigation water quality indices i.e. EC, TDS, SAR, SSP, RSC, RSBC, MR, PI, CR and KR and the various physiochemical parameters as well as toxic trace metals in different parts of the world for surface water bodies like rivers and canals.

Augoustis et al. (2012) studied assessment of an irrigation canal ecosystem to evaluate the physiochemical parameters and heavy metals in sediment of Asmaki Canal water of Thessaly region, Greece and the nature of pollution along the canal in relation to the SAR, %Na with the help of piper diagram. They found that EC or salinity and SAR were highly unsuitable for irrigation and % Na was suitable for irrigation. The ions like Cl^-, SO_4^{2-}, Ca^{2+}, and Mg^{2+} were unfit for irrigation and the heavy metals like Cd, Cr, Cu, and Pb concentration in sediment were significantly lower for use of sludge in agriculture. They concluded that pollution of the canal water was not only cutting edge environmental issue but it was also a problem of development and character. Islam and Shamsad (2009) assessed irrigation water quality to evaluate important physiochemical parameters of surface (canal and river) water and groundwater over Bogra district, Bangladesh. They found all the parameters i.e. T_w, pH, EC, TDS, SAR, SSP, RSC and KR were within the permissible limits concerned to irrigation purposes, and hence, concluded no salinity problem for surface and ground waters. Mohamed (2013) carried out evaluation of irrigation water quality in terms of chemical properties for the El-Salam canal in Egypt over three seasons (winter, spring and summer). Comparing the results with FAO (Ayers & Westcott, 1994) standards, an increase was found for EC, cations and anions during summer season relative to other seasons. The analyzed parameters were within the permissible values for plants in all seasons of the year. However, a progressive increase in soluble cations, anions, SAR, Na and Cl content at different locations was observed with increasing salinity content of water. Semwal and Akolkar (2011) considered four canals (Agra, Hindu, west Yamuna and Ganga) in NCR Delhi, India, to study their suitability for irrigation in terms of critical pollutants such as TDS, pH, EC, SAR and B. Moreover, collected water samples were analyzed for sodium, potassium, calcium, magnesium and chloride parameters. They concluded that, results of the average TDS and EC were good for irrigation. However, the water bodies were adjudged unfit for irrigation due to effects of the critical pollutants altogether. Nazif et al. (2006) carried out evaluation of irrigation water sources (canal and Bara River) for heavy metal contents in Akbarpura area of the district Nowshera and they found that heavy metal concentrations were significantly lower in the irrigation canal water relative to Bara River water in which only Mn and Zn were found in different concentration. Joshi et al. (2009) studied the irrigation water quality of River Ganga in Haridwar district for three seasons by analyzing the parameters namely EC, TDS, MR, % Na, SAR, RSC, and PI. The results reveal for an unsuitability of river water during rainy season due to a high percentage of EC, TDS and Na. Sultana et al. (2009) carried out evaluation of surface irrigation water quality in Muktagacha, Bangladesh. Water samples were collected from 19 different sites of the surface water bodies (canal, river, pond, khal, beel, etc.) and analyzed for chemical properties of surface water to categorize them based on irrigation applicability. The salinity, EC and SAR were found to be excellent, good and normal respectively. Regarding pH, water was neutral to slightly alkaline. Few locations possessed high nitrate content in water and hence, should be applied for irrigation cautiously. The Boron concentrations for almost all the samples were excellent. Overall, they concluded that the surface water quality of the Muktagacha to be suitable for irrigation.

Hence, pollution is a serious problem in different countries. In India, especially Ganga, the origin of UGC system, is the most polluted River today by garbage, sewage and industrial waste is being poured into the river (NRCD, 2009). This implies a possibility of UGC water to be polluted. As UGC water is used for irrigation in many districts of Uttar Pradesh and Uttarakhand, the quality should be suitable for the same. Management of water quality of agriculture and monitoring is necessary to check the suitability of water for any purpose which is linked to its physical, chemical and biological quality. Thus, it is essential to check the water quality of canal water at regular time interval before it is used for irrigation purposes. In this chapter, the physicochemical parameters, toxic trace metals, irrigation water quality metrics are assessed to evaluate the suitability of the UGC water for irrigation.

4.2 Data and Methods

In this study, water samples were collected from eighteen sites i.e., S1, S2, S3,…, S17 and S18, at monthly interval for a period of one year (from November 2014 to October 2015) with the aim of understanding the seasonal (winter, summer, and monsoon) variation in the UGC water quality. The water samples were analyzed in laboratory for obtaining the concentration of physicochemical parameters and toxic trace metals. The data obtained from this laboratory analysis is compared with the reliable standards and guidelines of irrigation water quality.

The detailed procedure for collection of water samples and brief description of the physicochemical parameters as well as the toxic trace metals has been provided in **Section 3.2** of the Chapter-III (Materials and Methods). The instruments and detailed laboratory procedures to obtain the physicochemical parameters and toxic heavy metals from the water samples are appended as **Annexure A**. The data obtained for physicochemical parameters at monthly level are appended as **Annexure B** (**Tables B1 to B13**). The seasonal data converted from these monthly observations over all the 18 sites are presented for winter, summer and monsoon seasons in **Tables 3.3, 3.4 and 3.5** respectively. Similarly, for the toxic trace metals, the seasonal observations and the statistical summary for winter, summer and monsoon seasons are given in **Tables 3.7, 3.8 and 3.9** respectively (**Chapter 3**). The guidelines and standards by Food and Agricultural Organization (Ayers & Westcott, 1985) for irrigation water are also presented in **Table 3.10** of previous chapter, which has been used to decide the suitability of the UGC water for irrigation purpose.

For evaluating the suitability of the UGC water for irrigation, exclusive irrigation water quality indices or metrics were studied and evaluated. A detailed description of these parameters and their computation procedure is presented in **Section 3.4** of **Chapter 3**. These metrics, viz., Sodium Adsorption Ratio (SAR), Sodium Soluble Percentage (SSP), Residual Sodium Content (RSC), Residual Sodium Bicarbonate (RSBC), Magnesium Adsorption Ratio (MAR), Permeability Index (PI) and Kelley’s Ratio (KR) are calculated by the equations **3.1, 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7** respectively. The inter-dependencies amongst these irrigation water quality metrics and EC as well as TDS are obtained by Pearson’s correlation matrix, as explained in **Section 3.6** of the **Chapter 3** (Materials and Methods).

Water Quality Index (WQI) represents the state of complex water quality data in a simple numerical value, which can be easily understood and used by public. It expresses overall water quality based on several water quality parameters. A WQI value less than 100 is considered usable for agricultural applications. The WQI for all the sampling sites during all the three seasons is also determined by considering the physicochemical parameters and toxic trace metals separately as well as in combined form, of which, the later represents the overall water quality. The computation procedure and explanations of WQI is presented in **Section 3.5** of the **Chapter 3** (Materials and Methods).

4.3 Results and Discussion

4.3.1 Physicochemical Parameters

The physicochemical parameters relevant to irrigation are considered and compared with respect to the authentic international standards/guidelines. These parameters are electrical conductivity, total dissolved solids, cations (sodium, magnesium, potassium and calcium), anions (chloride, sulfate, nitrate, carbonate and bicarbonate), water temperature, pH, total alkalinity, total hardness and Boron. Any alterations in these parameters may significantly affect the suitability of water for irrigation purposes. Therefore, it is necessary to compare the results obtained from the analysis with the reliable standards. In this study, results were compared to the guidelines by Food and Agricultural Organization (FAO, 1985), to assess suitability for irrigation in all eighteen sampling sites of the UGC, Roorkee. The condition of UGC water in terms of these parameters (analyzed on field and at laboratory) at all the eighteen sampling sites during November 2014 to October 2015, at seasonal level (winter, summer and monsoon season) are discussed below.

Electrical Conductivity (EC)

Electrical conductivity (EC) accounts for the concentration of soluble salts in water and hence, is a potent tool to recognize salinity issues of crops. The EC values (μmhos/cm at 25^0C) of the study area in the UGC, Roorkee varied from 181 to 1316 with an average of 351 and SD of 348.9 for winter season; from 161 to 1237 with an average of 356 and SD of 375 for summer season; and from 153 to 1064 with an average of 331 and SD of 281 for monsoon season (**Figure 4.1**). Based on the guidelines of Wilcox (1950) and FAO (1985) , an EC value of < 250 μmhos/cm is considered as excellent, 250-750 μmhos/cm as good, 750-2250 μmhos/cm as permissible, 2000-3000 μmhos/cm as doubtful and >3000 μmhos/cm as unsuitable for irrigation water quality of canal (Ayers & Westcott , 1985; Semwal and Akolkar, 2011; Sharma et al., 2014). Thus, the results are found to be excellent, good and permissible for winter, summer and monsoon season respectively, based on the mentioned irrigation water quality classification. It is easily presumable that in terms of EC values, water of the UGC, Roorkee, from all the sampling sites was suitable for irrigation purposes.

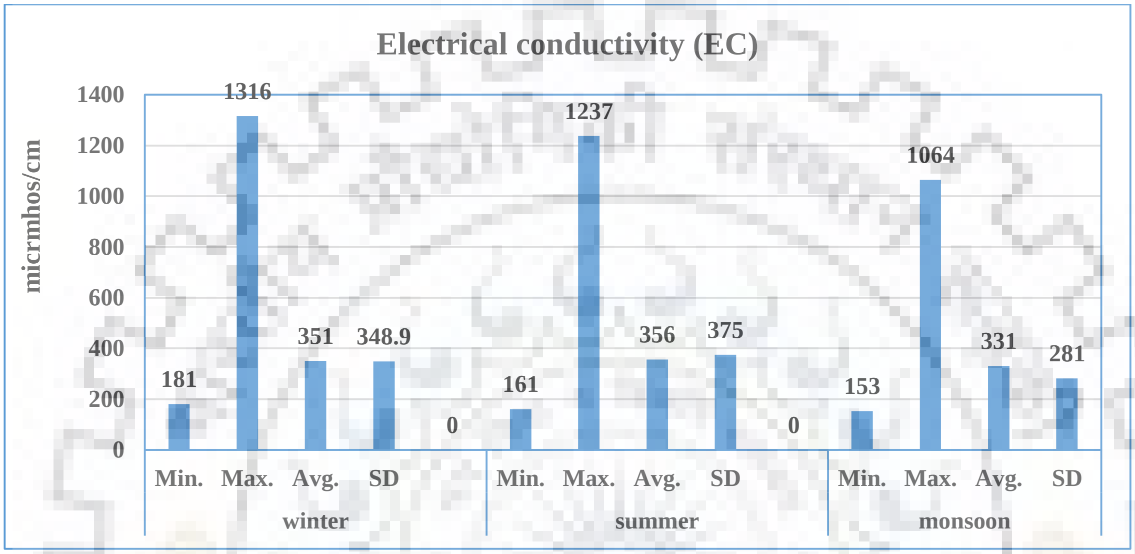


Figure 4.1: Seasonal EC values (µS/cm) of the UGC, Roorkee during November, 2014 to October, 2015

Total Dissolved Solids (TDS)

In case of irrigation, weathering or dissolution of rocks, soil and minerals (gypsum, lime, etc.) leads to TDS (salts). The soil minerals and agrochemicals are the respective natural and anthropogenic sources of TDS in water (Kundu, 2012). These salts get into the croplands when water is applied for irrigation and subsequently, when water gets evaporated or utilized by crop, these salts remain behind. Accumulation of salts in root zone hinders water extraction by crops, which results in water stress for considerable period of time and hence, reduction in yield (Joshi et al., 2009). Regarding irrigation water quality of canal, the TDS values < 175 mg/L is considered as excellent, 175-525 mg/L as good, 525-1400 mg/L as permissible, 1400-2100 as doubtful and > 2100 mg/L as unsuitable (Semwal and Akolkar, 2011). The TDS values of the study area ranged from 116 to 826 mg/L with an average of 225 mg/L and SD of 222 during winter season, from 103 to713 mg/L with an average of 218 mg/L and SD of 214 during summer season, and from 98 to 734 mg/L with an average of 217 mg/L and SD of 192 during monsoon season, as can be observed from **Figure 4.2**. In all the seasons (monsoon, summer and winter), TDS was within the allowable limits according to FAO Standards (Ayers and Westcott, 1985). Thus, TDS values of the UGC water were suitable for irrigation uses.

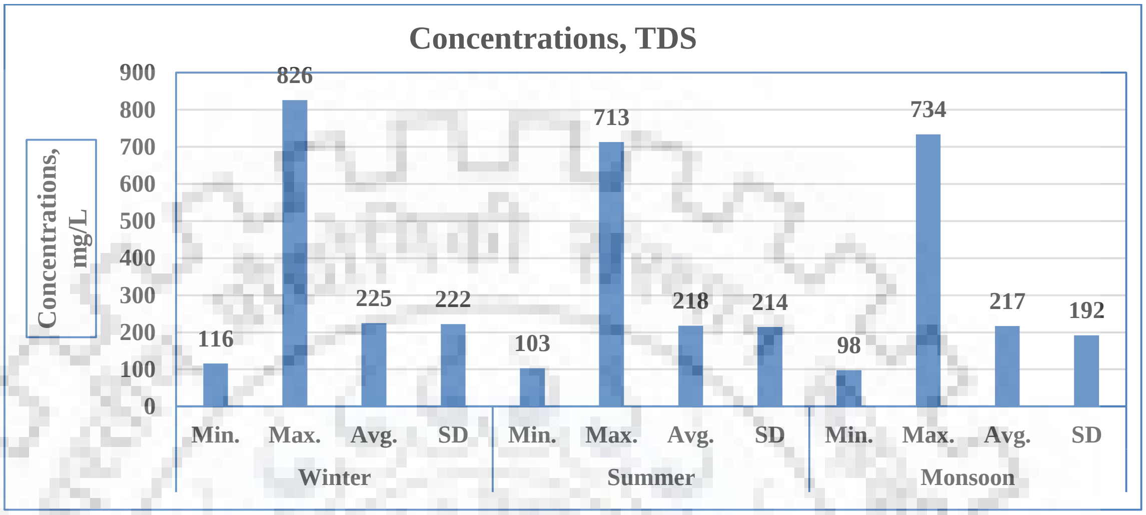


Figure 4.2: Seasonal concentrations of TDS (mg/L) of the UGC, Roorkee during November, 2014 to October, 2015

Cations

In this study, the cations and the anions constituents were used for calculating various irrigation water quality indices i.e. SSP, SAR, RSC, RSBC, MAR, PI and KR. The major cations and anions present in water are the prominent chemical parameters, which need to be analyzed prior to application for irrigation (Samanta et al., 2013). The details of the cations (Ca^+, Mg^{2+}, Na^+ and K^+) are presented below. The statistical summary of all these cations for winter, summer and monsoon seasons are presented in Figure **4.3**.

Calcium (Ca^{2+})

Calcium is an essential plant nutrient. It also maintains the physical condition of soil in good form, which leads to good water penetration and supports tilling (Wattoo, 2004). Thus, Ca^{2+} is considered good for irrigation. In this study, the various total cationic constituents of Ca^{2+} values varied from 2.65 to 16.76meq/L, with an average of 0.3.28meq/L and SD of 3.67 for winter season, from 2.09 to 8.69meq/L with an average of 3.05meq/L and SD of 2.03 for summer season, and from 2.49 to 6.22meq/L with an average value of 3.26meq/L and SD value of 1.20 for monsoon season **(Figure 4.3)**. Therefore, all samples of the UGC, Roorkee during all the three seasons had no problems with Calcium and the canal water is suitable for irrigation purpose. Thus, UGC water is suitable for irrigating all low tolerance and high tolerance crops.

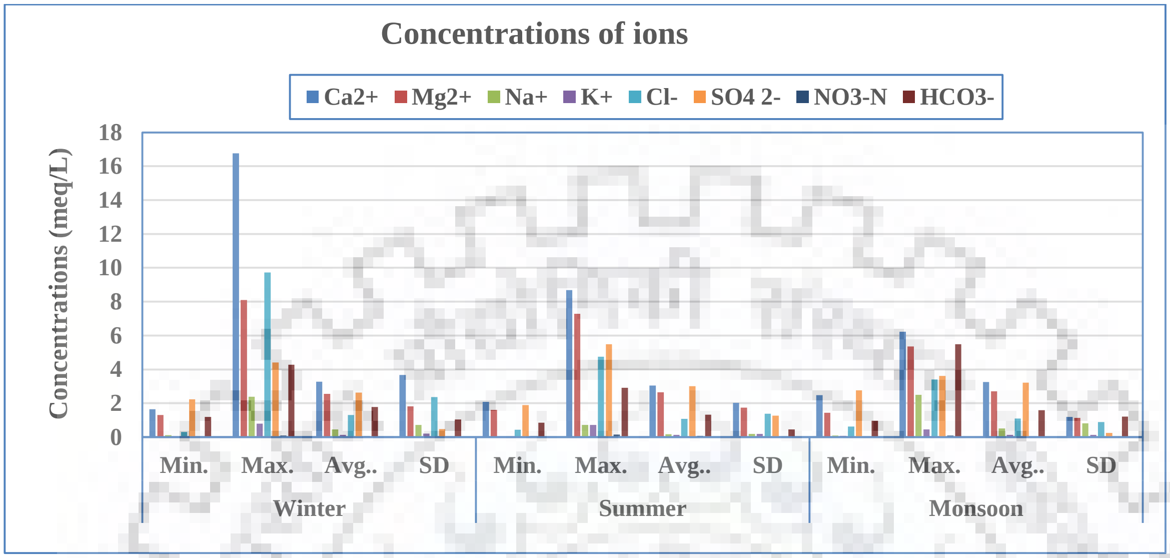


Figure 4.3: Seasonal concentrations of cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (Cl^{-}, SO_4^{2-}, NO_3^{-}-N, and HCO_3^{-}) of the UGC, Roorkee during November, 2014 to October, 2015

Magnesium (Mg^{2+})

Mg is an important plant nutrient. Generally, it occurs at almost half of calcium concentration, but higher amount of it may cause serious effect on soil, which is irrigated with this water (Wattoo, 2004). Mg^{2+} is also a main constituent of water responsible for hardness in neutral water, which may combine with carbonates and bicarbonates to result in lime deposits, very hard water and salinity. In this study, the total ionic constituent of Mg^{2+} varied from 15.75 to 98.0 meq/L with an average of 31.0 meq/L and SD of 22.07 for winter season, from 19.5 to 88.25 meq/L with an average of 32.15 meq/L and SD of 21.13 for summer season, and from 17.5 to 64.9 meq/L with an average of 32.72 meq/L and SD of 13.77 for monsoon season **(Figure 4.3)**. Therefore, the samples of the UGC, Roorkee during all the three seasons were above the permissible limits when results were compared to the guidelines by Ayers and Westcott (1985). Thus, the UGC canal water was not suitable for irrigation from the point of view of Magnesium concentrations. This can lead to excessive hardness in water, which may be harmful to crops.

Sodium (Na^+)

Unlike Chloride toxicity, it is very difficult to diagnose Sodium toxicity, but many cases are observed with high sodium concentrations in the water. The leaf burn is the typical symptom for sodium toxicity. These normally develop at older leaves and then progressively move towards the leaf center. The citrus plants, avocadoes, nuts, deciduous fruits, beans etc. are the mostly sensitive to Na^+(Ayers and Westcott, 1994). Water with high sodium concentration is regarded as 'Soft water' and is normally considered unsuitable for irrigation. This results in soil slowly taking water to form hard clods that seal the soil surface after melting and leaves a slick appearance. In addition to soil structure, sodium also has toxic effects on plants (Wattoo, 2004). Moreover, the reaction of Sodium with soil causes reduction in permeability (Joshi et al., 2009). Natural component of water, salts and weathering of sodium bearing minerals, rocks, industrial brine, reclaimed effluent water and sea water etc. are sources of occurrence for sodium. Sodium is hazardous when applied for irrigating heavy clay soils as it leads to reduction in stability of particles causing physical degradation. This feature is called as sodicity (Aftab et al., 2011). In this study, the total ionic constituent of Na^+ ranged between0.12 to 2.38meq/L with an average of 0.46meq/L and SD of 0.73 for winter season, from 0.05 to 0.73meq/L with an average of 0.18meq/L and SD of 0.20 for summer season, and from 0.1 to 2.5meq/L with an average of 0.51 and SD value of 0.81 for monsoon season **(Figure 4.3)**. The Na^+ concentration values were within the permissible limits for all the samples during all three seasons (monsoon, summer and winter) when the results were compared with the guidelines by Ayers and Westcott (1985). Therefore, all samples from UGC, Roorkee had no problems during all the three seasons. Thus, the canal water is suitable for irrigation purpose to all low as well as high tolerance crops.

Potassium (K^+)

Potassium is an essential plant nutrient. The main sources of K^+ are fertilizers, rock, salt and soil. The water with high potassium content, if applied for irrigation, may cause a significant increase of forage grasses (Wattoo, 2004). In this study, the total ionic constituent of K^+ ranged from 0.04 to 0.8meq/L with an average of 0.14meq/L and SD of 0.2 for winter season, from 0.03 to 0.72meq/L with an average of 0.13meq/L and SD of 0.2 for summer season, and from 0.07 to 0.46 meq/L with an average of 0.14meq/L and SD of 0.13 for monsoon season **(Figure 4.3)**. Therefore, all samples of the UGC, Roorkee during all the three seasons had no problems. Thus, the canal water is suitable for irrigation purpose and for all low tolerance and high tolerance crops.

Anions

In this study, the major anions present in the irrigation water were also analyzed. The details of the anions viz., Cl^- , SO_4^{2-} , CO_3^{2}- and HCO_3^- are discussed below. **Figure 4.3** presents a statistical summary (minimum, maximum, average and standard deviation) of these anions during all the three seasons.

Chloride (Cl^-)

Chloride is required by plants in fewer amounts but can cause toxicity to sensitive crops if, it is used at amply high concentrations. If the accumulation is great enough, it results reduction of crop yields. The sources of chlorides are dissolving minerals, surface water from septic tank effluents and animal feeds, road salt, fertilizers, industrial wastes or sewages, water additive used to control microbes, disinfectants etc. Sodium chloride dissolves in water from soil and rocks; and it occurs in natural water in varying concentrations (Kundu, 2012). Chloride is not absorbed by soils; but the crop takes it up. After moving through the transpiration stream, Cl^- ion gets accumulated in the leaves. The concentration of Chloride exceeding tolerance limit of crop may cause plant injuries such as leaf burn or dying of leaves. Generally, leaf tips are more vulnerable to plant injury caused by chlorine toxicity (Ayers and Westcott, 1994; Sundaray et al., 2009). The total anionic constituent of Cl^- values in the UGC, Roorkee ranged from 10.75 to 345 mg/L with a mean of 46.486 mg/L and SD of 83.802 for winter season; from 15.75 to 169 mg/L with a mean of 38.46 mg/L and SD of 48.93 for summer season; and from 22.25 to 120.75 mg/L with average value of 39.07 mg/L and SD of 31.63 for monsoon season **(Figure 4.3)**. For all water samples of the UGC, Roorkee, during all the three seasons, the concentration of Cl^- ions were within the permissible limits by FAO (Ayers and Westcott, 1985). Also, plants require Cl^- in traces, but a high concentration may lead to toxicity to crops. The chloride below 70 ppm is generally safe for all plants; if, it is from 70-140 ppm, sensitive plants show injury; if, it is from 141-350 ppm, moderately tolerant plants show injury and if it is above 350 ppm, can cause severe problems (Bauder et al., 2007). Therefore, all the samples of the study area during all the three seasons (winter, summer and monsoon) had no problems and the UGC canal water was suitable for irrigation purposes and for all low tolerance and high tolerance crops when results values were compared to the guidelines by Ayers and Westcott (1985).

Sulfate (SO_4^{2-})

Salinity in irrigation water is significantly contributed by Sulfate ion. Sufficient content of sulfate ion in irrigation water enhances the fertility of soil and hence, acts as a catalyst for maximum crop yield. Sulfate is widely distributed in natural waters. Normally, it enters as an industrial pollutant to the surface water mostly from sewage or industrial effluents, coal or metal sulfide (Fe, Mg, Ca) mining wastes, etc. In this study, the total ionic constituent of SO_4^{2-} varied between 2.23 to 4.41 meq/L with a mean of 2.63 meq/L and SD of 0.47 for winter season; it ranged between 1.9 to 5.49 meq/L with a mean of 3.02meq/L and SD value of 1.27 for summer season; and it ranged from 2.76 to 3.61 meq/L with average value 3.22 meq/L and SD of 0.24 for monsoon season **(Figure 4.3)**. The results of the concentrations of SO_4^{2-} in all water samples of the study area were within the permissible limits by Ayers and Westcott (1985, 1994) during all the three seasons. Therefore, all samples of the UGC, Roorkee during all the three seasons had no problem and it is suitable for irrigation purposes**.**

Nitrate-Nitrogen (NO_3-N^-)

Nitrogen acts as an essential plant nutrient. The nitrogen in fertilizers and in irrigation water fulfil the same purpose, i.e. they support growth of plants. However, excessive nitrogen in both fertilizers and irrigation water can be harmful. Based on the guidelines for interpretation of water quality for irrigation, the degree of problem by NO_3-N (mg/L) of the water varies no problem (<5), increasing problem (5-30) and severe problem (>30) (Ayers and Westcott (1985); Savci, and Bellitürk, (2013). Nitrate is an oxidised form of nitrogen and an important source of nourishment for organic environment (Sivakumar et al., 2010). The source of Nitrate is runoff from fertilizer, leaking septic tanks, sewages disposal systems and soil erosion, natural deposits. In this study, the total ionic constituent of NO_3^- ranged between 0.03 to 0.10meq/L with an average of 0.06meq/L and SD of 0.02 for winter season; it ranged between 0.06 to 0.16 with an average of 0.08 and SD of 0.03 for summer season; and it ranged between 0.02 to 0.09 meq/L with an average value of 0.03meq/L and SD of 0.03 for monsoon season **(Figure 4.3)**. All water samples of the study area in the UGC, Roorkee during all the three seasons the concentrations of NO_3-N values are within the permissible limits by FAO (1985). Therefore, all samples of the UGC, Roorkee during all the three seasons had no problem and it was suitable for irrigation purposes.

Bicarbonate (HCO_3^-) and Carbonate (CO_3^{2-})

Carbonates and bicarbonates have an indirect influence on the water quality by precipitating calcium and magnesium and resulting to increased sodium percentage and sodium hazards of water (Majumdar, 2001). The source of Carbonates is dissolution of CO_2. Al-Mashagbah (2015) assured that the amount of CO_3^{2-}, HCO_3^- and H_2CO_3 (carbonic acid) in water are having a relation with the hydrogen ion concentration. The CO_3^{2-} concentration predominates in surface water with pH < 9. The concentration of CO_3^{2-} in natural waters possesses remarkable variation i.e. from < 25 mg/L in non-carbonate-rocks areas to > 400 mg/L in carbonate-rocks areas. The pH touching 8.3 is an indicative for presence of carbonates. The CO_3^{2-} converts to an equivalent amount of HCO_3^- below the pH threshold of 8.3 (Augoustis et al., 2012). In this study, the total ionic constituent of HCO_3^- ranged between 1.2 to 4.27meq/L with an average of 1.78meq/L and SD of 1.04 for winter season; it ranged between 0.86 to 2.916meq/L with an average of 1.32meq/L and SD of 0.46 for summer season; and it ranged between 0.96 to 5.49meq/L with an average of 1.59meq/L and SD of 1.22 for monsoon season **(Figure 4.3)**. The total ionic constituent of all CO_3^{2-} values at all samples during monsoon, summer and winter seasons were 'zero' value in milli equivalent per liter. All samples of the UGC, Roorkee during all the three seasons were within the permissible limits of the guidelines by Ayers and Westcott (1985, 1994) and thus, the canal water is suitable for irrigation purposes.

Water Temperature (T_w)

The temperature of canal water (T_w) fluctuates in accordance with the season and climate. Water temperature is known to influence the growth and death of micro-organisms, kinetics of biochemical oxygen demand, pH, alkalinity, and dissolved oxygen concentration in the water. A biological activity is enhanced by higher temperature up to 60℃. Temperature may affect dissolution of gases, pH and conductivity, Total dissolved salts (Jayalakshmi et al., 2011; Semwal and Akolkar, 2011; Verma et al., 2012; Wattoo, 2004). In this study, temperature measurement was carried out using Mercuric thermometer. The mean temperature for irrigation is around 20℃ (FAO, 1985). But, temperature for irrigation water quality can be in the range of 20 to 30 ℃ (Sultana, et al., 2009). The present study indicated that the water temperature (T_w) of the UGC, Roorkee, ranged from 16.5 to 18.8 ℃ with a mean value of 17.3 ℃ and with SD of 0.67 for winter season; it ranged from 21.2 to 25.3 ℃ with a mean value of 22.7 ℃ and SD of 1.08 for summer season; and it also ranged from 21.5 to 27.8 ℃ with a mean value of 23.6 ℃ and SD of 1.9 for monsoon season (**Figure 4.4**). Compared to FAO (1985), at all 18 sites during the three seasons (monsoon, summer and winter), the observed T_w values were within the safe limit for irrigation purpose.

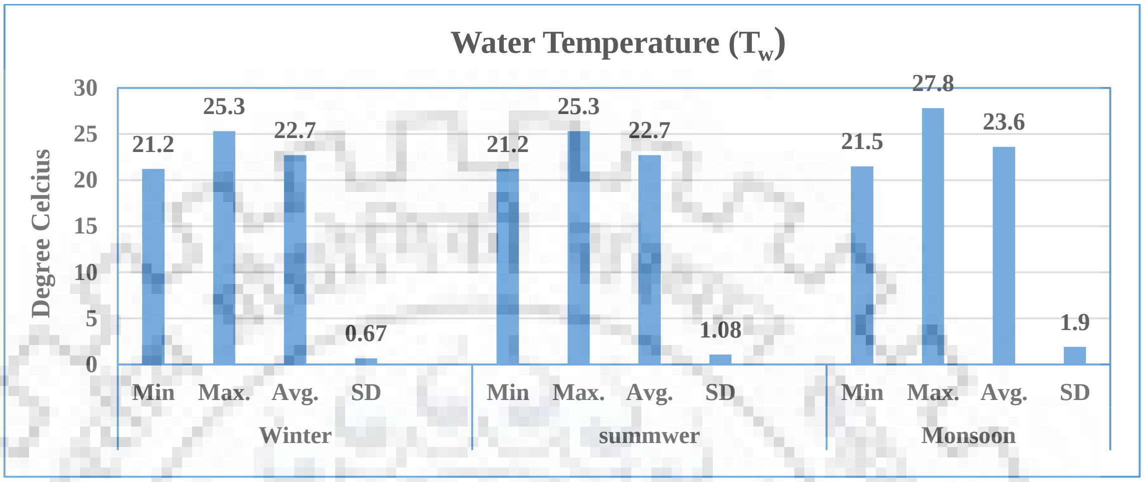


Figure 4.4: Seasonal temperature values of the UGC, Roorkee during November, 2014 to October, 2015

Acidity/ Alkalinity (pH)

The pH for irrigation water normally varies between 6.5 and 8.4. A pH outside this normal range may be harmful as they cause toxicity or nutritional imbalance (Semwal and Akolkar, 2011; Sundaray et al., 2009). In general, the ranges of pH values for irrigation water also alters between 6.0 to 8.5 by FAO (Ayers and Wescott, 1985; Raychaudhuri, 2014). The pH value in the UGC, Roorkee water samples varied between 6.8 to 8.4 with a mean value of 8.1 and SD = 0.5 for winter season; it varied between 7.1 to 8.0 with a mean value of 7.7 and SD = 1.1 for summer season; and it varied between 7.0 to 7.5 with a mean value of 7.3 and SD =0.1 for monsoon season (**Figure 4.5**). According to Michael (1978), the pH values are categorized into acidic (<5.5), slightly acidic (5.6-6.4), practically neutral (6.5-7.5), slightly alkali (7.6-8.0) and alkali (>8.0) water classes. In this study, the pH value of the UGC, Roorkee was practically neutral at sites S4, S5 and S7 for winter season; at sites S4, S5, S7, S13 and S14 for summer season; and at all sites for monsoon season. Hence, it was alkaline at all sampling sites during all the three seasons (monsoon, summer and winter). Thus, the pH values of all the water sampling sites of the study area in the UGC, Roorkee and during all the three seasons is suitable for irrigation purposes.

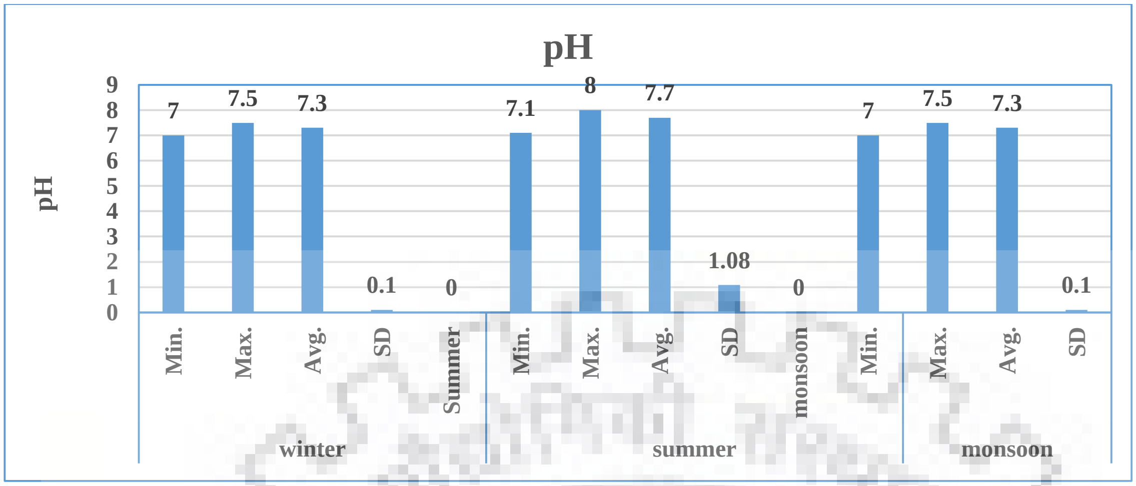


Figure 4.5: Seasonal pH values of the UGC, Roorkee during November, 2014 to October, 2015

Total Alkalinity (TA)

Alkalinity can be regarded as the sum of all constituents in water that would raise the pH above the neutral condition. Alkalinity (expressed in mg/L as CaCO3) is a property caused by the presence of CO_3^{2-} and HCO_3^-, but is computed on the basis of Ca^{2+} or Mg^{2+} concentration. Alkalinity stabilizes pH by neutralizing acid. The toxicity of many constituents in water is remarkably affected by pH, alkalinity and hardness. Total alkalinity of canal surface water for irrigation purpose varies with climate and seasons (Augoustis et al., 2012 and Verma et al., 2012). The present study indicated that in the UGC water the value of TA ranged from 73 mg/L to 260.5 mg/L with an overall mean value of 108.76 mg/L and SD of 63.18 mg/L for winter season; ranged from 52.75 mg/L to 177.25 mg/L with an overall mean value of 80.76 mg/L and SD of 27.86 mg/L for summer season; and ranged from 58.75 mg/L to 335 mg/L with an overall mean value of 97.22 mg/L and SD of 74.2 mg/L for monsoon season (**Figure 4.6**).

Total hardness (TH)

Total hardness (TH) is defined by the sum of bivalent cations (Ca^{2+} and Mg^{2+}) present in water. Similar to alkalinity, TH is expressed as mg/L of $CaCO_3$ (Ayres and Westcott, 1994 and Sultana et al., 2009). Hard water does not form lather with soap. The boiling point of water also rises with increasing hardness. Ca and Mg counteract sodicity in case of water use for irrigation purpose. The ample availability of Magnesium and Calcium in rock formation causes substantial hardness level in both surface and ground waters. The hardness is an indicative of water quality in terms of Mg^{2+}, Ca^{2+}, HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^- and NO_3^-, but it can't be considered for evaluating the water pollution. The line between hard and soft water is drawn at 75 mg/L of $CaCO_3$ i.e. water above and below this threshold is regarded as hard and soft water respectively (Ayers and Westcott, 1985; Matta, 2014). TH for irrigation purpose is < 180mg/L (Sundaray et al., 2009). According to Mathebula (2016), the water hardness is in the range of 0-50 mg/L, slightly hard in the range of 51-100 mg/L, moderately hard in the range of 101-200 mg/L and very hard in the range of 201-500 mg/L. In the present study, the UGC water exhibited the values of TH from 55.5 mg/L to 364.3 mg/L with an overall mean of 95.7 mg/L and SD of 84.3 mg/L for winter season, and ranged from 64.5 mg/L to 247.8 mg/L with an overall mean of 93.26 mg/L and SD of 61.12 mg/L for summer season; and ranged from 70.3 mg/L to 184 mg/L with an overall mean of 98 mg/L and SD of 36.6 mg/L for monsoon season (**Figure 4.6**). In all three seasons (winter, summer and monsoon), many observed values of TH at sites of the study area were slightly hard and moderately hard. Thus, the water samples of the UGC were within the safe limit for irrigation purposes when results were compared to the guidelines by Sundaray et al. (2009). However, the observed TH values at sites S4, (218 mg/L), S5 (364.3mg/L) and S7 (220.8 mg/L) during the winter season; and the observed values at sites S4(202.3 mg/L), S5 (247.8 mg/L) and S7 (224.5 mg/L) during the summer season were at 'very hard' (201-500 mg/L as $CaCO_3$) due to the usual domestic sewage flow to the UGC, Roorkee.

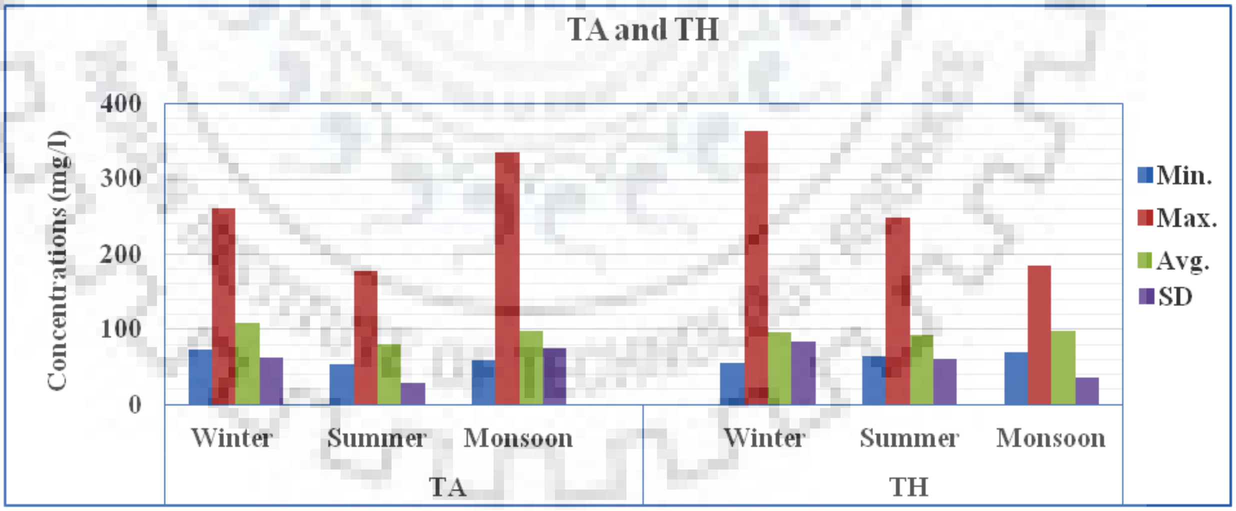


Figure 4.6: Seasonal concentrations of TA and TH of the UGC, Roorkee during November, 2014 to October, 2015

Boron (B)

Boron is essential for plant growth, though in traces. Boron is toxic at higher concentration in irrigation waters. Boron may become toxic (1-2 mg/L) to some plants when its concentration is more than the required amount. Boron content in irrigation water is usually more in arid and semi-arid regions. Usually, the irrigation water contains less than 1.0 ppm (Majumdar, 2001). Even at a concentration less than 1.0 ppm, it can cause toxicity to sensitive crops and affect the plant metabolism. For irrigation canal and river waters, Boron levels less than 0.33 ppm, between 0.33-0.67 ppm and above 0.67 ppm were used to categorize the crops as sensitive, semi-tolerant and tolerant ones respectively (Provin and Pitt, 2002; Semwal and Akolkar, 2011)**.** In this study, values of B ranged from 0.45 to 1.53 mg/L with a mean of 0.85 mg/L and SD of 0.22 for winter season, from 0.53 to1.35 mg/L and a mean of 0.85 mg/L and SD of 0.24 for summer season, and from 0.67 to 0.95 mg/L with a mean of 0.81 mg/L and SD of 0.08 for monsoon season (**Figure 4.7**). In all the sites of the study area during all the three seasons (winter, summer and monsoon), the value of B was within the permissible limit of the guidelines by Ayers and Westcott (1985) and BIS (2002) Standards for irrigation purposes. In the context of irrigation water quality, during all the three seasons (monsoon, summer and winter), the water of UGC, Roorkee at almost all sites was at ‘Excellent’, ‘Good’ and ‘Permissible’ classes for the sensitive, semi tolerant and Tolerant group of crops respectively. However, it was doubtful water class for irrigation at sites S4 (1.25mg/L), S5 (1.35 mg/L) and S7 (1.25 mg/L) for summer season; and it was unsuitable water class for irrigation at site S15 (1.53 mg/L) for winter season for the sensitive group of crops.

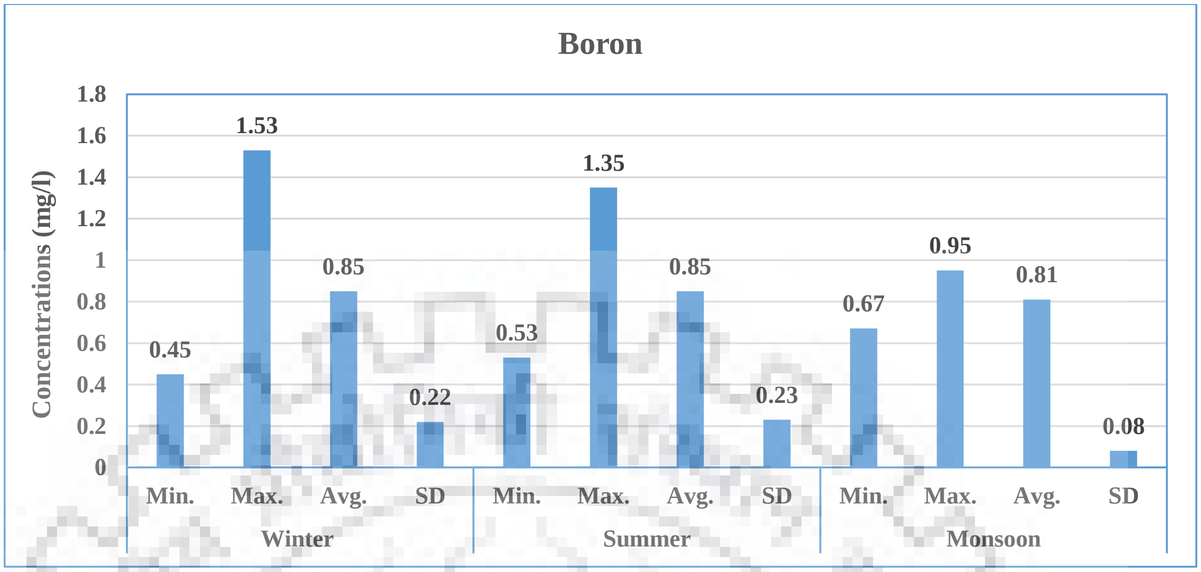


Figure 4.7: Concentrations of Boron of the UGC, Roorkee during the period from November, 2014 to October, 2015

4.3.2 Toxic Trace Metals

The recommended maximum concentration of toxic trace metals considered for this study and their adverse effects as per Food and Agriculture Organization (Ayers and Westcott, 1985) are discussed in **Table 4.1**. The UGC water is extensively used for irrigation purpose. Due to its importance for Agriculture, the evaluation of toxic trace metals viz., Aluminium, Arsenic, Cadmium, Cobalt, Chromium, Copper, Iron, Manganese, Lead and Zinc was carried out for its suitability for irrigation purpose. Results obtained from this study were compared to the guidelines by Ayers and Westcott (1985) for irrigation water quality in all sampling sites of the UGC, Roorkee.

Table 4.1: Recommended maximum concentrations and adverse effects of toxic trace metals in water for irrigation

Elements	Recommended maximum concentration^2 (mg/l)	Remarks
Al (Aluminum)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity
As (Arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Cd (Cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due

		to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co (Cobalt)	0.05	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Cr (Chromium)	0.05	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (Copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
Fe (Iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Mn (Manganese)	0.20	Toxic to a number of crops at few-tenths to a few mg/l, but usually only in acid soils.
Pb (Lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Zn (Zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

Sources: Irrigation water Quality Guidelines for Trace Elements and Heavy Metals by FAO (Ayers and Westcott, 1985)

The detailed results for the trace metals in water from Upper Ganga Canal for all the sites are presented below.

Aluminium (Al)

The concentration of Al in the samples collected from UGC, Roorkee varied from 0.131 mg/l to 2.327 mg/l with an average of 0.525 mg/l and SD of 0.707 for winter season, from 0.134 mg/l to 1.165 mg/l with an average of 0.642 mg/l and SD of 0.311 for summer season, and from 0.131 mg/l to 1.175 mg/l with an average of 0.407 mg/l and SD of 0.347 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Al in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 5 mg/l. The samples at all sites are within the permissible limit during all the three seasons and hence, suitable for irrigation.

Arsenic (As)

The concentration of As in the samples collected from UGC, Roorkee varied from 0.002 mg/l to 0.014 mg/l with an average of 0.0045 mg/l and SD of 0.0038 for winter season, from 0.002 mg/l to 0.013 mg/l with an average of 0.0041 mg/l and SD of 0.0035 for summer season, and from 0.002

mg/l to 0.017 mg/l with an average of 0.0051 mg/l and SD of 0.0042 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of As in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 0.1 mg/l. The UGC water samples at all sites were within the permissible limit during all the three seasons and hence, suitable for irrigation.

Cadmium (Cd)

The concentration of Cd in the samples collected from UGC, Roorkee varied from 0.001 mg/l to 0.019 mg/l with an average of 0.004 mg/l and SD of 0.004 for winter season, from 0.002 mg/l to 0.008 mg/l with an average of 0.005 mg/l and SD of 0.002 for summer season, and from 0.001 mg/l to 0.005 mg/l with an average of 0.003 mg/l and SD of 0.001 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Cd in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 0.01 mg/l. The samples at all the sites were within the permissible limit during all the three seasons and hence, suitable for irrigation.

Cobalt (Co)

The concentration of Co in the samples collected from UGC, Roorkee varied from 0.035 mg/l to 0.085 mg/l with an average of 0.044 mg/l and SD of 0.012 for winter season, from 0.035 mg/l to 0.085 mg/l with an average of 0.053 mg/l and SD of 0.014 for summer season, and from 0.02 mg/l to 0.065 mg/l with an average of 0.031 mg/l and SD of 0.016 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Co in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 0.05 mg/l. For the sites S4, S5 and S7, Cobalt concentrations during all the three seasons were beyond the allowable limits for irrigation purposes and thus, should be used for agricultural applications with utmost care. Also, the concentration of Co at sites S10, S11, S12, S13, S14, S15, S16, S17 and S18 for only winter season was just above the permissible limit. The discharge of industrial effluents at sites S4, S5 and S7 is possibly the major contributing factors of excessive Cobalt into the canal.

Chromium (Cr)

The concentration of Cr in the samples collected from UGC, Roorkee varied from 0.021 mg/l to 0.087 mg/l with an average of 0.04 mg/l and SD of 0.02 for winter season, from 0.021 mg/l to 0.098 mg/l with an average of 0.046 mg/l and SD of 0.023 for summer season, and from 0.02 mg/l to 0.055 mg/l with an average of 0.033 mg/l and SD of 0.011 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Cr in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 0.05 mg/l. The samples at all sites are within the permissible limit during all the three seasons and hence, suitable for irrigation.

Copper (Cu)

The concentration of Cu in the samples collected from UGC Roorkee, varied from 0.02 mg/l to 0.092 mg/l with an average of 0.054 mg/l and SD of 0.018 for winter season, from 0.023 mg/l to 0.176 mg/l with an average of 0.057 mg/l and SD of 0.033 for summer season, and from 0.02 mg/l to 0.069 mg/l with an average of 0.038 mg/l and SD of 0.013 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Cu in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 0.2 mg/l. The samples at all sites were within the permissible limit during all the three seasons and hence, suitable for irrigation.

Iron (Fe)

The concentration of Fe in the samples collected from UGC, Roorkee varied from 1.151 mg/l to 3.922 mg/l with an average of 2.976 mg/l and SD of 0.641 for winter season, from 1.151 mg/l to 3.016 mg/l with an average of 2.429 mg/l and SD of 0.392 for summer season, and from 1.299 mg/l to 2.438 mg/l with an average of 1.882 mg/l and SD of 0.354 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Fe in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 5 mg/l. The samples at all sites are within the permissible limit during all the three seasons and hence, suitable for irrigation.

Manganese (Mn)

The concentration of Mn in the samples collected from UGC, Roorkee varied from 0.035 mg/l to 0.214 mg/l with an average of 0.103 mg/l and SD of 0.056 for winter season, from 0.083 mg/l to 0.179 mg/l with an average of 0.131 mg/l and SD of 0.027 for summer season, and from 0.02 mg/l to 0.149 mg/l with an average of 0.093 mg/l and SD of 0.044 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Mn in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 0.2 mg/l. The water samples possessed Mn concentration within the permissible limit during all the three seasons, except the sites S4, S5 and S7 during winter season.

Lead (Pb)

The concentration of Pb in the samples collected from UGC, Roorkee, varied from 0.012 mg/l to 0.057 mg/l with an average of 0.029 mg/l and SD of 0.012 for winter season, from 0.022 mg/l to

0.099 mg/l with an average of 0.035 mg/l and SD of 0.017 for summer season, and from 0.011 mg/l to 0.045 mg/l with an average of 0.023 mg/l and SD of 0.01 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Pb in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 5 mg/l. The samples at all sites were within the permissible limit during all the three seasons and hence, suitable for irrigation.

Zinc (Zn)

The concentration of Zn in the samples collected from UGC, Roorkee, varied from 0.072 mg/l to 2.074 mg/l with an average of 1.061 mg/l and SD of 0.521 for winter season, from 0.57 mg/l to 3.141 mg/l with an average of 1.277 mg/l and SD of 0.775 for summer season, and from 0.37 mg/l to 1.954 mg/l with an average of 0.871 mg/l and SD of 0.478 for monsoon season (**Tables 4.2, 4.3 and 4.4**). The permissible limit of Zn in canal water, according to FAO (Ayers and Westcott, 1985) guidelines, is 2 mg/l. The samples at all sites except S4, S5 and S7 were within the permissible limit during all the three seasons. For these three sites, the Zn concentration was above the allowable limit during winter as well as summer season.

Overall, it can be concluded that the UGC water constituents are moderately variable with respect to the toxic trace metals in the three seasons during November 2014 to October 2015. Based on the average values of trace metal concentrations in mg/l, it can be observed from **Tables 4.2, 4.3 and 4.4** that, Fe and Cd are the most and least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Co > Cr > Pb > As > Cd, during winter season; similarly Fe and As are the most and least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Co > Cr > Pb > Cd > As, during the summer season; Fe and Cd are the most and least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Cr > Co > Pb > As > Cd during the monsoon season.

Table 4.2: Observed values of the toxic trace metals for winter season over UGC, Roorkee

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.532	0.134	0.131	0.152	0.165	0.236	0.153	0.136	0.136	0.166	2.327	0.166	0.136	0.186	0.186	1.184	1.168	2.157	0.131	2.327	0.525	0.707
As	0.002	0.003	0.003	0.014	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.014	0.0045	0.0038
Cd	0.001	0.001	0.002	0.005	0.009	0.001	0.003	0.002	0.002	0.002	0.006	0.001	0.019	0.003	0.005	0.002	0.001	0.006	0.001	0.019	0.004	0.004
Co	0.035	0.035	0.036	0.056	0.085	0.037	0.064	0.038	0.039	0.039	0.040	0.040	0.041	0.041	0.042	0.042	0.042	0.042	0.035	0.085	0.044	0.012
Cr	0.021	0.027	0.028	0.042	0.030	0.028	0.037	0.029	0.029	0.029	0.041	0.025	0.032	0.087	0.081	0.080	0.030	0.039	0.021	0.087	0.040	0.020
Cu	0.047	0.037	0.031	0.037	0.020	0.067	0.063	0.051	0.036	0.059	0.051	0.059	0.057	0.061	0.071	0.064	0.077	0.092	0.020	0.092	0.054	0.018
Fe	1.151	1.973	2.962	3.922	3.911	2.972	3.918	2.978	2.971	2.973	2.973	2.974	2.983	2.982	2.983	2.983	2.976	2.986	1.151	3.922	2.976	0.641
Mn	0.035	0.043	0.056	0.213	0.214	0.045	0.213	0.070	0.055	0.097	0.098	0.097	0.102	0.102	0.105	0.106	0.102	0.106	0.035	0.214	0.103	0.056
Pb	0.012	0.020	0.021	0.057	0.050	0.021	0.055	0.024	0.024	0.024	0.024	0.024	0.029	0.029	0.030	0.029	0.024	0.029	0.012	0.057	0.029	0.012
Zn	0.567	0.621	0.072	2.054	2.064	0.801	2.074	0.822	0.861	0.986	1.013	1.013	1.023	1.023	1.034	1.034	1.012	1.021	0.072	2.074	1.061	0.521

Table 4.3: Observed values of the toxic trace metals for summer season over UGC, Roorkee

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.134	0.234	0.335	1.152	1.165	0.336	1.153	0.446	0.456	0.548	0.547	0.548	0.766	0.757	0.859	0.735	0.548	0.843	0.134	1.165	0.642	0.311
As	0.002	0.003	0.003	0.013	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.013	0.0041	0.0035
Cd	0.002	0.002	0.003	0.008	0.008	0.003	0.008	0.003	0.004	0.004	0.004	0.004	0.007	0.007	0.007	0.007	0.004	0.006	0.002	0.008	0.005	0.002
Co	0.035	0.040	0.041	0.078	0.085	0.043	0.085	0.046	0.046	0.051	0.051	0.051	0.052	0.052	0.051	0.050	0.051	0.051	0.035	0.085	0.053	0.014
Cr	0.021	0.024	0.024	0.092	0.086	0.026	0.098	0.028	0.038	0.038	0.038	0.046	0.048	0.049	0.047	0.046	0.039	0.048	0.021	0.098	0.046	0.023
Cu	0.023	0.035	0.065	0.073	0.036	0.176	0.040	0.051	0.049	0.049	0.092	0.053	0.042	0.045	0.044	0.052	0.052	0.053	0.023	0.176	0.057	0.033
Fe	1.151	2.329	2.337	2.429	2.336	2.556	2.922	2.322	2.416	2.416	2.413	2.413	2.414	3.007	3.016	2.413	2.412	2.414	1.151	3.016	2.429	0.392
Mn	0.103	0.083	0.116	0.179	0.172	0.171	0.113	0.106	0.104	0.127	0.157	0.138	0.108	0.132	0.133	0.131	0.137	0.154	0.083	0.179	0.131	0.027
Pb	0.022	0.024	0.024	0.042	0.099	0.026	0.048	0.029	0.030	0.030	0.030	0.030	0.033	0.034	0.035	0.034	0.030	0.034	0.022	0.099	0.035	0.017
Zn	0.570	0.762	0.788	2.986	3.141	0.798	2.606	0.888	0.888	0.988	0.988	0.988	0.889	1.122	1.122	1.223	1.111	1.121	0.570	3.141	1.277	0.775

Table 4.4: Observed values the toxic trace metals for monsoon season over UGC, Roorkee

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.131	0.142	0.142	1.106	1.142	0.152	1.175	0.204	0.205	0.324	0.324	0.324	0.326	0.329	0.329	0.326	0.326	0.326	0.131	1.175	0.407	0.347
As	0.002	0.003	0.003	0.017	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.017	0.0051	0.0042
Cd	0.001	0.001	0.001	0.004	0.005	0.002	0.004	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.005	0.005	0.004	0.004	0.001	0.005	0.003	0.001
Co	0.025	0.020	0.021	0.064	0.065	0.021	0.065	0.021	0.021	0.021	0.021	0.022	0.031	0.031	0.032	0.032	0.023	0.026	0.020	0.065	0.031	0.016
Cr	0.020	0.024	0.025	0.055	0.054	0.026	0.053	0.026	0.026	0.029	0.029	0.029	0.035	0.037	0.037	0.036	0.030	0.034	0.020	0.055	0.033	0.011
Cu	0.020	0.022	0.023	0.056	0.069	0.027	0.063	0.028	0.030	0.038	0.041	0.040	0.035	0.035	0.038	0.039	0.043	0.039	0.020	0.069	0.038	0.013
Fe	1.299	1.363	1.377	2.424	2.244	1.387	2.438	1.767	1.777	1.823	1.815	1.828	2.019	2.088	2.142	2.089	1.839	2.158	1.299	2.438	1.882	0.354
Mn	0.062	0.086	0.115	0.149	0.135	0.088	0.145	0.112	0.114	0.115	0.116	0.115	0.020	0.021	0.022	0.021	0.119	0.115	0.020	0.149	0.093	0.044
Pb	0.011	0.015	0.016	0.042	0.041	0.015	0.045	0.017	0.019	0.021	0.021	0.021	0.023	0.024	0.024	0.022	0.016	0.024	0.011	0.045	0.023	0.010
Zn	0.370	0.551	0.588	1.873	1.834	0.592	1.954	0.677	0.678	0.688	0.688	0.688	0.776	0.756	0.777	0.738	0.688	0.758	0.370	1.954	0.871	0.478

4.3.3 Irrigation Water Quality Metrics

Salinity and sodicity are the crucial factors of water in the context of agriculture. These may affect soil, plant and human directly and indirectly. Various water quality metrics or indices are used to evaluate the quality of water, especially for agricultural applications. In this study, the suitability of UGC water for irrigation was assessed by indices viz., Sodium Adsorption Ratio (SAR), Residual Sodium Content (RSC), Residual Sodium Bicarbonate (RSBC), Sodium Soluble Percentage (SSP), Magnesium Adsorption Ratio (MR), Permeability Index (PI) and Kelley's Index Ratio (KR), along with EC and TDS, which are prominent factors for salinity. The values of these water quality metrics were obtained for all the eighteen sites along with the statistical summary (minimum, maximum, average and standard deviation) are presented in **Tables 4.5, 4.6 and 4.7**, followed by a detailed discussion on each of these metrics. A comprehensive analysis of all these water quality metrics over all the sampling sites at seasonal basis over UGC, Roorkee, is presented in **Table 4.8**. The intra-correlation amongst the irrigation water quality metrics along with EC and TDS are also presented by correlation matrix.

Table 4.5: Calculated results of the irrigation water quality metrics of the study area (UGC, Roorkee) during winter season from November 2014 to October 2015

Parameter	SAMPLING SITES																		Statistical Summary			
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min.	Max.	Avg.	SD
SAR	0.09	0.08	0.085	0.735	0.769	0.137	0.714	0.196	0.086	0.097	0.098	0.097	0.094	0.103	0.1	0.102	0.098	0.107	0.08	0.769	0.21	0.244
SSP	4.45	4.67	3.97	15.06	14.62	6.61	15.23	5.06	3.99	4.18	4.36	4.45	4.53	5.02	5.44	9.92	4.49	5.43	3.97	15.23	6.75	4.02
RSC	-2.14	-2.67	-2.74	-4.6	-8.76	-2.47	-3.63	-2.43	-2.51	-2.57	-2.26	-2.84	-2.48	-2.11	-2.71	-2.21	-2.51	-2.58	-8.76	-2.11	-3.01	1.55
RSBC	-0.93	-1.17	-0.85	3.43	-6.39	3.19	-0.55	-0.68	-0.75	-0.84	-0.29	-0.76	-0.41	-0.43	-1.6	-0.23	-0.24	-0.42	-6.39	3.43	-0.55	1.97
MAR	38.8	44.8	45.2	56.8	12.8	44.7	46.6	49.4	48.7	47.4	51.8	46.5	52.6	48.5	46.3	54.2	57.6	57	12.8	57.6	47.21	9.93
PI	36.34	30.71	30.86	25.99	21.21	33.99	24.04	31.41	31.38	31.71	35.45	30.27	33.39	36.2	32.66	33.51	32.59	32.33	21.21	36.34	31.33	4
KR	0.04	0.03	0.03	0.11	0.12	0.05	0.14	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.14	0.06	0.04

Table 4.6: Calculated results of the irrigation water quality metrics of the study area (UGC, Roorkee) during summer season from November 2014 to October 2015

Parameter	**SAMPLING SITES**																		**Statistical Summary**			
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**Min.**	**Max.**	**Avg.**	**SD**
SAR	0.097	0.094	0.103	0.1	0.102	0.098	0.107	0.08	0.769	0.21	0.244	0.114	0.064	0.095	0.052	0.065	0.071	0.072	0.032	0.267	0.107	0.06
SSP	4.45	4.53	5.02	5.44	9.92	4.49	5.43	3.97	15.23	6.75	4.02	5.35	3.41	3.7	3.67	3.25	3.74	3.91	1.7	8.84	4.41	1.85
RSC	-2.84	-2.48	-2.11	-2.71	-2.21	-2.51	-2.58	-8.76	-2.11	-3.01	1.55	-2.91	-3.35	-3.27	-4.07	-3.47	-3.24	-3.22	-6.09	-1.44	-3.33	0.93
RSBC	-0.76	-0.41	-0.43	-1.6	-0.23	-0.24	-0.42	-6.39	3.43	-0.55	1.97	-1.43	-1.5	-1.21	-2.12	-1.42	-1.48	-1.42	-2.12	5.33	-0.55	2.19
MAR	51.6	46.9	42.2	43.2	41.7	46.8	51.1	46.4	41.4	47.7	46.4	46.9	45.6	44.3	40.4	49.6	44.2	44.6	40.4	51.6	45.61	3.2
PI	22.38	23.2	20.29	14.89	15.42	27.98	11.5	22.97	22.01	23.06	24.66	24.43	22.56	23.5	22.41	21.57	24.82	25.06	11.5	27.98	21.82	4.05
KR	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.01	0.06	0.02	0.05	0.03	0.03	0.02	0.03	0.03	0.03	0.01	0.06	0.03	0.01

Table 4.7: Calculated results of the irrigation water quality metrics of the study area (UGC, Roorkee) during monsoon season from November 2014 to October 2015

Parameter	**SAMPLING SITES**																		**Statistical Summary**			
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**Min.**	**Max.**	**Avg.**	**SD**
SAR	0.05	0.06	0.06	0.69	0.96	0.08	0.73	0.07	0.07	0.08	0.08	0.08	0.09	0.08	0.22	0.09	0.09	0.09	0.05	0.96	0.2	0.28
SSP	3.04	2.79	3.18	11.9	18.3	3.77	14.95	3.49	3.74	3.8	3.92	3.78	4.3	4.2	6.05	4.58	4.56	4.69	2.79	18.3	5.84	4.45
RSC	-4.73	-4.75	-4.61	-2.86	-9.7	-4.04	-8.97	-4.84	-4.41	-5.13	-4.82	-5.13	-4.49	-4.97	-5.77	-4.56	-5.02	-4.86	-9.7	-2.86	-5.2	1.62
RSBC	-1.61	-1.56	-1.65	-5.99	-3.25	-3.4	-1.12	-1.67	-1.67	-1.71	-1.71	-1.77	-1.77	-1.64	-1.78	-1.51	-1.83	-1.71	-5.99	-1.12	-2.08	1.13
MAR	53.3	55.3	52.9	38.7	44.2	51.7	40.9	54.1	50.4	54.5	53.6	55.8	49.3	54.4	50	52.2	51.3	52.3	38.7	55.8	50.83	4.84
PI	19.39	26.11	20.19	20.2	28.9	23.96	25.9	21.15	20.88	18.44	19.19	18.32	20.62	19.31	22.07	21.72	19.94	20.31	18.32	28.9	21.48	2.84
KR	0.02	0.02	0.02	0.11	0.19	0.02	0.14	0.02	0.02	0.03	0.02	0.02	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.19	0.05	0.05

Sodium Adsorption Ratio (SAR)

The SAR of water samples in the UGC, Roorkee ranged from 0.08 to 0.769 with an average value of 0.21 and SD of 0.244 for winter season; from 0.032 to 0.867 with an average of 0.107 and SD of 0.06 for summer season; from 0.053 to 0.961 with an average value of 0.203 and SD of 0.278 for monsoon season (**Figure 4.8; Tables 4.5, 4.6, 4.7**). The water having SAR (< 10) is excellent, SAR (10-18) is good, SAR (18-26) is doubtful and SAR >26 is unsuitable for irrigation (Ayers and Westcott (1985); Eaton, 1950; FAO, (1985); Richard, 1954; USDA, 1954). Irrigation water containing large amounts of sodium has ill effects on soil as it changes soil properties and reduces permeability (Asiwaju-Bello, 2013). In this study, the results of SAR for all the 18 sites of UGC were excellent (SAR values <10) during all the three seasons (monsoon, summer and winter) and therefore, suitable for irrigation.

Residual Sodium Carbonate (RSC)

In this study, the value of RSC of water samples in the UGC, Roorkee ranged from -8.76 to -2.11 with a mean of -3.01 and SD of 1.55 for winter season, from -6.09 to -1.44 with a mean of -3.33 and SD of 0.96 for summer season, and from -9.7 to -2.86 with a mean of -5.20 and SD of 1.62 for monsoon season (**Figure 4.8; Tables 4.5, 4.6, 4.7**). The value of RSC < 1.25 is safe for irrigation as class I (USDA, 1954), a value between 1.25 and 2.5 is of marginal quality and a value > 2.5 is alkali water (Dhemebare, 2012) and unsuitable for irrigation (Dhembare, 2012; Majumdar, 2001; Richard, 1954). Thus, the RSC values at all sites were within the permissible limit during all the three seasons (monsoon, summer and winter) and hence, the UGC water is safe for irrigation. Interestingly, RSC values are negative at all sampling sites, indicating that there is precipitation of calcium and magnesium. This makes the sodium build up very unlikely, the reason being, sufficient Calcium and Magnesium are in excess of what can be precipitated as carbonate in the location of those samples (Asiwaju-Bello, 2013). This is a very good sign for desirable water quality.

Residual Sodium Bicarbonate Content (RSBC)

The value of RSBC of water samples in the UGC, Roorkee ranged from -6.39 to 3.43 with a mean of -0.55 and SD of 1.97 for winter season, it ranged from -2.12 to 5.33 with a mean value of -5.55 and SD of 2.19 for summer season, and it also ranged from -5.99 to -1.12 with a mean of -2.08 and SD of 1.13 for monsoon season (**Figure 4.8; Tables 4.5, 4.6, 4.7**). Typically, the value of RSBC less than 5 is considered safe for irrigation as class I (Gupta, 2013), a value between 5 – 10 is of marginal quality and a value greater than 10 is unsuitable for irrigation. Thus, the RSBC values of the UGC water at all the sites during all the three seasons are safe and marginal for irrigation purpose.

Kelly Index (KR)

The Kelly Index over the samples from the UGC, Roorkee, ranged from 0.03 to 0.14 with a mean of 0.06 and SD of 0.04 (winter season), from 0.01 to 0.06 with a mean of 0.03 and SD of 0.01(summer season) and from 0.02 to 0.19 with a mean of 0.05 and SD of 0.05 during monsoon season (**Figure 4.8; Tables 4.5, 4.6, 4.7**). The value of KR less than 1 for surface water is an indicative of suitability for irrigation and KR above 1 indicates water to be unsuitable (not good quality) for irrigation (Kelly`s, 1951). Therefore, according to these guidelines, all the water samples over the study area and during all the three seasons (winter, summer and monsoon), were suitable for irrigation.

Sodium Soluble Percentage (SSP)

The value of SSP of water samples in the UGC, Roorkee ranged from 3.97-15.23 with an average value of 6.75 and SD of 4.02 for winter season, from 1.7 to 8.84 with an average of 4.41 and with SD of 1.85 for summer season; and between 2.79 to 18.3 with a mean of 5.84 and SD of 4.45 for monsoon season, depending on locations (**Figure 4.9; Tables 4.5, 4.6, 4.7**). Based on the classification suggested by Wilcox (1955), SSP values less than 20 as excellent, 20-40 as good, 40-60 as permissible, 60-80 as doubtful and above 80 is unsuitable for irrigation. Compared to this classification, result of SSP values of the study area revealed that all the water samples during all the three seasons (monsoon, summer and winter) were suitable for agricultural purposes.

Magnesium Adsorption Ratio (MAR)

The computed MAR values at the study area in the UGC, Roorkee ranged from 12.8 to 57.6 with an average value of 47.21 and SD of 9.93 for winter season, it ranged from 40.4 to 5.33 with a mean of 45.61 and SD of 3.20 for summer season, and it also ranged from 38.7 to 55.8 with a mean of 50.83 and SD of 4.84 for monsoon season (**Figure 4.9; Tables 4.5, 4.6, 4.7**). According to the guidelines of Food and Agriculture Organization (FAO, 1985), the value of MAR (%) < 50 indicates suitability for irrigation, whereas MAR (%) > 50 is regarded as unsuitable (Ayers & Westcott, 1985). Therefore, the MAR values at sites S4, S11, S13, S16, S17 and S8 during winter season, at sites S1 and S7 during summer season, and almost all the sampling sites during winter season were higher than the permissible limits recommended by FAO (1985). This shows that the MAR values were unsuitable for irrigation purposes. More magnesium in irrigation water adversely affects soil potential i.e., the soil become more alkaline which reduces the crop yield (Asiwaju-Bello et al., 2013; Gopal and Joseph, 2015; Joshi, et al. 2009). The main cause for higher values of the MAR values are domestic and motor garage sewages, cow dungs, different solid and liquid organic disposals, surface asphalt roads during runoff and other anthropogenic activities. Especially, the silts deposited in the downstream plain lands of the study area.

Permeability Index (PI)

The computed Permeability Index (%) values of the water samples from UGC, Roorkee ranged from 21.21% to 36.34% with an average of 31.33% and SD of 4.0 during winter season, from 11.5% to 27.98% with an average of 21.82% and SD of 4.05 during summer season, and from 18.32% to 28.9% with an average of 21.48% and SD of 42.84 during monsoon season (**Figure 4.9; Tables 4.5, 4.6, 4.7**). According to Doneen (1964), PI values can be used to categorize water into three classes i.e. I, II and III, where Class I is regarded as favorable for irrigation with maximum permeability of 75% or more. On the contrary, Class III is considered as unsuitable for irrigation with 25% of maximum permeability. Hence, the value of PI (%) for water samples of the UGC, Roorkee were in low (class III) and moderate (Class II) categories, which make the canal water unsuitable for irrigation purpose. The permeability of soil is influenced by several factors like continual application of irrigation; the contents of Na, Ca, Mg, CO_3^{2-}, HCO_3^- etc., in water; and the soil type (Asiwaju-Bello et al., 2013). The high Magnesium content may be crucial in causing such unsuitable PI values.

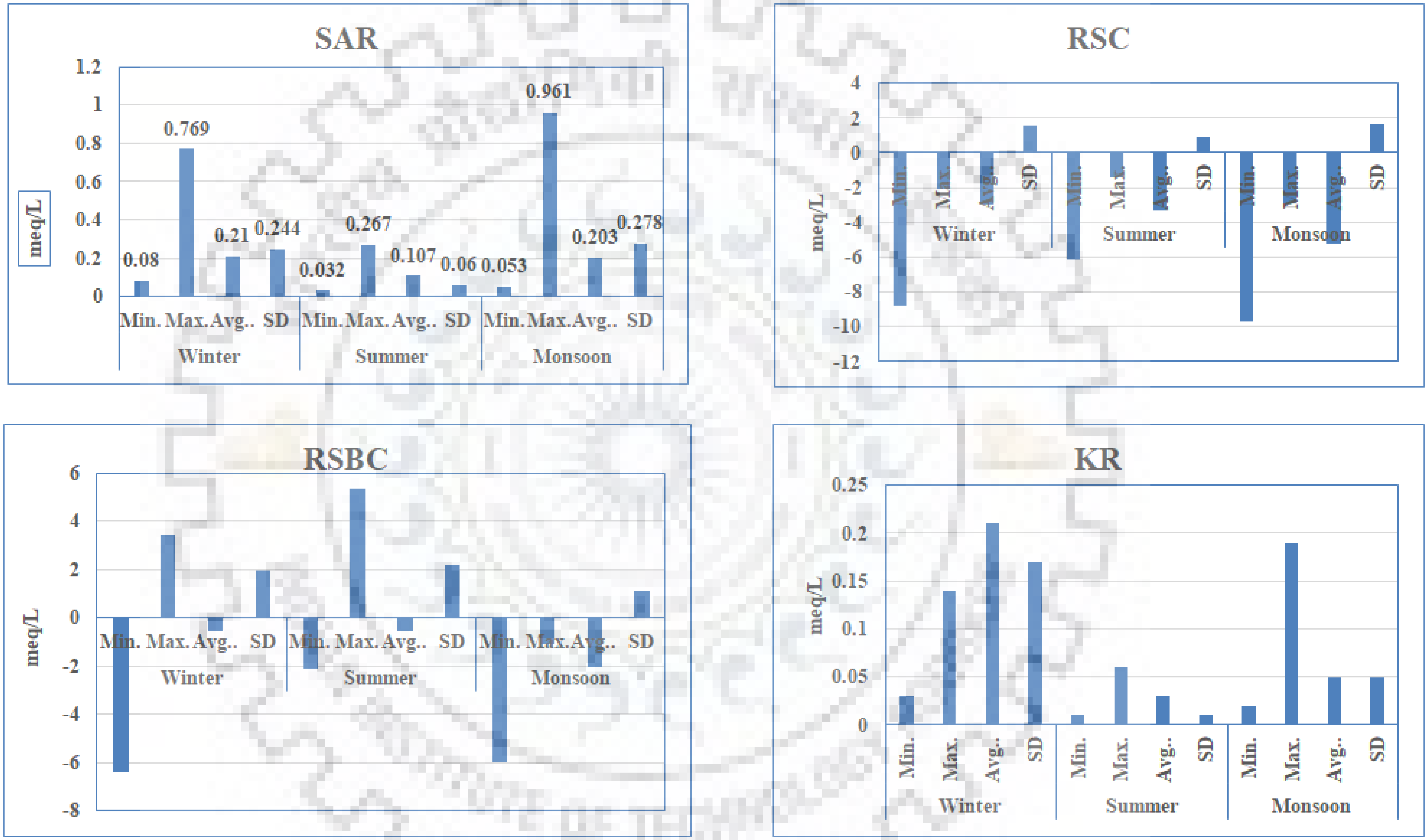


Figure 4.8: Seasonal variations of SAR, RSC, RSBC and KR, (meq/L) of the UGC, Roorkee during the period from November, 2014 to October, 2015

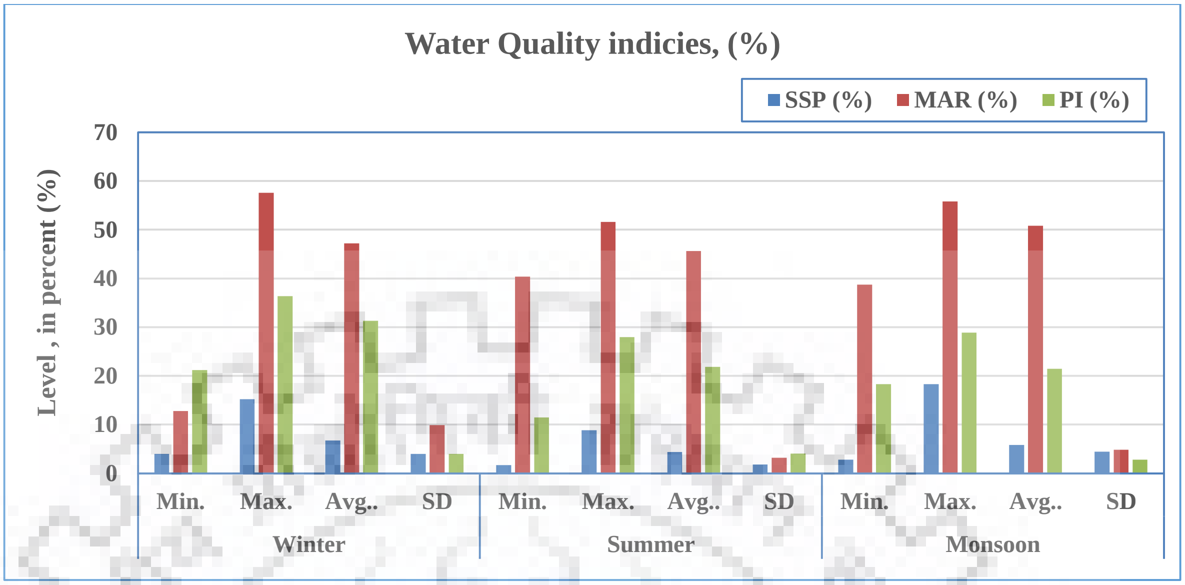


Figure 4.9: Seasonal variations of SSP, MAR and PI of the UGC, Roorkee during the period from November, 2014 to October, 2015

It can be observed from **Table 4.8** that, most of the important water quality indices are suitable for irrigation purpose. The values of the irrigation water quality indices are compared with various national as well as international guidelines used in this study for irrigation water. The table also shows percentage results for each irrigation metric (considering the 18 sampling sites) during every season.

Table 4.8: Guidelines used for comparisons of the results of irrigation water quality metrics over UGC, Roorkee during October, 2014 to November, 2015

Irrigation parameters	**Standard Range**	**Water class for irrigation**	**Percentage of the water samples** in the three seasons		
			Winter	**Summer**	**Monsoon**
SAR (Eaton, 1950; Richard, 1954)	< 10	Excellent	All Sites (100 %)	All Sites (100 %)	All Sites (100 %)
	10 - 18	Good	-	-	-
	18 - 26	Doubtful	-	-	-
	> 26	Unsuitable	-	-	-
SSP (Todd, 1980; Wilcox, 1955)	< 20	Excellent	All Sites (100 %)	All Sites (100 %)	All Sites (100 %)
	20 – 40	Good	-	-	-
	40 - 60	Permissible	-	-	-
	60 - 80	Doubtful	-	-	-
	> 80	Unsuitable	-	-	-
RSC (Richard, 1954)	< 1.25	Safe	All Sites (100 %)	All Sites (100 %)	All Sites (100 %)
	1.25 - 2.0	Moderate	-	-	-
	2.0- 2.5	Unsuitable	-	-	-
	2.5-3.0	-	-	-	-
	>3.0	-	-	-	-
RSBC (Ayers & Westcott, 1985; Gupta, 2013)	< 5	Safe	All Sites (100 %)	All Sites (100 %)	All Sites (100 %)
	5-10	Marginal	-	-	-
	>10	Unsuitable	-	-	-
PI (%), (Doneen, 1964)	< 25	Low class (III)	Sites S5 and S7 (11.11%)	Sites S1, S2, S3, S4, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16,S17 and S18 (88.89%) (94.4%)	Sites S1, S3, S4, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17 and S18 (83.34%)
	25 - 75	Moderate (II)	Sites S1, S2, S3, S4, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16,S17 and S18 (88.89%)	Site S18 (5.6%)	Sites S2, S5 and S7 (16.66%)
	> 75	High (I)	-	-	-

MAR (%), (Ayers & Westcott, 1985 and FAO, 1985)	> 50	Harmful and unsuitable	Sites S4, S11, S13, S16, S17 and S18 (33.33%)	Sites S1 and S7 (11.11%)	Sites S1, S3, S5, S6, S8, S9, S10, S12, S14, S15, S16, S17 and S18 (77.78%)
	< 50	Not harmful and suitable	Sites S1, S2, S3, S5, S6, S7,S8, S9, S10, S12, S14 and S15 (66.67%)	Sites S2, S3, S4, S5, S6, S8, S9, S10, S12, S13, S14, S15, S16, S17 and S18 (88.89%)	Sites S2, S4, S5, S7 and S13 (22.22%)
KR (Kelley`s, 1951)	<1	Suitable (Good)	All Sites (100 %)	All Sites (100 %)	All Sites (100 %)
	>1	Unsuitable (Not Good)	-	-	-
EC (µmhos/L, at 25℃ (Wilcox, 1950)	< 250	Excellent	Sites S1, S2, S3, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17 and S18 are (83.25%)	Sites S1, S2, S3, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17 and S18 are (83.33%)	Sites S1, S2, S3, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17 and S18 are (77.69%)
	250-750	Good	Sites S5 and S7 (11.11%)	-	Sites S5, S11 and S14 (16.67%)
	750 -2250	Permissible	Sites S4 (5.64.7%)	Sites S4, S5 and S7 (16.67%)	Sites S4 (5.64%)
	2000 - 3000	Doubtful	-	-	-
	>3000	Unsuitable	-	-	-
TDS (mg/L) (Ayers and Westcott, 1985; FAO,1985)	< 175	Excellent	Sites S1, S2, S3, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17 and S18 are (83.33%)	Sites S1, S2, S3, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17 and S18 are (83.33%)	Sites S1, S2, S3, S4, S6, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17 and S18 are (83.33%)
	175-525	Good	-	-	S5 (5.56%)
	525-1400	permissible	Sites S4, S5 and S7 (16.67%)	Sites S4, S5 and S7 (16.67%)	Sites S4 and S7 11.11%)
	1400-2100	Doubtful	-	-	-
	>2100	Unsuitable	-	-	-

4.3.4 Correlation Matrix of Irrigation Water Quality Metrics

The water quality metrics obtained were checked for presence of strong inter-dependencies. The Pearson’s correlation coefficient is a robust measure of association between two variables. In this study, the relationship amongst different irrigation water quality indices was established by the Pearson correlation matrix. The correlation matrix considering all these 9 metrics (SAR, RSC, RSBC, SSP, MAR, PI, KR, EC and TDS) for winter, summer and monsoon season are presented in Tables **4.9, 4.10 and 4.11** respectively. The statistical analysis shows both positive and negative correlation among the different irrigation indices. Significance of correlations were assessed among the irrigation indices at $p < 0.05$ level and at $p < 0.001$ level.

During winter season, results showed that the SAR possessed an excellent match with SSP (r =0.94), KR (r =0.98), EC (r =0.97), and with TDS (r =0.98); SSP had high positive correlation with KR (r =0.94), EC (r =0.93), and with TDS (r = (0.94); RSC had positive correlation with RSBC (r =0.55), MAR (r =0.75) and with PI (r =0.84); RSBC had positive correlation with MAR r = (0.73) and with PI (r = (0.36); MAR had positive correlation with PI (r =0.49); KR had high positive correlation with EC (r = (0.96) and with TDS (r = (0.94) and EC had maximum positive correlation with TDS (r =1.00). SAR and SSP had little linear correlation with RSBC and MAR; Similarly, RSBC and MAR had weakly or zero linear correlation with KR, EC and TDS. PI had strong negative significant with SAR, EC and TDS (**Table 4.9**).

Table 4.9: Pearson Correlation coefficient among various irrigation water quality indices of UGC, Roorkee during the winter season from November, 2014 and October, 2015

Parameters	SAR	SSP	RSC	RSBC	MAR	PI	KR	EC	TDS
SAR	1								
SSP	0.94**	1							
RSC	-0.8	-0.7	1						
RSBC	-0.1	-0.1	0.55**	1					
MAR	-0.4	-0.3	0.75**	0.73**	1				
PI	-0.9	-0.8	0.84**	0.36*	0.49*	1			
KR	0.98**	0.94**	-0.8	-0.2	-0.4	-0.85	1		
EC	0.97**	0.93**	-0.7	-0	-0.3	-0.82	0.93**	1	
TDS	0.98**	0.94**	-0.7	-0	-0.3	-0.82	0.94**	1**	1

During summer season, SAR had an excellent agreement with SSP (r =0.92), RSBC (r =0.55), KR (r =0.78), EC (r =0.93), and with TDS (r =0.92); SSP had positive correlation with RSBC (r =0.44), MAR (r =0.0.03), KR (r =0.86), EC (r =0.86), and with TDS (r =0.86); RSC had positive correlation with RSBC (r =0.33) and with PI (r =0.36); RSBC had positive correlation with KR (r =0.454, EC (r =0.561) and with TDS (r =0.531); MAR had no correlation with PI (r =0.01); KR had positive correlation with EC (r =0.59) and with TDS (r =0.57) and EC had maximum positive correlation with TDS (r =1.00). PI had strong negative significant with KR, EC and TD (**Table 4.10**).

Table 4.10: Pearson Correlation coefficient among various irrigation water quality indices of UGC, Roorkee during the summer season from November, 2014 and October, 2015

Parameter	SAR	SSP	RSC	RSBC	MAR	PI	KR	EC	TDS
SAR	1								
SSP	0.92**	1							
RSC	-0.1	-0.3	1						
RSBC	0.55**	0.44*	0.33*	1					
MAR	-0.2	0.03*	-0.2	-0.15	1				
PI	-0.8	-0.7	0.36*	-0.18	-0.01	1			
KR	0.78**	0.86**	-0	0.45**	0.01*	-0.34	1		
EC	0.93**	0.86**	-0.1	0.56**	-0.11	-0.87	0.59**	1	
TDS	0.92**	0.86**	-0.2	0.53**	-0.06	-0.89	0.57**	0.99**	1

During monsoon season, SAR got almost perfectly correlated with SSP (r =0.99), PI (r =0.62), KR (r = 0.99), EC (r =0.89), and with TDS (r =0.88); SSP had positive correlation with PI (r =0.63), KR (1.00), EC (r =0.87), and with TDS (0.85); RSC had positive correlation with MAR (0.37)); RSBC had positive correlation with MAR (r =0.61; PI had positive correlation with KR (r =0.65), EC (r =0.43) and TDS (r =0.39); KR had positive correlation with EC (r =0.87) and with TDS (r =0.84) and EC had positive correlation with TDS (r =1.00). SAR had strong negative significant with MAR and MAR had strong negative correlated with KR, EC and TDS (**Table 4.11**).

Table 4.11: Pearson Correlation coefficient among various irrigation water quality indices of UGC, Roorkee during the monsoon season from November, 2014 and October, 2015

Parameter	SAR	SSP	RSC	RSBC	MAR	PI	KR	EC	TDS
SAR	1								
SSP	0.99**	1							
RSC	-0.7	-0.73	1						
RSBC	-0.5	-0.44	-0.23	1					
MAR	-0.9	-0.85	0.37*	0.61**	1				
PI	0.62**	0.63**	-0.66	-0.1	-0.44	1			
KR	0.99**	1**	-0.73	-0.5	-0.85	0.65**	1		
EC	0.89**	0.87**	-0.44	-0.5	-0.92	0.43*	0.87**	1	
TDS	0.88**	0.85**	-0.38	-0.6	-0.93	0.39*	0.84**	1**	1

Note: in all Tables 13, 14 and 15, correlation relationships were * at significant level of 0.05 or (5%); ** at significant level of 0.01 or (1%).

4.3.5 Water Quality Index

WQI is a robust measure to express the condition of water quality. A WQI value of zero represents absolute absence of pollutants; when WQI < 100 shows that the water is under consideration and fits for utilization and when WQI > 100 indicates its unsuitability for use (Gadekar et al. 2012; Pandey, 2014). The weighted arithmetic of WQI is computed to assess the water quality of the UGC, Roorkee, to classify the water quality based on the degree of purity by using the standard variables. An example (for site S1) of calculation of WQI for irrigation is provided in **Table 4.12**. The WQI results for all sites considering the physicochemical parameters are presented in **Table 4.13** and that of considering toxic trace metals are also presented in **Table 4.14**. The overall WQI at all the sites considering both physicochemical and toxic trace metals together, for all the three seasons are presented in **Table 4.15**.

Table 4.12: An example for calculation of WQI for Irrigation (at site S1 during winter season)

parameter	Measured value (V_{actual}) for site S1	Permissible Limit for Irrigation (FAO, 1985)	Relative Weight (Wi)	Quality Rating (Q_i)	Weighted value
pH	8.3	6.0 – 8.5	0.118	86.667	10.196
EC	200	3000	0.0003	6.667	0.002
TDS	128	2000	0.0005	6.4	0.003
Ca^{2+}	2.1	20	0.05	10.5	0.525
Mg2+	1.3	5	0.2	26	5.2
Na^{+}	0.12	40	0.025	0.3	0.008
K^{+}	0.04	2	0.5	2	1
Cl^{-}	0.45	30	0.033	1.5	0.05
SO_4^{2-}	2.36	20	0.05	11.8	0.59
NO_3^{-}	0.07	10	0.1	0.7	0.07
HCO_3^{-}	1.25	10	0.1	12.5	1.25
CO_3^{2-}	0	1	1	0	0
B	0.453	2	0.5	22.65	11.325
Al	0.532	5	0.2	10.64	2.128
As	0.002	0.1	10	2	20
Cd	0.001	0.01	100	10	1000
Co	0.035	0.05	20	70	1400
Cr	0.021	0.1	10	21.1	211
Cu	0.047	0.2	5	23.5	117.5
Fe	1.151	5	0.2	23.02	4.604
Mn	0.035	0.2	5	17.5	87.5
Pb	0.012	5	0.2	0.232	0.046
Zn	0.567	2	0.5	28.37	14.185
			$\sum Wi =$ 153.777		$\sum WiQi =$ 2887.182
$\sum WiQi / \sum Wi = 18.78$					

The detailed calculation procedure of WQI considering 23 parameters (13 physico-chemical and 10 toxic trace metals) over site S1 during winter season can be observed from **Table 4.12**. It can be observed that the relative weight of a parameter is reciprocal to its permissible limit. Thus, the relative weight of Cadmium is very high (equal to 100) compared to all other parameters, owing to its lowest permissible limit. The WQI value obtained by the weighed arithmetic method is 18.78, which shows the quality of water to be excellent.

Table 4.13: WQI of Physicochemical parameters for Irrigation purpose (all sites)

Site	Winter	Summer	Monsoon
S1	11.29	11.37	12.17
S2	13.39	12.76	12.37
S3	14.45	12.70	11.33
S4	27.15	28.25	23.23
S5	25.03	27.78	22.08
S6	19.15	18.65	14.99
S7	22.74	25.84	19.17
S8	15.62	12.64	11.50
S9	16.23	12.84	11.86
S10	15.93	14.39	14.55
S11	15.54	13.81	13.66
S12	16.03	13.86	14.37
S13	16.17	13.96	13.04
S14	16.67	14.64	12.39
S15	22.90	14.94	18.83
S16	16.53	15.36	16.13
S17	16.41	14.05	14.67
S18	17.17	13.97	14.26
Min	11.29	11.37	11.33
Max	27.15	28.25	23.23
Avg	17.84	16.57	15.26
SD	4.14	5.33	3.56

The WQI values obtained at all the sampling sites in different seasons (winter, summer and monsoon), considering only physicochemical parameters for irrigation purpose are presented in **Table 4.13.** The WQI ranged from 11.29 to 27.15 with a mean of 17.84 and SD of 4.14 for winter season, from 11.37 to 28.25 with an average of 16.57 and SD of 5.33 for summer season, and from 11.33 to 23.33 with the average value of 15.26 and SD value of 3.56 for monsoon season. It can be noticed that the site S4 had highest WQI during all the seasons, whereas S1 had lowest WQI values during summer and winter seasons. Similarly, S3 possessed lowest WQI during monsoon season, taking only physicochemical parameters.

Table 4.14: WQI of toxic trace metals for Irrigation purpose (all sites)

Site	Winter	Summer	Monsoon
S1	18.91	26.24	16.15
S2	21.36	27.78	15.64
S3	23.02	35.57	16.33
S4	53.53	85.37	51.72
S5	90.44	85.95	58.40
S6	23.22	39.03	22.72
S7	47.63	85.63	51.67
S8	24.34	36.77	23.17
S9	24.19	44.05	23.34
S10	25.82	45.86	30.20
S11	54.57	47.08	30.33
S12	23.79	46.64	30.36
S13	38.59	66.24	38.34
S14	36.34	66.73	38.42
S15	50.22	66.34	45.25
S16	30.20	66.13	45.21
S17	23.82	46.17	37.45
S18	53.79	60.27	38.41
Min.	18.91	26.24	15.64
Max.	90.44	85.95	58.40
Avg	46.06	54.50	34.36
SD	30.29	19.25	13.09

The WQI values obtained at all the sampling sites in different seasons (winter, summer and monsoon), considering only toxic trace metals for irrigation purpose are presented in **Table 4.14.** The WQI ranged from 18.91 to 90.44 with a mean of 46.06 and SD of 30.29 for winter season, from 26.24 to 85.95 with an average of 54.5 and SD of 19.25 for summer season, and from 15.64 to 58.4 with the average value of 34.36 and SD value of 13.09 for monsoon season. It can be noticed that the site S5 had highest WQI during all the seasons, whereas S1 had lowest WQI values during summer and winter seasons. Similarly, S2 possessed lowest WQI during monsoon season, taking only toxic trace metals.

Table 4.15: WQI of physicochemical and toxic trace metals for Irrigation purpose

Site	Winter	Summer	Monsoon
S1	18.78	25.99	16.09
S2	21.22	27.52	15.58
S3	22.87	35.17	16.24
S4	53.07	84.37	51.23
S5	89.31	84.94	57.76
S6	23.15	38.68	22.59
S7	47.19	84.59	51.11
S8	24.19	36.35	22.97
S9	24.05	43.51	23.14
S10	25.65	45.31	29.93
S11	53.89	46.50	30.04
S12	23.66	46.07	30.08
S13	36.46	65.33	37.90
S14	36.00	65.82	37.97
S15	49.75	65.45	44.79
S16	29.96	65.24	44.70
S17	23.69	45.61	37.05
S18	53.16	59.46	37.99
Min	18.78	25.99	15.58
Max	89.31	84.94	57.76
Avg.	45.56	53.84	34.02
SD	29.79	18.99	12.91

From **Table 4.15**, it can be noticed that the overall WQI values (considering both physicochemical parameters and toxic trace metals) of the UGC water sites ranged from 18.78 to 89.31 with a mean of 45.56 and SD of 29.79 for winter season, from 25.99 to 84.94 with an average of 53.84 and SD of 18.99 for summer season, and from 15.58 to 57.76 with the average value of 34.02 and SD value of ±12.91 for monsoon season. The site S5 possessed highest value of WQI throughout all the seasons, which is indicative of highest pollution amongst all the sites. On the other hand, S1 during winter as well as summer and S2 during monsoon season were the least polluted sites, based on WQI values. However, as the limiting value for the water to be suitable for agricultural applications is 100, this reflects that the surface canal water at all the sampling sites is suitable for irrigation uses.

4.4 Conclusions

The Upper Ganga Canal water was evaluated for irrigation purpose. A total of 18 surface water samples were collected from the Upper Ganga Canal. Following conclusions are drawn from this analysis:

1. Based on guidelines and Standards by Ayers and Westcott (1985), T_w, pH, TA, TH, Ca^{2+}, Na^+, K^+ , Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-, CO_3^{2-} values at all the sites of UGC, Roorkee, during all the three seasons were within maximum allowable limits for irrigation. However, the concentration of Mg^{2+} was higher than the prescribed range for irrigation. The Boron value was within the permissible limits at all the sites during all seasons, except for sensitive crops at sites S4, S5 and S7 during summer season and S5 for winter seasons.
2. The toxic metals (except Cobalt) in UGC water for all the sites except at S4, S5 and S7, were within the permissible limits of FAO (Ayers and Westcott, 1985) during all the three seasons. For these three sites, Mn concentrations during winter season, Zn concentrations during winter as well as summer seasons, and Cobalt concentration during all the three seasons were beyond the allowable limits for irrigation purposes. The concentration of Cobalt at sites S10, S11, S12, S13, S14, S15, S16, S17 and S18 for winter season was just above the permissible limit.
3. The water quality indices: SAR, SSP, EC and TDS were 'excellent'; RSC and RSBC were 'safe', KR was 'good' for irrigation. However, MAR values at sites S4, S11, S13, S16, S17 and S8 (winter season), sites S1 and S7 (summer season) and almost all water samples (monsoon season) were higher than the permissible limits (MR >50). PI values were 'moderate (class II)' except that it was 'Low (class III)' at sites S5 and S7 during winter, at almost all sites during summer and at sites S2, S5 and S7 during monsoon season, which indicate that the canal water at these sites may be 'Unsuitable' for irrigation.
4. The WQI values of the UGC water sites ranged from 18.78 to 89.31 with a mean of 45.56 (winter season); from 25.99 to 84.94 with an average of 53.84 (summer season); and from 15.58 to 57.76 with the average value of 34.02 (monsoon season). This reflects that the surface canal water at all water samples is suitable for irrigation.
5. The Upper Ganga Canal (UGC), Roorkee water is suitable for irrigation except that the parameters such as B, Mg^{2+}, Co, Mn, Zn, MAR and PI should be checked at the sites during monsoon, summer and winter seasons before the start of irrigation. Moreover, the application of water for irrigation from S4, S5 and S7 sites should be carried out with utmost care.

CHAPTER 5

WATER QUALITY ASSESSMENT OF UPPER GANGA CANAL FOR LIVESTOCK DRINKING

This chapter presents a detailed water quality analysis of the Upper Ganga Canal (UGC) water for assessing its suitability specific to livestock drinking purposes. The relevant physicochemical variables and toxic trace metals in UGC water are computed and compared with the authentic Standards as well as with the previous literatures. Their effects pertaining to livestock drinking are also discussed. Water Quality Index, which is acclaimed as a robust indicator of overall water quality, is computed for all three seasons (winter, summer and monsoon) of a year, considering the effects of physicochemical parameters and toxic trace metals, separately as well as in combined form. The intra-correlations amongst the toxic trace metals at every season are also calculated to obtain the dependencies.

5.1 Introduction

Water is the most precious and naturally gifted resource on earth and is essential for all life processes in plants and animals including human beings. The existence of life is impossible without reliable water supply at suitable quality (Boyd, 2000). But, population explosion, urbanization, industrialization, agricultural activities etc., have led to discharge of substantial wastewater and sewage into water bodies (rivers, canals, etc.), which has significantly polluted the surface and ground water. Water pollution is a serious problem in India because the safe drinking water for animals and human beings is decreasing at an alarming rate. According to Sharma et al. (2017), almost 75% water bodies of India has become polluted due to discharge of domestic sewage, municipal waste drains, urban agricultural waste, and large scale industrial effluents. Cattles need quality water because loss of body water occurs through milk production, fecal excretion, urine excretion, sweet and vapor loss. The quality of water is a very important aspect for successful livestock production.

Livestock and poultry require large quality of water to survive and perform their maximum potential. Water constitutes 60 to 70 percent of the body of livestock (Looper, 2012). It is also a vital nutrient, involved in many aspects of poultry metabolism and other animals. It has a significant role in metabolic processes such as digestion, food absorption, nutrient transport and waste products elimination. Halls (2008) and Abd-El-Kader et al. (2009) explained that water constitutes almost 65% of the weight of a chicken and its eggs. Consequently, water considered suitable for poultry should fulfil the requirement for human consumption. Thus, the livestock drinking water must be of international standard, that is, free of contaminants in terms of physicochemical parameters and organism load. Korgaonkar et al. (2014) stated that freshwater systems provide human and his livestock with important survival medium that is water. Water availability and quality are extremely important for animal health and productivity (Looper, 2012; Olkowski, 2009; Oketola, et al., 2013). Poor quality of water may cause livestock health deterioration and consequential inferiority in livestock products. As a result, the producer may incur monetary losses. Moreover, the contaminated water may propagate to human beings through consumption of livestock products and thereby, affect adversely to human health (CCME, 2008). It also affects the growth and reproduction ability of animals (Alabama A & M and Auburn University, 1995). Consumption of water with excessive salts may be detrimental to livestock and some ions can cause specific problems, even leading to death (Ayers & Westcott, 1985). Water of low quality may affect layer production performance which is indicated by decreased egg production and egg quality (Abd-El-Kader et al. 2009). It is important to supply drinking water of an optimum quality to livestock. In general, a major portion of water for animal farming is utilized for their drinking purposes, which are supplied through troughs or other devices or from ponds, streams, canals etc. Hence, it is imperative to monitor the water quality at these sources, so that they will have a positive impact on livestock health and products. However, 99% of the water in the world has been polluted by man-made resources mainly due to rapid urbanization, industrialization and increasing population (Al-Badaii et al., 2013). Water bodies often become polluted or are prone to pollution due to developmental activities of human beings. Anthropogenic activities, land use development, industrialization and urbanization severely affect their water quality and endanger the habitants of aquatic organisms (Maglangit et al., 2014). According to Ojutiku, et al. (2014), water pollution has become a pivotal issue and needs continuous monitoring, as alterations in quality of natural waters may interrupt the equilibrium system and be unusable for designated purposes. The availability of water through surface and groundwater sources has become critical day-by-day. Pollution of the Upper Ganga Canal (UGC) water may result from human activities such as dumping of solid waste, discharge of effluent from industries, sewages from house holdings, and urban agriculture into the canal that can affect the livestock, poultry, Pigs or Swine and horse drinking waters. Many urbans around the UGC, Roorkee and its environs around depend on water from this canal and ground water for their livestock, poultry, swine and horses drinking waters uses.

The Upper Ganga Canal (UGC) system, commissioned as far back as in 1855, has its origin from the Ganga River, India (Mishra et al., 2013; Sharma and Singh, 2011). This canal water is currently used for irrigation, livestock watering, navigation etc. However, it has been severely polluted due to discharge of domestic and industrial effluents into it (Goel, 2006). The major sources of pollution to the UGC are the rivers and canals flowing from upper stream cities and villages. Wastes pouring from urban areas into those rivers pollute water sources in rural areas. According to Matta et al. (2015), the UGC is being polluted due to mass bathing (canal is frequently used for human bathing), washing clothes and buffalo, and disposal of sewage, industrial waste and other human activities. Besides, trace metals may enter directly from the river either due to natural causes such as geological erosion, due to atmospheric deposition, or anthropogenic activities i.e. dumping of industrial effluents, domestic sewages, and mining. The human activities such as swimming, dipping, dumping of idols, washing clothes, defecating, cattle wadding, domestic sewages and disposing solid materials are common and could be the sources of pollution, which may make the water unfit for livestock drinking. According to Goel (2006), the Ganges (which is the source of the UGC water) has regrettably become the receiving waste bin for untreated waste; industries withdrawal of water for their consumptive use and discharge the untreated used water in the water bodies. Sardar et al. (2013) discussed that heavy metals pollution has adverse effects on soil, atmosphere and water resources. This may propagate through food chain to impart harmful effects to plants and animals. These heavy metals are harmful when their accumulation rate is more than the discharge and their sources are natural and man-made, as industries and air borne sources. The canal water is predisposed to heavy metals pollution due to anthropogenic activities and the lithology of the water. Heavy metals are non-degradable and can accumulate in the body system of animals, causing damage to internal organs and nervous system. They are toxic and thus, cause growth reductions in livestock animals. The National Academy of Sciences (1972) proposed recommendations for permissible concentration levels of these toxic substances; which depends on amount of water consumed by an animal per day and the corresponding weight of that animal (Ayers & Westcot, 1985, 2015). Reza and Singh (2010) explained that trace metals contaminations are important due to their potential toxicity for environment and human beings and micronutrients for livestock have also stated that heavy metals occur in the environment and naturally are released during anthropogenic activities. Therefore, the necessity of regular monitoring of heavy metal pollution in the water sources for livestock is important as there are multiple sources of heavy metals (pollutants) discharged from cities, atmospheric precipitation and industrial domestic sewage. According to Pandey and Madhuri (2014), the metals possessing toxicity and high density at low concentration are called ‘heavy metals’. Zinc (Zn), Selenium (Se), Copper (Cu), Thallium (Tl), Chromium (Cr), Cadmium (Cd), Mercury (Hg), Manganese (Mn), Lead (Pb), Arsenic (As) are some of the heavy metals, which are useful for metabolic activities at very low concentrations, but become toxic at higher quantities. The metals like Chromium show carcinogenic effect due to its unusual oxidation phases and hence, may cause toxicity. It has been documented that the heavy metals are normally non-toxic in their metallic and insoluble compound forms. The toxicity in metals is imparted mainly by the ligands. The elementary researches in this context are based on study of several animal species. Owing to their poor biodegradability and environmental stability, the pollutants amass and persist in the animal bodies. Also, the wastes and effluents gets accumulated over soil and cause soil pollution. These are absorbed by plants from soil and similarly, by animals through grazing (Alemu et al., 2017).

WQI (Weighted Arithmetic Index Method) as described by Khwakaram et al. (2012) and Mukhtar et al. (2014), is the most effective way to communicate water quality. Hence, it is widely applied to assess, monitor and manage the ground as well as surface water. WQI is a numerical value representing the overall water quality. Therefore, it can be used to draw a line between the polluted and clean water. WQI is not a new concept. It was formulated by Horton (1965) has been modified and used by other scientists (Al-Mashagbah, 2015). There is evidence from other canals in the Indian Subcontinent that the water quality of these systems has been degrading. Kumar and Chopra (2012) studied the hydrological characteristics i.e. physicochemical and microbiological of abandoned Old Ganga Canal at Haridwar, Uttrakhand, India. They concluded that it has high contaminants in terms of physicochemical and microbiological parameters and metal contents deteriorated the canal water. WQI showed that the canal water quality changed badly after drainage and discharge of domestic wastewater and agricultural runoff. Matta (2014) carried out assessment of water quality of Ganga canal system at Haridwar and studied the physicochemical parameters in the monsoon, summer and rainy seasons. He found that results exceeded the permissible limit during rainy season and summer season at Bahadrabad when the results were compared by Bhimgoda Barrage water. The main source of contamination was from domestic, human and industries. Sewage, solids and liquid contaminants or organic nature were found to be the prime source of pollution. As the untreated effluents are continuously discharged to the canal, the water was found to be unfit for drinking or irrigation.

Keeping the aforementioned issues in mind, the present study was formulated with the following objectives:

1. To assess some of the important physicochemical parameters for water quality of UGC and their seasonal variation to obtain the pollution status of the canal during the three seasons (winter, summer and monsoon) relevant to livestock drinking.
2. To assess the important toxic trace metals composition like Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Pb, and Zn during the three seasons (winter, summer and monsoon) for livestock drinking.
3. To compare results of the analyzed physicochemical parameters and trace metals of livestock drinking water with the authentic guidelines and Standards namely, Australia and New Zealand for fresh and Marine Water Quality (ANZECC, 2000), Food and Agriculture Organization (Ayers and Westcott, 1985), Canadian Council of Ministers of the Environment (CCME, 2008) and, South African Water Quality Guidelines for Livestock Watering Use, Department of Water Affair and Forestry (DWAF, 1996).
4. To compute WQI (using the weighted arithmetic method) to obtain the pollution status of the UGC water around Roorkee.
5. To establish the nature of relationships between the trace metals using correlation analysis.

5.2 Data and Methods

In this study, water samples were collected from eighteen sites i.e., S1, S2, S3…, S17 and S18, at monthly interval for a period of one year (from November, 2014 to October, 2015) with the aim of understanding the seasonal (winter, summer, and monsoon) variation. The water samples were analyzed in laboratory for obtaining the concentration of physicochemical parameters and toxic trace metals. The data obtained from this laboratory analysis was compared with respect to the reliable standards and guidelines for livestock drinking purposes.

The detailed procedure for collection of water samples and brief description of physicochemical parameters as well as the toxic trace metals is provide in **Section 3.2** of the **Chapter 3 (Materials and Methods)**. The instruments and detailed laboratory procedure to obtain the physicochemical parameters and toxic heavy metals from the water samples are provided in **Annexure A**. The data obtained for physicochemical parameters at monthly level are presented in **Annexure B** (Tables B1 to B13). The seasonal data converted from these monthly observations over all the 18 sites are presented for winter, summer and monsoon season in **Tables 3.3, 3.4 and 3.5** respectively. Similarly, for toxic trace metals, the seasonal observations and the statistical summary for winter, summer and monsoon seasons are given in **Tables 3.7, 3.8 and 3.9** respectively (**Chapter 3**). The traces of heavy metals i.e. Zn, Hg, Pb, Mn, Fe, Cu, Cr, Co, Cd, As and Al have been identified as toxic substances causing adverse effects on livestock drinking waters. The water quality may even alter naturally, but contamination due to anthropogenic activities is the usual factor impairing water quality. The human practices leading to water pollution has already become a giant societal concern (Claude, 2000). Goel (2006) categorized the adverse effects of water pollution as physicochemical and biological effects of pollution. These trace metals are selected in this study for analysis because up to some extent these elements are good but if, they are beyond certain limit they are toxic and have harmful effects on livestock.

Water quality Index (WQI) represents the state of complex water quality data in a simple numerical value, which can be easily understood and used by public. It expresses overall water quality based on several water quality parameters. A WQI value less than 100 is considered usable for a specific application, considering the relevant permissible limits for each influential parameter. The WQI for all the sampling sites during all the three seasons is also determined by considering the physicochemical parameters and toxic trace metals separately as well as in combined form, of which, the later represents the overall water quality. The computation procedure and explanations of WQI is presented in **Section 3.5** of **Chapter 3**. The standards and guidelines by Canadian Council of Ministers of the Environment (CCME, 2005) and, Food and Agricultural Organization (Ayers & Westcott, 1985), are presented in **Table 3.11** of **Chapter 3**, which are referred for taking the limiting values of different parameters to compute WQI for livestock drinking.

Correlation is a measure of agreement or association between two variables. It is widely used to obtain the dependencies amongst the influential variables pertinent to specified applications, using correlation matrix. The inter-dependencies amongst the toxic trace metals pertaining to livestock drinking are obtained by Pearson’s correlation matrix, as explained in **Section 3.6** of the **Chapter 3 (Materials and Methods)**.

5.3 Results and Discussions

5.3.1 Physicochemical Parameters

The physicochemical parameters relevant to livestock drinking are considered and compared with respect to the authentic international standards/guidelines. These parameters are electrical conductivity, total dissolved solids, Magnesium, Calcium, Chloride, Sulfate, Nitrate, water temperature and Boron. Any alterations in these parameters may significantly affect the suitability of water for livestock drinking purposes. Therefore, it is necessary to compare the results obtained with the reliable standards. In this study, water quality results were compared to the guidelines provided by the Canadian Council of Ministers of the Environment (CCME, 2008), to assess its suitability for livestock drinking in all eighteen sampling sites of the UGC, Roorkee. The condition of UGC water in terms of these parameters (analyzed on field and at laboratory) at all the eighteen sampling sites during November 2014 to October 2015, at seasonal level (winter, summer and monsoon season) are discussed below.

Electrical Conductivity (EC)

The electrical conductivity (EC) is a measure of the total salts present in a solution. The EC values (dS/m) are directly proportional to the total dissolved solids (mg/L) in natural waters. The proportionality factor varies between 550 to 900 and is dependent on the kind of dissolved salts in water. The detailed guideline of EC based on Canadian Council of Ministers of the Environment (CCME, 2008) is presented in **Table 5.1**. Electrical conductivity is directly measured by EC-meter automatically, which can be used to estimate TDS. 1dS/m is equal to 1000 µS/cm. The EC value of the UGC is presented in **Figure 5.1**, wherein the W, S and M denoted in colours represents winter, summer and monsoon season respectively. Thus, these values reflect that the water from all the sampling sites of UGC, Roorkee, was found to be in excellent conditions (low salinity) as per the guidelines of CCME (200).

Table 5.1: Guidelines to the use of saline waters for livestock and poultry

Total soluble salts Content of water (mg/L)	**Remarks**
Less than 1000 mg/L (EC < 1.5 ds/m*)	Relatively low level of salinity. Safe to drink; should pose no health problems. Excellent for all classes for livestock and poultry.
1000-3000 mg/L (EC = 1.5-5 ds/m)	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to them or watery droppings in poultry.
3000-5000 mg/L (EC = 5-8 ds/m)	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to them. Poor waters for poultry, often causing water feces, increased mortality and decreased growth, especially in turkeys,
5000-7000 mg/L (EC= 8-11 ds/m)	Can be used with reasonable safety for dairy and been cattle, for sheep, swine and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.
7000 -10000 mg/L (EC= 11-16 ds/m)	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lactating cows, horses, sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
Over 10000 mg/L (EC > 16 ds/m)	Risks with these highly saline waters are so great that they cannot be recommended for use under any condition.

*1ds/m=1000μs/cm, **Source**: CCME (2008)

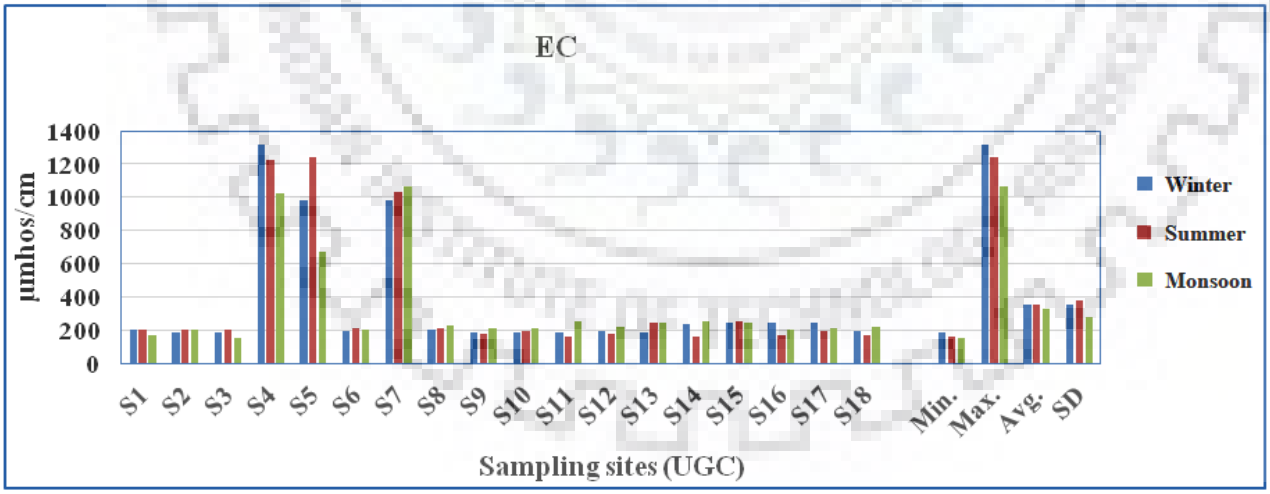


Figure 5.1: EC (μS/cm) of the analyzed water samples of the study area during the three seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

Total Dissolved Solids (TDS)

TDS is an estimate of water quality and accounts for all inorganic salts present in water in dissolved form, including the dissolved organic compounds. The TDS concentration possesses remarkable variation in natural waters. In rainwater (which is taken as purest form of natural water), TDS values are less than 1 mg/L whereas in seawater, it reaches up to 35000 mg/L and maybe even higher in brines. The TDS also reflects the geology of the regions, as the weathering of rocks, minerals and soil affects its concentration. The TDS is mainly contributed by the cations such as sodium, magnesium, potassium and calcium; and the anions such as chloride, carbonate, bicarbonate, sulfate and nitrate. Highly mineralized waters can cause physiological upset and sometimes death in terrestrial animals, including humans. The highly saline water is generally very difficult and undesirable for livestock drinking as it may cause gastrointestinal problems and their weight reduction. This consequently leads to adverse effects on the egg or milk production. The permissible limit (as per CCME guidelines) of TDS for livestock is 10000 mg/L. In all the sampling sites of the study area (UGC), results revealed that TDS values are within the permissible limits of the standards. Therefore, the UGC water is suitable for livestock drinking **(Figure 5.2).**

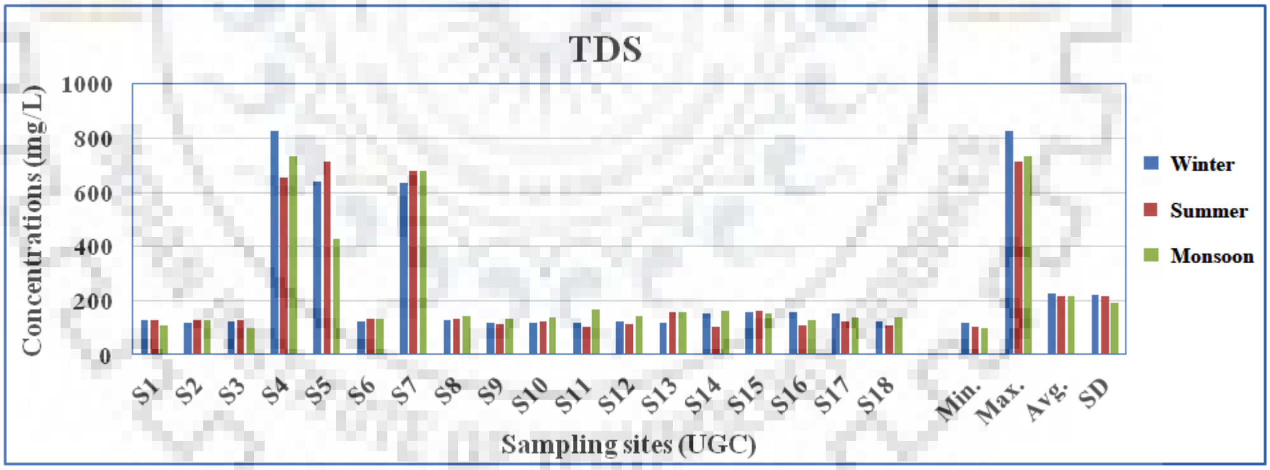


Figure 5.2: TDS concentration values (mg/L), of water samples of the UGC, Roorkee during local seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

Calcium (Ca^{2+})

The Calcium is a necessary element for animals and should be available in livestock diet at desirable amounts, as higher concentrations may cause phosphorus deficiency (by impeding phosphorus adsorption in the gastrointestinal tract) and calcium formation in the body. The calcium content in water has close relation with the geology of the source regions, as it is contributed by weathering of rocks and minerals. It is also responsible for hardness in water. Calcium is naturally present in aquatic systems, but substantial addition of effluents or sewage increases its concentration, which is undesirable (Kumar, 2015). The concentration of Calcium possesses a wide range of variation in natural waters. The maximum allowable limit of Ca in water for livestock drinking is 1000 mg/L, subject to the adequacy of phosphorous level in diet. However, the limit may be lesser if the concentration is high in the feed or dietary supplements. In all the sampling sites of the study area (UGC), results revealed that Ca concentration values are within the permissible limits of the standards. Therefore, the UGC water is suitable for livestock drinking **(Figure 5.3).**

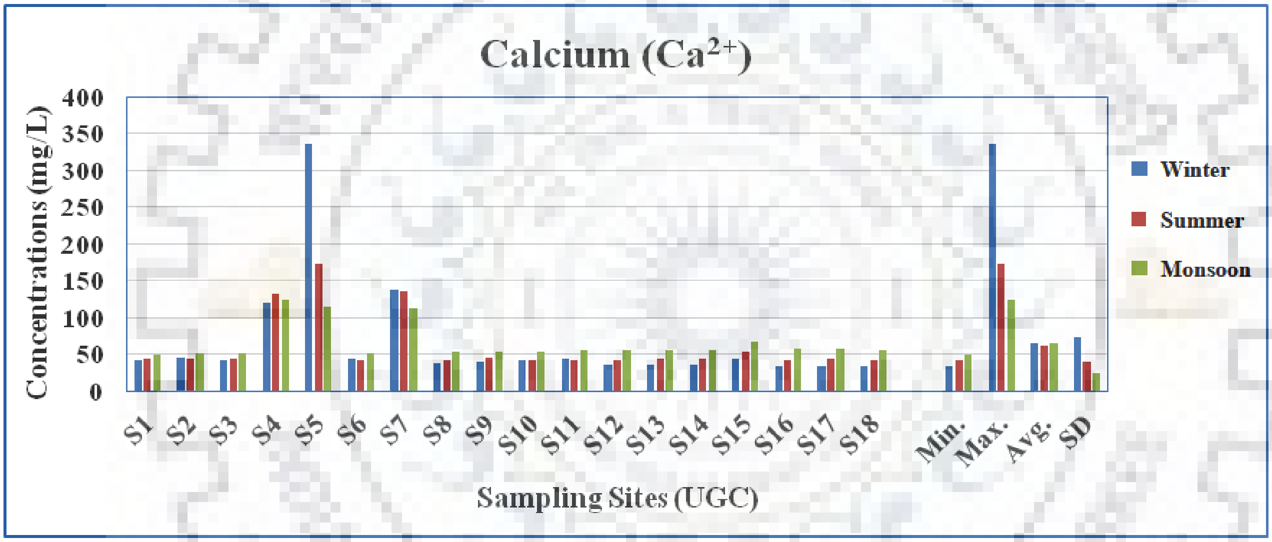


Figure 5.3: Ca Concentrations values (mg/L) of the analyzed water samples of the study area during the three seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

Magnesium (Mg^{2+})

The magnesium concentration possesses considerable variation in natural waters. Based on the geology of catchment, concentration of Mg may vary from less than 1 mg/L to nearly 1000 mg/L or above. Magnesium imparts hardness in water, which can lead to scaling issues in fittings and troughs. Based on FAO guidelines, the permissible limit of Magnesium varies for animals; however, for drinking purposes of most of the domesticated animals, the concentration should be less than 250 mg/L. The concentration of Mg in water has a close association with that of TDS and thus, complications arising due to high Mg concentration may be attributed to high TDS levels (CCME, 2008). Magnesium concentration values in the UGC are presented in **Figures 5.4)**. In all the sampling sites of the study area (UGC), results revealed that Mg concentration values are within the permissible limits of the standards. Therefore, the UGC water is suitable for livestock drinking **(Figure 5.4).**

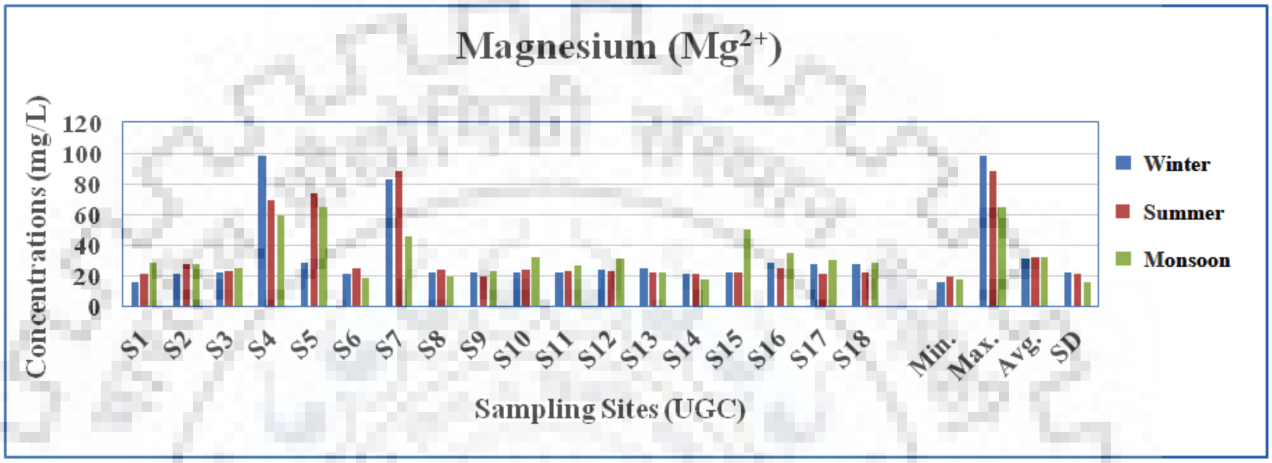


Figure 5.4: Mg Concentrations values (mg/L), the analyzed water samples of the study area during the three seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

Chloride (Cl^-)

Naturally occurring chloride is caused by dissolving minerals. Chlorides may be found in surface water from road salt, fertilizers, industrial wastes or sewages. The total anionic constituent of Cl^- values in the UGC, Roorkee ranged from 10.75 to 345 mg/L with a mean of 46.486 mg/L and SD value of 83.802 for winter season; it ranged from 15.75 to 169 mg/L with a mean of 38.46 mg/L and SD value of 48.93 for summer season; and it ranged from 22.25 to 120.75 mg/L with average value of 39.07 mg/L and SD value of 31.63 for monsoon season **(Figure 5.5)**. For all water samples of the UGC, Roorkee, during all the three seasons, the concentration of Cl^- ions was within the permissible limits by FAO (Ayers & Westcot, 1985, 2015) and BIS (IS 2296: 1992).

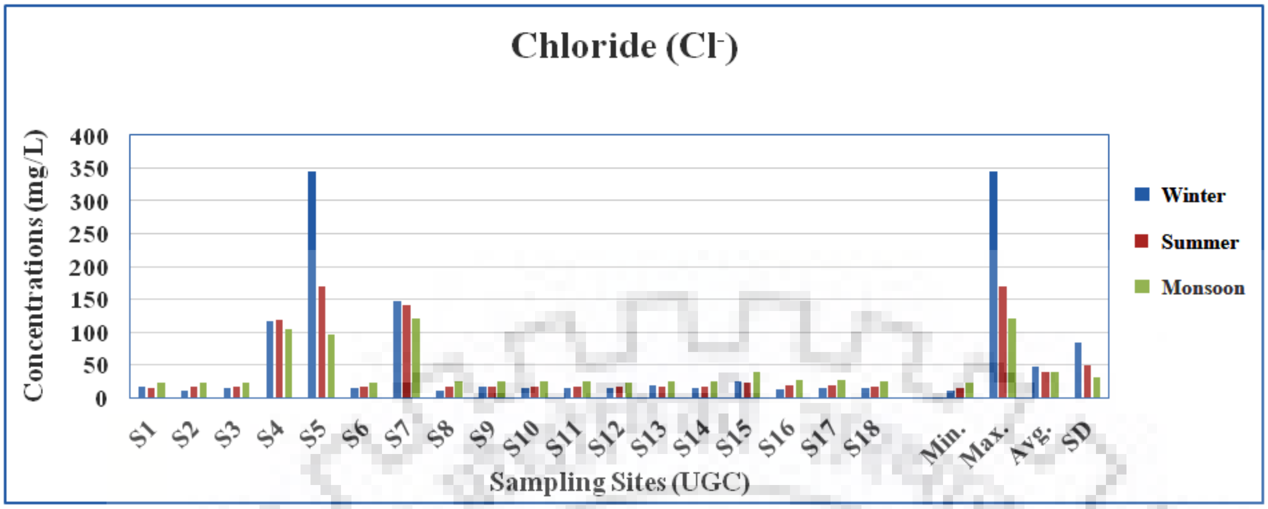


Figure 5.5: Cl^- Concentrations values (mg/L), the analyzed water samples of the study area during the three seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

Sulfate (SO_4^{2-})

In general, drinking water with the sulfate concentration less than 1000 mg/L doesn't have ill effects on livestock. However, sulfate contents above this threshold may be harmful to lactating or young animals, especially in hot and dry conditions, as the intake of water is high. Severe chronic issues for livestock may arise, if sulfate level exceeds 2000 mg/L (ANZECC, 2000; CCME 2008). A high concentration of sulfate in natural water may be attributed to the dissolution or breakdown of sulfate-rich minerals in rocks and soil. In groundwater, sulfates may naturally occur at excessive concentrations. Considering the drinking purposes, the permissible limit of sulfates for dairy cattle is up to 1500-2500 mg/L for groundwater whereas, it should be less than 1000 mg/L for surface water. Sulfate concentration in UGC is presented in **Figures 5.6)**. The sulfate concentration of UGC was found suitable for livestock drinking purposes.

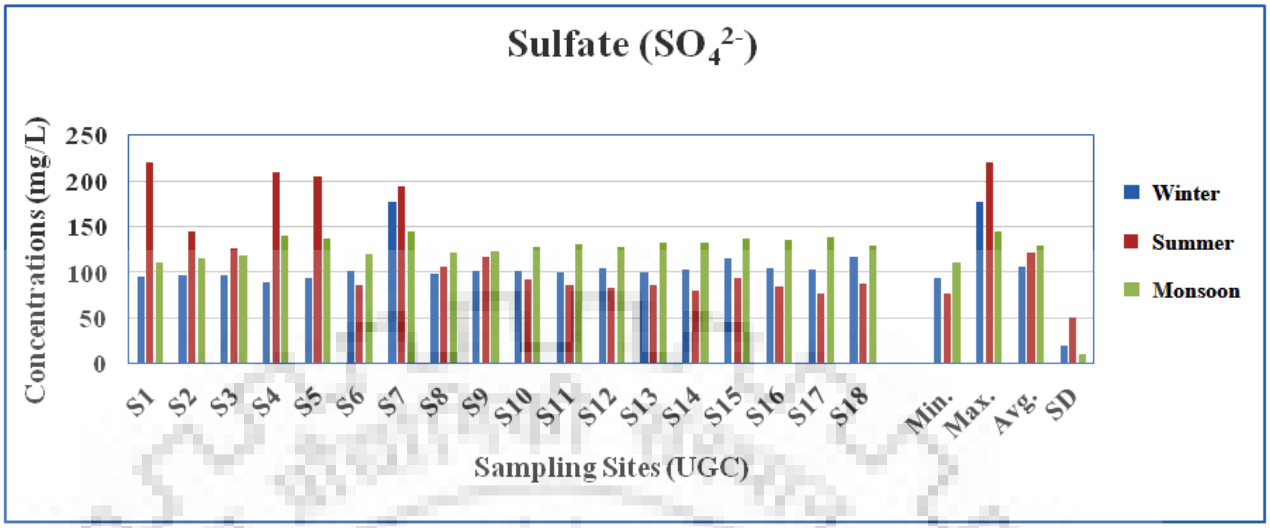


Figure 5.6: SO_4 Concentrations values (mg/L), the analyzed water samples of the study area during the three seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

Nitrate Nitrogen (NO_3-N)

Nitrate does not have toxicity by itself, but it undergoes to form nitrite which may be harmful. Nitrate poisoning is very difficult to be tolerated by young animals. In general, shallow water tables mainly result in higher nitrate levels in water. Even nitrate leaching from soils and application of nitrogen-rich fertilizers also contribute to the high nitrate level in water. According to ANZECC (2000) guidelines, the nitrogen concentration below 400 mg/L in livestock drinking water is not harmful to animal health. The concentration above 1500 mg/L must be avoided as it can be toxic to animals. Nitrate occurs naturally in waters, but at a tiny concentration (< 1 mg/L for unpolluted streams). Results of the Nitrate concentration in the UGC water are presented in **Figure 5.7).** For all water samples of the UGC, Roorkee, during all the three seasons, the concentration of **NO_3-N** was within the permissible limits by FAO (Ayers and Westcott, 1985) and BIS (IS 2296: 1992).

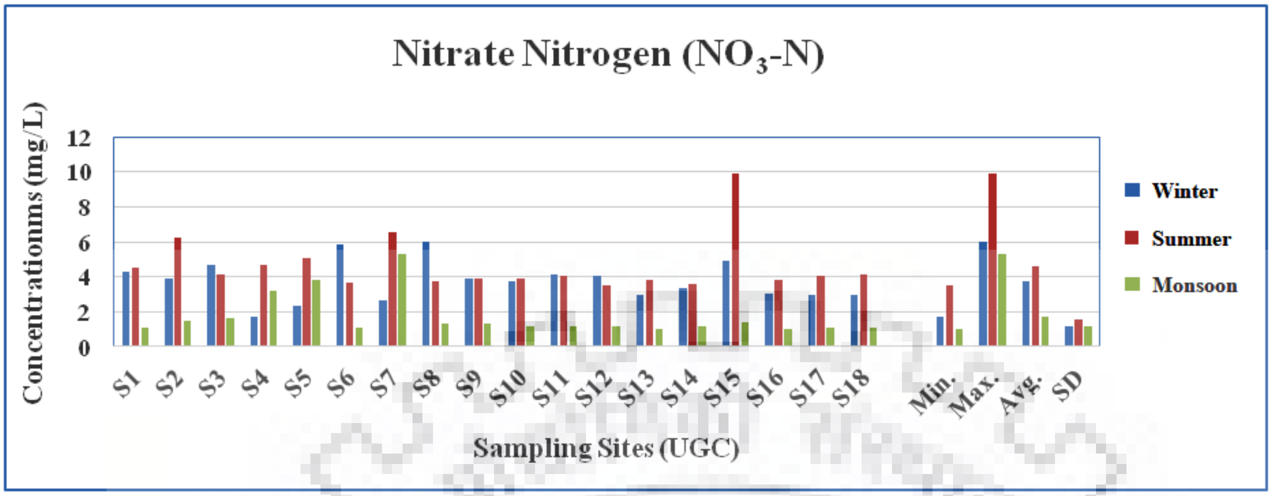


Figure 5.7: NO_3-N concentration values (mg/L) of the analyzed water samples of the study area during the three seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

Water Temperature (Tw)

Temperature is a crucial factor which is responsible for regulating the biogeochemical activities (Mahesh Kumar, 2014). Temperature of water used for animals is of great importance as a physiological factor. In Canadian standards the temperature is 15 ^{0}C (CCME, 2008). However, many countries use between 15 and 30 ^{0}C. The temperature values of the samples in the UGC water are presented in **Figure 5.8**.

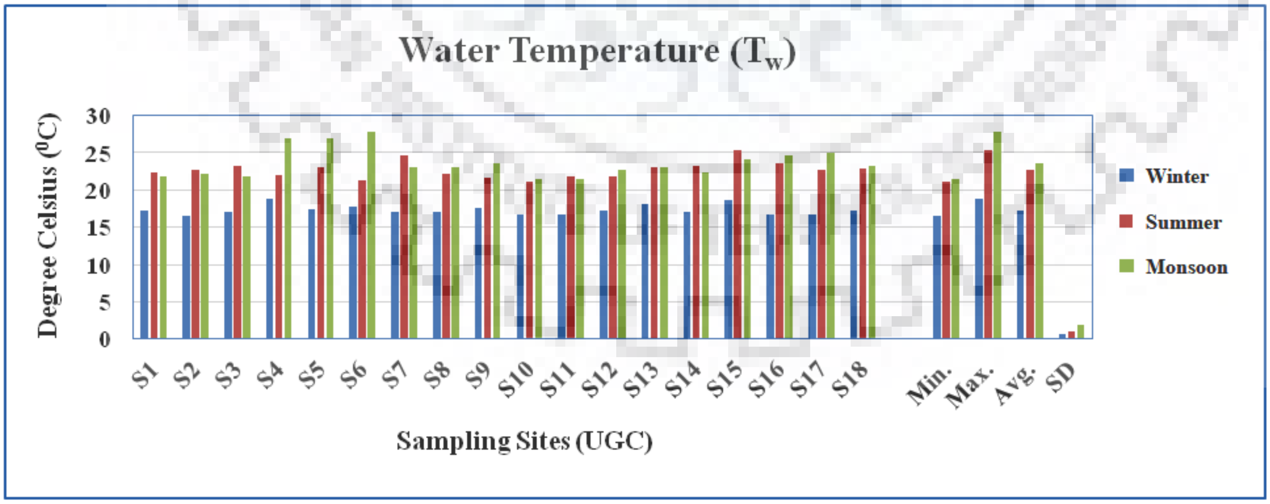


Figure 5.8 Water Temperature (˚C) of samples of UGC, Roorkee during the three seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

Boron (B)

The specific toxic effects of Boron (B) even at high concentrations, on animals, especially livestock, are not well characterized (DWAF, 1996). But Boron concentration above 5 mg/L in water for livestock diet is not desirable (ANZECC, 2000 and CCME, 2008). In general, the concentration of Boron in unpolluted water is less than 0.1 mg/L. But the fertilizers and pesticides with Boron content, contaminates the water supplied to farms. In this study, the UGC water exhibited the value of B from 0.453 to 1.531 mg/L with a mean of 0.848 mg/L and SD value of 0.218 (winter season), from 0.525 to 1.352 mg/L with a mean of 0.853 mg/L and SD of 0.226 (summer season) and from 0.671 to 0.952 mg/L with a mean of 0.811 mg/L and SD of 0.082 (monsoon season) **(Figure 5.9)**. In all seasons, the observed values were within the safe limit for livestock drinking when compared with the guidelines by ANZECC (2000), Ayers and Westcott (1985, 1994), CCME (2008), DWAF (1996c) and Ayers & Westcot, (1985, 2015).

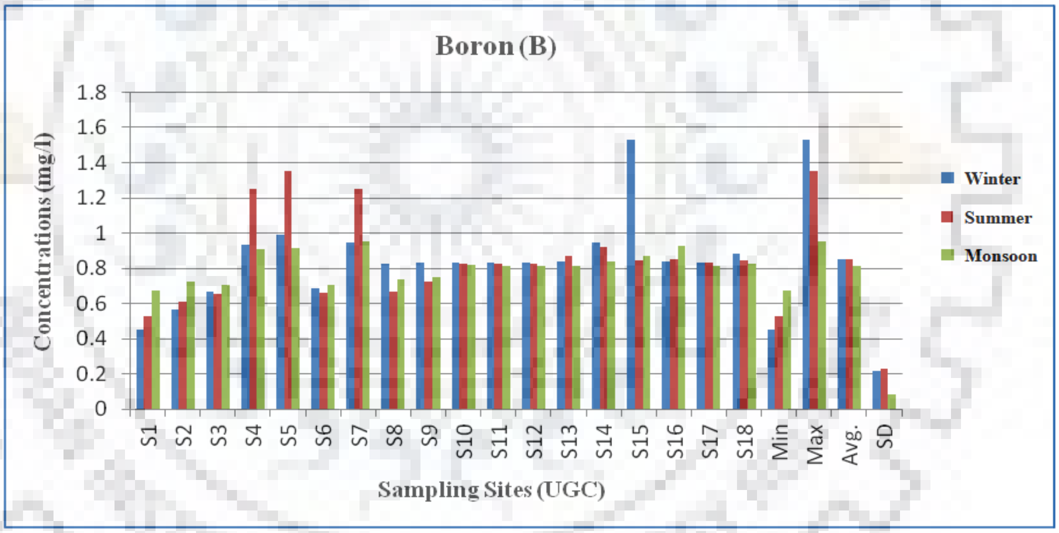


Figure 5.9: Boron concentration values (mg/L) of the water samples from 18 sites of the study area during the three seasons (winter, summer and monsoon) for the period of November, 2014 to October, 2015

5.3.2 Toxic Trace Metals

The UGC water is widely used for livestock drinking purposes, among the associated districts. Therefore, the evaluation of toxic trace metals viz., Aluminium, Arsenic, Cadmium, Cobalt, Chromium, Copper, Iron, Mercury, Manganese, Lead and Zinc was carried out for its suitability for livestock drinking uses. The recommended maximum concentration of toxic trace metals considered for this study and their adverse effects as per South African Water Quality Guidelines for Livestock Watering (DWAF, 1996) are discussed in **Table 5.2**.

Table 5.2: Recommended range of no adverse effects of trace metals in livestock water quality guidelines and the effects of water pollution

Trace Metals	**Range of no adverse effects, (mg/L)**	**Effects**
Al	0-5	Aluminum (Al) is relatively non-toxic and occurs as a trace element in milk. Ingestion of high concentrations of soluble aluminum salts may result in symptoms of neurotoxicity, although aluminum is usually rapidly excreted in the urine of healthy subject. If Al ranges from 0-5 mg/L, it has adverse chronic effects, such as neurotoxicity may occur.
As	0-1.0	If Arsenic (As) ranges from1.0-1.5 mg/L, adverse acute effects such as hemorrhagic diarrhea and dehydration may occur in sensitive species (pigs and poultry), although short-term exposure is usually tolerated. Acute effects unlikely in larger animals (cattle, sheep, goats and horses), but may occur if feed concentrations of arsenic are also elevated. Could even be tolerated in the long term, depending on site-specific factors such as water requirement; If As >1.5 mg/L, Adverse acute effects may occur, particularly in more sensitive species, although short-term exposure could be tolerated depending on site-specific factors, such as adequate zinc intake and water requirement.
Cd	0-0.01	The presence of cadmium (Cd) in the aquatic environment and in livestock drinking water is of concern because it bio-accumulates. If Cd ranges from 0.01-0.02 mg/L, adverse chronic effects such as anemia, testicular degeneration, reduced feed intake and milk production and reduced growth may occur; adverse acute effects such as abortions, still births, hepato- and nephrotoxicity may occur; but suckling and pregnant livestock are principally at risk.
Cr (IV)	0-1	Chromium (Cr) can function as an essential element, being a component of a hormone and a vitamin and as a co-factor with insulin, required for normal glucose utilization and growth. If Cr (IV) ranges from 1-2mg/L, it has diverse chronic effects such as diarrhea may occur. If Cr (IV) >2 mg/L, adverse chronic effects such as diarrhea and possible carcinogenic effects may occur.
Co	0-1	Cobalt (Co) is an essential trace element in nutrition and forms part of vitamin B_{12} and it is required for red blood cell synthesis, 12 and the methyl malonyl CoA and methionine synthase enzyme pathways. If Co ranges from 1-2 mg/L, Adverse chronic effects such as in appetence and

		weight loss may occur.
Cu	0-0.5	Copper (Cu) is an essential trace element in plants, animals and man. If Cu ranges from 0-5 mg/L, no adverse effects on horse, pigs, poultry; if Cu ranges from 0-1 mg/L, it has no adverse effects on cattle; and If Cu range 0-0.5 mg/L, it no adverse effects on sheep and pre-weaned calves.
Fe	0-10	Biologically, iron (Fe) is an essential micronutrient required by all living organisms. If Fe ranges from 10-50 mg/L, it has adverse chronic effects such as liver and pancreas damage, may occur. If Fe >50 mg/L, it has adverse chronic and acute effects such as diarrhea, vomiting, acidosis and respiratory failure and liver and pancreas damage respectively, may occur.
Hg	0-1	Mercury (Hg) and organo-mercurial complexes are severely neurotoxic. Intake may occur via air, food or water. Food, particularly fish and fish products, are usually the major source of exposure to mercury. If Hg ranges from 1-6 mg/L, adverse chronic effects may occur if mercury is in the organic form.
Mn	0-10	Manganese (Mn) is an essential element for humans and animals, but is neurotoxic in excessive amounts. At typical concentrations encountered in water, manganese has aesthetic rather than toxic effects. If Mn ranges from 10-50 mg/L, it has adverse chronic effects such as weight loss due to in appetence may occur.
Pb	0-0.1	Lead (Pb) is highly resistant to corrosion. Pb is a cumulative poison. Lead may accumulate in the roots of some plants, for example hay, potatoes and lettuce to concentrations toxic to humans and animals. If Pb ranges from 0.5-1 mg/L, it has adverse effects on pigs; if Pb ranges from 0-0.2, it has adverse effect on all other livestock.
Zn	0-20	Biologically, zinc (Zn) is an essential nutritional trace element for plants and animals, but is toxic at high concentrations. If Zn ranges 20-40 mg/L, it has adverse chronic effects such as in-appetence, anemia icterus and diarrhea may occur. If Zn >40 mg/L, Adverse chronic effects (as above) and acute effects such as hemolysis and icterus may occur.

Source: South African Water Quality Guidelines for Livestock Watering Use, volume 5, Department of Water Affair and Forestry, **DWAF (1996**).

The guidelines of South African Water Quality Guidelines for Livestock Watering (**DWAF, 1996**) provided in **Table 5.2** explain the harmful effects of each parameter in details. However, there are several reliable guidelines/standards developed by other organizations specifically for livestock drinking purposes. The comparison of results obtained from this study with respect to these will be helpful to get a clear picture regarding suitability of UGC for livestock drinking. In this study, along with DWAF (1996), the guidelines provided by Food and Agricultural Organization (FAO;

Ayers and Westcott, 1985), Canadian Council of Ministers of the Environment (CCME, 2008), Australian and New Zealand Environment and Conservation Council (ANZECC, 2000), are also considered for assessment of water quality in all sampling sites of the UGC, Roorkee. The permissible limits for the toxic trace metals pertinent to livestock drinking by all the aforementioned standards are presented in **Table 5.3**.

Table 5.3: Different national and international Guidelines of Livestock drinking water used for data interpretation and comparisons

Parameter	**Guidelines for Livestock drinking water**			
	Ayers and Westcott (1985)	**CCME (2008)**	**ANZECC (2000)**	**DWAF (1996)**
Al, mg/L	5.0	5.0	5	0-5
As, mg/L	0.2	0.5	0.5	0-1.0
Cd, mg/L	0.05	0.02	0.01	0-0.01
Co, mg/L	1.0	0.05	0.05	0-1
Cr (VI), mg/L	1.0	1.0	1.0	0-1
Cu, mg/L	0.5	1.0	0.5	0-0.5
Fe, mg/L	ND	ND	ND	0-10
Hg, mg/L	0.01	0.003	0.002	0-1
Mn, mg/L	0.05	ND	ND	0-10
Pb, mg/L	0.1	0.1	0.1	0-0.1
Zn, mg/L	24	50	20	0-20

Sources: Australian and New Zealand Guidelines for fresh and Marine Water Quality (ANZECC, 2000), Food and Agriculture Organization (Ayers and Westcott, 1994) for livestock drinking water, Canadian Council of Ministers of the Environment (CCME (2008), South African water quality Guidelines for Livestock watering use, Department of Water Affair and Forestry (DWAF, 1996).

The detailed results for the trace metals in water from Upper Ganga Canal on seasonal basis for all the sites and their comparative assessment with respect to the authentic standards considered are presented below. The values of all the toxic trace metals during winter, summer and monsoon seasons are presented in **Tables 5.4, 5.5** and **5.6** respectively.

Aluminum (Al)

Aluminum (Al) is generally non-toxic. But, ingesting large concentrations of soluble aluminum salts can cause neurotoxicity (DWAF, 1996 c). Aluminum is a trace constituent of milk. A diet with Aluminum concentrations less than 500 mg/kg is not harmful to poultry but above that limit could be dangerous (Butcher, 1988). In this study, UGC water exhibited Al values ranging from 0.1311 to 2.3274 mg/L with a mean of 0.5249 mg/L and SD of 0.707 (winter season), from 0.1342 to 1.1652 mg/L with a mean of 0.642 mg/L and SD of 0.214 (summer season) and from 0.1311 to 1.1751 mg/L with a mean of 0.407 mg/L and SD of 0.346 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. In all seasons, the observed values were within the safe limits for livestock drinking when compared with the guidelines suggested by Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000) and DWAF (1996), **(Table 5.3)**.

Arsenic (As)

Arsenic (As) levels are normally low in surface water except if they are exposed to industrial contaminants. It naturally occurs as a trace component in livestock feeds. The main contribution of Arsenic comes from its compounds which are applied as additives to fodder of poultry and pigs, as it leads to their rapid growth. However, the contribution from water can't be ignored (Olkowski, 2009). The concentration of As in the samples collected from UGC, Roorkee, varied from 0.002 mg/l to 0.014 mg/l with an average of 0.0045 mg/l and SD of 0.0038 during winter season, from 0.002 mg/l to 0.013 mg/l with an average of 0.0041 mg/l and SD of 0.0035 during summer season, and from 0.002 mg/l to 0.017 mg/l with an average of 0.0051 mg/l and SD of 0.0042 during monsoon season (**Tables 5.4, 5.5 and 5.6)**. In all seasons, the observed values were within the safe limit for livestock drinking when compared with the guidelines by Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3)**.

Cadmium (Cd)

Cadmium (Cd) is very toxic, although its toxicity is not commonly observed. Exposure of livestock to Cd may have detrimental effects on maternal organs, during pregnancy (DWAF, 1996 c). A high concentration of Cd may cause Anemia, stillbirths, abortions, stillbirths, immunity reduction and birth defects in livestock. In this study, the UGC water exhibited the Cd values ranging from 0.001 to 0.0185 mg/L with a mean of 0.004 mg/L and SD of 0.004 (winter season), from 0.002 to 0.008 mg/L with a mean of 0.005 mg/L and SD of 0.001 (summer season) and from 0.001 mg/L to 0.005 mg/L with a mean of 0.003 mg/L and ± SD of 0.001 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. In all seasons, the observed values were within the safe limit for livestock drinking when compared with the guidelines by Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3).**

Cobalt (Co)

Cobalt (Co) is a crucial trace constituent in various animal enzyme systems and hence, carries importance in the context of livestock diet. Co generally gets stored in liver, kidney, bones, adrenal glands and retained by body tissues. The toxicity of Cobalt may lead to loss of appetite and subsequently, loss in body weight (South Africa water Quality Guidelines, 1998). In this study, UGC water exhibited concentration of Co from 0.035 to 0.0846 mg/L with a mean of 0.044 mg/L and SD of 0.012 (winter season), from 0.035 to 0.0846 mg/L mg/L with a mean of 0.053 mg/L and SD of 0.014 (summer season) and from 0.0202 mg/L to 0.0646 mg/L with a mean of 0.031 mg/L and SD of 0.016 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. In all seasons, the observed values were within the safe limit for livestock drinking when compared with the guidelines of Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3).**

Chromium(Cr)

Cr (III) and Cr (VI) are the naturally occurring forms of Chromium (Cr), among which, Cr (VI) possess high toxicity. The Cr (III) adsorbs on food fibers and precipitates in the animal digestive system, in an insoluble form. In this study, the UGC water exhibited concentration of Cr (VI) from 0.0211 to 0.0865 mg/L with a mean of 0.04 mg/L and SD of 0.02 (winter season), from 0.0211 to 0.098 mg/L with a mean of 0.046 mg/L and SD of 0.023 (summer season), and from 0.0201 to 0.055 mg/L with a mean of 0.033 mg/L and SD of 0.01 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. In all seasons, the observed values were within the safe limit for livestock drinking when compared with the guidelines by Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3).**

Copper (Cu)

Copper (Cu) is essential nutritional micronutrient element for the life of plants, animals and man (Renza, 2010; DWAF, 1996 c). But, a high concentration of total copper in livestock drinking water is undesirable. The permissible Cu concentration in drinking water greatly varies from animal to animal. Normally, in natural water, the concentrations of Copper are not above 1 mg/L. Excessive ingestion of Copper can be generally attributed to its high content in feed rather than in water. But, this may be harmful as accumulation of Copper in liver of animals hinders their growth. Continuous intake of high quantities of Copper may result in chronic disorders like hemolytic jaundice and liver damage. In this study, the UGC water exhibited Cu concentration varying between 0.02 to 0.092 mg/L with a mean of 0.054 mg/L and SD of 0.018 (winter season), from 0.023 to 0.176 mg/L with a mean of 0.057 mg/L and SD of 0.077 (summer season), and from 0.02 to 0.069 mg/L with a mean of 0.038 and SD of 0.013 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. In all seasons, the observed values were within the safe limit for livestock drinking when compared with the guidelines by Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3).**

Iron (Fe)

There has been no established guideline for Iron (Fe) in livestock drinking water. Though, it normally does not pose a threat of toxicity, consumption in excessive quantities is always undesirable. If the iron content is above 0.3 ppm in water, then methods for removal of Fe should be adopted, before using it for drinking purposes (Beede, 2006). Fe is an essential as micronutrients for the life of animal diets and it can be harmful in high concentrations (Renza, 2010; DWAF, 1996 c). The dissolution of minerals and rocks mainly impart Fe in natural water. In this study, concentration of Fe in UGC water ranged from 1.151 to 3.922 mg/L with an average of 2.976 mg/L and SD of 0.641 (winter season), from 1.151 to 3.016 mg/L with an average of 2.4281 mg/L and SD of 0.392 (summer season), and from 1.299 to 2.4382 with an average of 1.88 mg/L and SD of 0.354 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. Fe is relatively high in June, July and August months because of rainfall and runoff and house-holdings discharges through the cement-pipes. In all seasons, the observed values of Fe were within the safe limit for livestock drinking as per Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3).**

Mercury (Hg)

Mercury (Hg) can cause acute poisoning, much the same as arsenic (Water Quality for Livestock and Poultry). Among the metals present in environment of farm animals, Hg possesses a very high toxicity. Mercury is not essential to animal nutrition and is not readily absorbed. It can have dangerous effects on the livestock health, especially on the reproductive system (Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996). In this study, UGC water exhibited Hg values ranging from 0.0011 to 0.0211 mg/L with a mean value of 0.0052 mg/L and SD of 0.0066 (winter season), from 0.0012 to

0.0199 mg/L with a mean value of 0.0049 mg/L and SD of 0.0061 (summer season) and from 0.0011 to 0.0222 mg/L with a mean value of 0.0062 mg/L and SD of 0.0071 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. In all three seasons, the observed values were not within the safe limits for livestock drinking when results were compared to the guidelines of Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3).**

Manganese (Mn)

Manganese (Mn) is vital for livestock nutrition, but only 3% ingested manganese is absorbed (ANZECC, 2000; CCME, 2005, 2008; Olkowski, 2009). There have been no established guideline for Manganese (Mn) in livestock drinking water. Manganese is commonly taken along with iron for conveying quality of water (Beede, 2006). Mn is essential as micronutrients for the life of animals (Renza, 2010). An essential element for growth and fertility, Mn is little toxic (or non-toxic) unless taken in excessive quantity (DWAF, 1996 c). In natural surface water, Mn is present as suspended or dissolved matter, but at a very low concentration (0.001-0.6 mg/L), unless polluted. In this study, UGC water exhibited Mn values ranging between 0.035 to 0.214 mg/L with an average of 0.103 mg/L and SD of 0.056 (winter season), from 0.083 to 0.179 mg/L with an average of 0.131 mg/L and SD of 0.027 (summer season), and from 0.062 to 0.149 mg/L with an average of 0.114 mg/L and SD of 0.020 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. In all seasons, the observed values were within the safe limit for livestock drinking **(Table 5.3)**.

Lead (Pb)

Lead (Pb) possesses high toxicity and its accumulation in body above critical amounts may cause poisoning. Pb can even cause death of animals, if consumed in higher quantity. Horses are highly sensitive to lead in comparison to cattle or sheep. The Pb contents in surface water varies significantly based on sources of pollution i.e. sediments, pH, salinity and organic matter content of the water (ANZECC, 2000; CCME, 2005,2008; DWAF (1996 c; Olkowski, 2009).In this study, the concentration of Pb ranged between 0.0116 to 0.0569 mg/L with an average of 0.029 mg/L and SD of 0.012 (winter season), from 0.0221 to 0.0989 mg/L with an average of 0.035 mg/L and SD of 0.017 (summer season), and from 0.111 to 0.045 mg/L with an average of 0.023 mg/L and SD of 0.01 (monsoon season) (**Tables 5.4, 5.5 and 5.6)**. In all seasons, the observed values were within the safe limit for livestock drinking when compared with the guidelines by Food and

Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3).**

Zinc (Zn)

Zinc (Zn) is essential as micronutrients for the life of animals (Renza, 2010). Normal growth and development of all animals requires adequate levels of dietary zinc (Water Quality for Livestock and Poultry). It is a crucial constituent of livestock food as it maintains the metabolism of proteins, nucleic acids and carbohydrates. The specified effects of Zinc toxicity over livestock health have not been properly characterized. However, its concentration in livestock drinking water should be less than 50.0 mg/L (DWAF, 1996 c). In this study, UGC water exhibited the Zn contents between 0.0723 to 2.074 mg/L with an average of 1.061 mg/L and SD of 0.521 (winter season), from 0.57 to 3.1405 mg/L with an average of 1.28 mg/L and SD of 0.773 (summer season), and from 0.37 to 1.954 mg/L with the average value of 0.871 mg/L and SD of 0.478 (monsoon season) (**Tables 5.4, 5.5 and 5.6).** The main reason for high Zn is because of corrosion in the discharging cement-pipes. In all seasons (Table 7), the observed values were within the safe limit for livestock drinking when compared with the guidelines by Food and Agriculture Organization (Ayers and Westcott, 1985, 2015), CCME (2005, 2008), ANZECC (2000), and DWAF (1996) **(Table 5.3).**

Table 5.4: Observed values of the toxic trace metals for winter season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.532	0.134	0.131	0.152	0.165	0.236	0.153	0.136	0.136	0.166	2.327	0.166	0.136	0.186	0.186	1.184	1.168	2.157	0.131	2.327	0.525	0.707
As	0.002	0.003	0.003	0.014	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.014	0.0045	0.0038
Cd	0.001	0.001	0.002	0.005	0.009	0.001	0.003	0.002	0.002	0.002	0.006	0.001	0.019	0.003	0.005	0.002	0.001	0.006	0.001	0.019	0.004	0.004
Co	0.035	0.035	0.036	0.056	0.085	0.037	0.064	0.038	0.039	0.039	0.040	0.040	0.041	0.041	0.042	0.042	0.042	0.042	0.035	0.085	0.044	0.012
Cr	0.021	0.027	0.028	0.042	0.030	0.028	0.037	0.029	0.029	0.029	0.041	0.025	0.032	0.087	0.081	0.080	0.030	0.039	0.021	0.087	0.040	0.020
Cu	0.047	0.037	0.031	0.037	0.020	0.067	0.063	0.051	0.036	0.059	0.051	0.059	0.057	0.061	0.071	0.064	0.077	0.092	0.020	0.092	0.054	0.018
Fe	1.151	1.973	2.962	3.922	3.911	2.972	3.918	2.978	2.971	2.973	2.973	2.974	2.983	2.982	2.983	2.983	2.976	2.986	1.151	3.922	2.976	0.641
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0211	0.0022	0.0011	0.0028	0.0034	0.0039	0.0021	0.0022	0.0011	0.0012	0.0023	0.0021	0.0011	0.0211	0.0052	0.0066
Mn	0.035	0.043	0.056	0.213	0.214	0.045	0.213	0.070	0.055	0.097	0.098	0.097	0.102	0.102	0.105	0.106	0.102	0.106	0.035	0.214	0.103	0.056
Pb	0.012	0.020	0.021	0.057	0.050	0.021	0.055	0.024	0.024	0.024	0.024	0.024	0.029	0.029	0.030	0.029	0.024	0.029	0.012	0.057	0.029	0.012
Zn	0.567	0.621	0.072	2.054	2.064	0.801	2.074	0.822	0.861	0.986	1.013	1.013	1.023	1.023	1.034	1.034	1.012	1.021	0.072	2.074	1.061	0.521

Table 5.5: Observed values of the toxic trace metals for summer season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.134	0.234	0.335	1.152	1.165	0.336	1.153	0.446	0.456	0.548	0.547	0.548	0.766	0.757	0.859	0.735	0.548	0.843	0.134	1.165	0.642	0.311
As	0.002	0.003	0.003	0.014	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.013	0.0041	0.0035
Cd	0.002	0.002	0.003	0.008	0.008	0.003	0.008	0.003	0.004	0.004	0.004	0.004	0.007	0.007	0.007	0.007	0.004	0.006	0.002	0.008	0.005	0.002
Co	0.035	0.040	0.041	0.078	0.085	0.043	0.085	0.046	0.046	0.051	0.051	0.051	0.052	0.052	0.051	0.050	0.051	0.051	0.035	0.085	0.053	0.014
Cr	0.021	0.024	0.024	0.092	0.086	0.026	0.098	0.028	0.038	0.038	0.038	0.046	0.048	0.049	0.047	0.046	0.039	0.048	0.021	0.098	0.046	0.023
Cu	0.023	0.035	0.065	0.073	0.036	0.176	0.040	0.051	0.049	0.049	0.092	0.053	0.042	0.045	0.044	0.052	0.052	0.053	0.023	0.176	0.057	0.033
Fe	1.151	2.329	2.337	2.429	2.336	2.556	2.922	2.322	2.416	2.416	2.413	2.413	2.414	3.007	3.016	2.413	2.412	2.414	1.151	3.016	2.429	0.392
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0199	0.0022	0.0012	0.0028	0.0034	0.0039	0.0021	0.0022	0.0012	0.0012	0.0023	0.0021	0.0012	0.0199	0.0049	0.0061
Mn	0.103	0.083	0.116	0.179	0.172	0.171	0.113	0.106	0.104	0.127	0.157	0.138	0.108	0.132	0.133	0.131	0.137	0.154	0.083	0.179	0.131	0.027
Pb	0.022	0.024	0.024	0.042	0.099	0.026	0.048	0.029	0.030	0.030	0.030	0.030	0.033	0.034	0.035	0.034	0.030	0.034	0.022	0.099	0.035	0.017
Zn	0.570	0.762	0.788	2.986	3.141	0.798	2.606	0.888	0.888	0.988	0.988	0.988	0.889	1.122	1.122	1.223	1.111	1.121	0.570	3.141	1.277	0.775

Table 5.6: Observed values of the toxic trace metals for monsoon season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
Al	0.131	0.142	0.142	1.106	1.142	0.152	1.175	0.204	0.205	0.324	0.324	0.324	0.326	0.329	0.329	0.326	0.326	0.326	0.131	1.175	0.407	0.347
As	0.002	0.003	0.003	0.017	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.017	0.0051	0.0042
Cd	0.001	0.001	0.001	0.004	0.005	0.002	0.004	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.005	0.005	0.004	0.004	0.001	0.005	0.003	0.001
Co	0.025	0.020	0.021	0.064	0.065	0.021	0.065	0.021	0.021	0.021	0.021	0.022	0.031	0.031	0.032	0.032	0.023	0.026	0.020	0.065	0.031	0.016
Cr	0.020	0.024	0.025	0.055	0.054	0.026	0.053	0.026	0.026	0.029	0.029	0.029	0.035	0.037	0.037	0.036	0.030	0.034	0.020	0.055	0.033	0.011
Cu	0.020	0.022	0.023	0.056	0.069	0.027	0.063	0.028	0.030	0.038	0.041	0.040	0.035	0.035	0.038	0.039	0.043	0.039	0.020	0.069	0.038	0.013
Fe	1.299	1.363	1.377	2.424	2.244	1.387	2.438	1.767	1.777	1.823	1.815	1.828	2.019	2.088	2.142	2.089	1.839	2.158	1.299	2.438	1.882	0.354
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0222	0.0022	0.0011	0.0028	0.0034	0.0039	0.0021	0.0022	0.0011	0.0012	0.0023	0.0021	0.0011	0.0222	0.0062	0.0071
Mn	0.062	0.086	0.115	0.149	0.135	0.088	0.145	0.112	0.114	0.115	0.116	0.115	0.020	0.021	0.022	0.021	0.119	0.115	0.020	0.149	0.093	0.044
Pb	0.011	0.015	0.016	0.042	0.041	0.015	0.045	0.017	0.019	0.021	0.021	0.021	0.023	0.024	0.024	0.022	0.016	0.024	0.011	0.045	0.023	0.010
Zn	0.370	0.551	0.588	1.873	1.834	0.592	1.954	0.677	0.678	0.688	0.688	0.688	0.776	0.756	0.777	0.738	0.688	0.758	0.370	1.954	0.871	0.478

Overall, it can be concluded that the UGC water constituents are moderately variable with respect to the toxic trace metals in all the three seasons during November 2014 to October 2015. Based on the average values of trace metal concentrations in mg/l, it can be observed from **Tables 5.4, 5.5 and 5.6** that, Fe and Cd are the most and the least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Co > Cr > Pb > Hg > As > Cd, during winter season; similarly Fe and As are the most and the least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Co > Cr > Pb > Cd > Hg > As, during the summer season; Fe and Cd are the most and the least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Cr > Co > Pb > Hg > As > Cd during the monsoon season. For most of the sites, the parameters are within the permissible limits of reliable standards and hence, are suitable for livestock drinking purposes. However, the sites S4, S5 and S7 possess higher concentration of trace metals and thus, water from these sites should be avoided for livestock drinking, unless treated before being used.

5.3.3 Water Quality Index

WQI is a robust measure to express the condition of water quality. A WQI value of zero represents absolute absence of pollutants; when WQI < 100 shows that the water is under consideration and fits for utilization and when WQI > 100 indicates its unsuitability for use (Gadekar et al., 2012; Pandey & Madhuri, 2014). The weighted arithmetic of WQI is computed to assess the water quality of the UGC, Roorkee, to classify the water quality based on the degree of purity by using the standard variables. An example (for site S1) of calculation of WQI for livestock drinking is provided in **Table 5.7**. The WQI results for all sites considering the physicochemical parameters are presented in **Table 5.8** and that of considering toxic trace metals are also presented in **Table 5.9**. The overall WQI at all the sites considering both physicochemical and toxic trace metals together, for all the three seasons are presented in **Table 5.10**.

Table 5.7: An example for calculation of WQI for livestock drinking (at site S1 during winter season)

Parameter	**Measured value (V_{actual}) for site S1**	**Permissible Limit for Livestock**	**Relative Weight (Wi)**	**Quality Rating (Q_i)**	**Weighted Value**
EC	200	1500.00	0.001	13.333	0.009
TDS	128	1000.00	0.001	12.8	0.013
Ca	42	1000	0.001	4.2	0.004
SO_4	94.5	1000	0.001	9.45	0.009
NO_3	4.3	100	0.01	4.3	0.043
B	0.453	5	0.2	9.06	1.812
Al	0.532	5	0.2	10.64	2.128
As	0.002	0.2	5	1	5
Cd	0.001	0.05	20	2	40
Co	0.035	1	1	3.5	3.5
Cr	0.021	1	1	2.11	2.11
Cu	0.047	0.5	2	9.4	18.8
Hg	0.0021	0.01	100	21	2100
Mn	0.035	0.05	20	70	1400
Pb	0.012	0.1	10	11.6	116
Zn	0.567	24	0.042	2.364	0.099
			$\sum Wi$ = 159.455		$\sum WiQi$ = 3689.527
$\sum WiQi / \sum Wi$ = 23.14					

The detailed calculation procedure of WQI considering 16 parameters (physicochemical and toxic trace metals) over site S1 during winter season is provided in **Table 5.7**. It can be observed that the relative weight of a parameter is reciprocal to its permissible limit. Thus, the relative weight of Mercury (Hg) is very high (equal to 100) compared to all other parameters, owing to its lowest permissible limit. The WQI value obtained by the weighed arithmetic method is 23.14, which shows the quality of water to be excellent.

Table 5.8: WQI of Physicochemical parameters for Livestock drinking purpose

Site Code	Winter	Summer	Monsoon
S1	8.85	10.26	12.77
S2	10.98	11.94	13.86
S3	12.83	12.58	13.47
S4	18.36	24.38	17.88
S5	19.31	26.32	17.71
S6	13.32	12.75	13.49
S7	18.50	24.45	18.73
S8	15.94	12.78	14.02
S9	15.90	13.92	14.23
S10	15.89	15.84	15.56
S11	15.93	15.82	15.55
S12	15.91	15.81	15.53
S13	15.95	16.69	15.52
S14	18.05	17.59	15.94
S15	29.09	16.50	16.51
S16	15.98	16.31	17.55
S17	15.92	15.98	15.49
S18	16.86	16.16	15.73
Min	8.85	10.26	12.77
Max	29.09	26.32	18.73
Avg	16.58	16.63	15.55
SD	4.14	4.43	1.69

The WQI values obtained at all the sampling sites in different seasons (winter, summer and monsoon), considering only physicochemical parameters for irrigation purpose are presented in **Table 5.8.** The WQI ranged from 8.85 to 29.09 with a mean of 16.58 and SD of 4.14 for winter season, from 10.26 to 26.32 with an average of 16.63 and SD of 4.43 for summer season, and from 12.77 to 18.73 with the average value of 15.55 and SD value of 1.69 for monsoon season. It can be noticed that the sites S4, S5 and S7 possessed highest WQI during winter, summer and monsoon seasons respectively. On the other hand, S1 had lowest WQI values during all the seasons, taking only physicochemical parameters.

Table 5.9: WQI of toxic trace metals for Livestock drinking purpose

Site Code	Winter	Summer	Monsoon
S1	23.16	41.08	29.82
S2	30.76	41.23	41.12
S3	34.74	50.48	49.10
S4	179.18	170.72	162.11
S5	173.19	165.52	151.89
S6	35.25	67.86	45.68
S7	190.69	166.33	173.19
S8	33.49	43.23	43.67
S9	22.80	36.15	37.41
S10	44.08	52.59	48.72
S11	49.19	63.99	52.75
S12	50.90	62.27	55.64
S13	45.52	44.38	20.98
S14	42.18	51.11	21.74
S15	36.60	44.49	15.36
S16	36.68	44.56	15.60
S17	42.16	51.98	46.54
S18	43.37	55.75	44.76
Min	22.80	36.15	15.36
Max	190.69	170.72	173.19
Avg	66.37	73.03	62.23
SD	55.44	45.82	49.46

The WQI values obtained at all the sampling sites in different seasons (winter, summer and monsoon), considering only toxic trace metals for livestock drinking purpose are presented in **Table 5.9.** The WQI ranged from 22.8 to 190.69 with a mean of 66.37 and SD of 55.44 for winter season, from 36.15 to 170.72 with an average of 73.03 and SD of 45.82 for summer season, and from 15.36 to 173.19 with the average value of 62.23 and SD value of 49.46 for monsoon season. It can be noticed that the site S7 had highest WQI during winter and monsoon seasons, whereas S4 had highest WQI values during summer season. On the contrary, the sites S9 possessed lowest WQI during winter and summer season. Similarly, S15 had lowest WQI during monsoon season. The limiting value of WQI is 100 for its suitability for livestock drinking. However, the sites S4, S5 and S7 possessed WQI values above 100 during all the three seasons. Hence, for all the sites except S4, S5 and S7, the UGC water is suitable for livestock drinking, considering the toxic trace metals.

Table 5.10: WQI of physicochemical and toxic trace metals for Livestock drinking purpose

Site Code	Winter	Summer	Monsoon
S1	23.14	41.04	29.80
S2	30.73	41.19	41.08
S3	34.71	50.43	49.05
S4	178.97	170.52	161.91
S5	172.98	165.34	151.71
S6	35.22	67.79	45.64
S7	190.46	166.14	172.99
S8	33.47	43.19	43.63
S9	22.79	36.12	37.38
S10	44.04	52.54	48.68
S11	49.14	63.93	52.70
S12	50.86	62.21	55.59
S13	45.48	44.34	20.97
S14	42.14	51.07	21.73
S15	36.59	44.45	15.36
S16	36.65	44.53	15.61
S17	42.12	51.93	46.49
S18	43.33	55.70	44.72
Min	22.79	36.12	15.36
Max	190.46	170.52	172.99
Avg	66.30	72.95	62.17
SD	55.37	45.77	49.39

From **Table 5.10**, it can be noticed that the overall WQI values (considering both physicochemical parameters and toxic trace metals) of the UGC water sites ranged from 22.79 to 190.46 with a mean value of 66.30 and SD of 55.37 for winter season, from 36.12 to 170.52 with an average of 72.95 and SD of 45.77 for summer season, and from 15.36 to 172.99 with the average value of 62.17 and SD value of 49.39 for monsoon season. The site S7 for winter as well as monsoon seasons and site S4 for summer season possessed highest value of WQI, which is indicative of highest pollution amongst all the sites. On the other hand, S9 during winter as well as monsoon and S15 during summer season were the least polluted sites, based on WQI values. The limiting value for the water to be suitable for livestock drinking is 100, which is exceeded by the sites S4, S5 and S7 during all the three seasons. For all other sites, the WQI values are much lesser. This reflects that the surface canal water at all the sampling sites except the three sites (S4, S5 and S7) is suitable for livestock drinking purposes.

5.3.4 Correlation Matrix

The relationship among different toxic trace metals for irrigation water quality were established by the Pearson correlation matrix for winter, summer and monsoon seasons are presented in **Tables 5.11, 5.12 and 5.13** respectively. The statistical analysis showed the correlation among different irrigation indices to be both positive and negative. Significant correlations were found among the irrigation indices at $p > 0.05$ level and at $p < 0.01$ level. The season wise discussions on intra-correlation of trace metals relevant to livestock drinking are presented below.

The correlation matrix for toxic trace metals during winter season is presented in **Table 5.11**. Results show that some toxic trace metals have poor correlations during winter, except correlations between Fe, Hg, Mn, Pb and Zn elements. These metals possess a very good correlation amongst them. On the contrary, the elements like Al, As, Cd, Cr, Co and Cu possess a little or mediocre correlation amongst themselves. However, a significant correlation of Arsenic is observed with Fe ($r = 0.65$), Hg ($r = 0.76$), Mn ($r = 0.77$), Pb ($r = 0.81$) and Zn ($r = 0.77$). Similarly, Cobalt also had a significant correlation with Fe ($r = 0.69$), Hg ($r = 0.74$), Mn ($r = 0.88$), Pb ($r = 0.85$) and Zn ($r = 0.86$) (**Table 5.11**). These correlations were significant at $p>0.01$ level.

The correlation matrix for toxic trace metals during summer season is presented in **Table 5.12**. It can be observed that only Cu element do not show any significant correlation as with respect to other trace metals. This indicates that Copper is the non-sensitive metal during summer season over the samples from UGC, Roorkee. Other metals are fairly correlated amongst themselves with the highest between Co and Zn ($r = 0.966$) as well as between Al and Cd ($r = 0.954$).

Table 5.11: Pearson Correlation Coefficient Matrix of toxic trace metals in the UGC, Roorkee the during winter season

Parameters	*Al*	*As*	*Cd*	*Co*	*Cr*	*Cu*	*Fe*	*Hg*	*Mn*	*Pb*	*Zn*
Al	1										
As	-0.0967	1									
Cd	0.03068*	0.0857*	1								
Co	-0.138	0.733**	0.3381*	1							
Cr	0.11121*	0.338*	-0.008	-0.002	1						
Cu	0.46972*	-0.215	-0.053	-0.327	0.3182*	1					
Fe	-0.0833	0.6473**	0.2817*	0.692**	0.1669*	-0.0444	1				
Hg	-0.0326	0.7645**	0.4235*	0.737*	0.4684*	0.076*	0.7376**	1			
Mn	-0.0451	0.7673**	0.3465*	0.881**	0.1653*	-0.1041	0.8098**	0.904*	1		
Pb	-0.1616	0.8133**	0.312*	0.847**	0.1682*	-0.168	0.8333**	0.913*	0.9645**	1	
Zn	-0.0676	0.7672**	0.3146*	0.862**	0.1196*	-0.0728	0.7371**	0.8599**	0.9465**	0.9313**	1

Note: The strikes *and ** indicate that the correlations are significant at the level $p < 0.05$ and $p < 0.01$ respectively.

Table 5.12: Pearson Correlation Coefficient Matrix of toxic trace metals in the UGC, Roorkee during the summer season

Parameters	*Al*	*As*	*Cd*	*Co*	*Cr*	*Cu*	*Fe*	*Hg*	*Mn*	*Pb*	*Zn*
Al	1										
As	0.7886**	1									
Cd	0.9543**	0.6725**	1								
Co	0.9097**	0.9425**	0.7907**	1							
Cr	0.9365**	0.9129**	0.8521**	0.9773**	1						
Cu	-0.174	-0.1389	-0.2	-0.1346	-0.179	1					
Fe	0.5309**	0.1755**	0.5436**	0.3775*	0.3873*	0.1795**	1				
Hg	0.7128**	0.4891*	0.6412**	0.6505**	0.6201**	0.1456*	0.753**	1			
Mn	0.5033**	0.411*	0.4199*	0.4737*	0.4394*	0.5441	0.21*	0.44*	1		
Pb	0.7119**	0.8336**	0.6256**	0.7995**	0.7197**	-0.196	0.161*	0.453*	0.454*	1	
Zn	0.8562**	0.9781**	0.7346**	0.9663**	0.9443**	-0.113	0.254*	0.578**	0.514**	0.817**	1

Note: The strikes *and ** indicate that the correlations are significant at the level $p < 0.05$ and $p < 0.01$ respectively.

The correlation matrix for toxic trace metals during monsoon season is presented in **Table 5.13**. It can be observed that, during monsoon season, all the toxic trace metals are significantly correlated at $p<0.05$ and $p<0.01$ levels, except between Cd and Mn which are negatively correlated (r = -0.186). The metals As, Fe and Pb possess a very strong correlation ($p<0.01$ level) with respect to all metals considered for livestock drinking.

Table 5.13: Pearson Correlation Coefficient Matrix of toxic trace metals in the UGC, Roorkee during the monsoon season

Parameters	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Pb	Zn
Al	1										
As	0.9917**	1									
Cd	0.5606**	0.4871*	1								
Co	0.9714**	0.9778**	0.5558**	1							
Cr	0.9547**	0.9337**	0.7297**	0.9572**	1						
Cu	0.9326**	0.8918**	0.741**	0.8592**	0.9179**	1					
Fe	0.7707**	0.713**	0.8731**	0.7468**	0.8802**	0.8382**	1				
Hg	0.9495**	0.918**	0.7741**	0.9359**	0.986**	0.94754**	0.8991**	1			
Mn	0.4649**	0.4799*	-0.186	0.3031*	0.2509*	0.42406*	0.0971**	0.264*	1		
Pb	0.9718**	0.955**	0.6316**	0.949**	0.9747**	0.91865**	0.8578**	0.9556**	0.3701*	1	
Zn	0.9912**	0.9909**	0.5274**	0.9698**	0.9544**	0.90309**	0.764**	0.9326**	0.4725*	0.9742**	1

Note: The strikes *and ** indicate that the correlations are significant at the level $p < 0.05$ and $p < 0.01$ respectively.

This correlation analysis reveals that sensitivity of trace metals varies with seasonal changes. A high sensitivity was observed in monsoon season as all the metals are strongly correlated. It was comparatively lesser for summer season and least for winter season. Especially for Al and Cu elements, the seasonal variation was remarkable.

Apart from the canal, it is vital to study the groundwater, pond and well water around the study area for all the physicochemical and biological or microbiological parameters for livestock drinking water quality, especially at the downstream of the Upper Ganga Canal area which is relatively plain area with unlined canal and slow water velocity, because the base of the UGC from Civil Lines in Roorkee city up to the downstream sampling sites is not lined or cemented and there may be a higher water seepage and evaporation. Also, since the left side of the UGC starting from Piran Kaliyar up to the downstream (branched canals) is covered by densely weeds (such as Hyacinth), grasses, bushes and big trees, shaded leaves, perished food, vegetables & fruits, other solid waste materials and deposited human defected, sewages discharge from motor cycle garages. During monsoon season, the runoff carries all oils and other waste materials from the road along the UGC into the canal water and finally aggravates the pollution of the canal. Therefore, canal water shall be fenced and lined with pavements to protect it from any such problems.

5.4 Conclusions

The Upper Ganga Canal water was evaluated for livestock drinking purpose. A total of 18 sampling sites were located in Upper Ganga Canal. Based on the analysis, following conclusions are drawn from the present study:

1. All the physicochemical parameters considered were within the permissible limits for livestock drinking purposes.
2. The toxic trace metals in the UGC water were within the permissible limits during all the three seasons for livestock drinking purposes, at all the sites except at S4, S5 and S7. In these three sites, some metals exceed the allowable limits.
3. The overall WQI values of the UGC water sites ranged from 22.79 to 190.46 with a mean of 66.30 for winter season; from 36.12 to 170.52 with an average of 72.95 for summer season; and from 15.36 to 172.99 with the average value of 62.17 for monsoon season. However, the sites S4, S5 and S7 had WQI values above 100 in all the seasons, whereas it was much lesser for other sites.
4. The correlation analysis revealed that sensitivity of trace metals varies with seasonal changes. A high sensitivity was observed in monsoon season as all the metals are strongly correlated. It was comparatively lesser correlated for summer season and least for winter season.

CHAPTER 6

WATER QUALITY ASSESSMENT OF UPPER GANGA CANAL FOR HUMAN DRINKING

This chapter presents a detailed water quality analysis of the Upper Ganga Canal (UGC) water for assessing its suitability pertaining to human drinking purposes. The relevant physicochemical variables and toxic trace metals in UGC water are computed and compared with the authentic Standards and guidelines. Their effects pertaining to human drinking are also discussed. Water Quality Index, which is acclaimed as a robust indicator of overall water quality, is computed for all the three seasons (winter, summer and monsoon) of a year, considering the effects of physicochemical parameters and toxic trace metals, separately as well as in combined form.

6.1 Introduction

Water is indispensable for the existence of all living organisms, including human beings. Water is involved in many of the daily human activities, e.g. drinking, bathing, cooking, washing, etc. (Choudhary et al., 2014). According to Kundu (2012) and Tomar (1999), utilization of water for various activities depends on its physical, chemical and biological characteristics. Its uses for drinking, agriculture, domestic purposes, industrial activities, transport, power generation and recreation show the extent to which water is an integral part of life. Thus, the availability of adequate water supply in terms of its quality and quantity is essential for the existence of life. Almost 97% of total water in the globe lies in oceans and are unsuitable for drinking. Remaining 3% is freshwater, of which, a majority (i.e. 2.7% of the global water) is in the form of glaciers or ice caps. Only 0.3% exists as ground and surface water for human use. Safety of drinking water is a preliminary requirement for good health. The availability of freshwater is already a thought-provoking concern in various parts of the globe. The situation is predicted to be further detrimental in the future, driven by urbanization, population explosion and climate change (Mohsin et al., 2013).

The major resources of freshwater include rivers, lakes, reservoirs, streams etc., which are also the sources of canal waters (Michael, 1978). Today, water pollution is largely a problem due to rapid urbanization and industrialization (Srivastava et. al., 2011). Water resources are polluted so much that 70% of rivers and streams not only of India but also of many countries contain polluted waters. The river and the canal water are under threat due to undesired alterations in biological as well as physico-chemical nature of water, air and soil. According to Goel (2006), the pollution of water is on the increase and has become a global challenge in recent times. The industry, agriculture and human activities have proven to be the main causes as well as the victims.

Canal system is one of the important requirements of modern civilization for the sustainable utilization of water in river basins (Matta, 2014) and they may be polluted by various means. The Upper Ganga Canal (UGC) system around Roorkee is originated from the River Ganga. The current head discharge in the canal is 295 cumecs, which facilitates irrigation to an area of 20 lakh ha. The UGC system consists of a main canal of 291 kilometers and 428 kilometers long distribution channels. The agricultural lands of Uttarakhand and Western Uttar Pradesh (9000 km^2) are benefitted by irrigation through this canal system (Mishra et al., 2013; Sharma and Singh, 2011; NRCD, 2009). People from Delhi, Ghaziabad, Noida, etc. utilize the UGC water for drinking purposes. The water demand for drinking purposes is huge in its associated districts, which is growing day-by-day. Moreover, many industries, mainly the thermal power plants, set up in these cities also use water from this canal. Looking to the aforementioned issues, the present investigation has been carried out to assess the physicochemical parameters and trace metals relevant to water quality of Upper Ganga Canal, Roorkee, for human drinking purpose. The concentration of these physicochemical parameters and trace metals are to be compared with the authentic standards/guidelines. The pollution status of the canal at different sampling sites was also determined using Water Quality Index (WQI).

6.2 Data and Methods

In this study, water samples were collected from eighteen sites i.e., S1, S2, S3,…, S17 and S18, at monthly interval for a period of one year (from November 2014 to October 2015) with the aim of understanding the seasonal (winter, summer, and monsoon) variation. The water samples were analyzed in laboratory for obtaining the concentration of physicochemical parameters and toxic trace metals. The data obtained from this laboratory analysis is compared with respect to the reliable standards and guidelines for human drinking purposes.

The detailed procedure for collection of water samples and brief description of physicochemical parameters as well as the toxic trace metals is provided in **Section 3.2** of the **Chapter 3**. The instruments and detailed laboratory procedures to obtain the physicochemical parameters and toxic heavy metals from the water samples are presented in **Annexure A**. The data obtained for physicochemical parameters at monthly level are presented in **Annexure B** (Tables B1 to B13). The seasonal data converted from these monthly observations over all the 18 sites are presented for winter, summer and monsoon season in **Tables 3.3, 3.4 and 3.5** respectively. Similarly, for toxic trace metals, the seasonal observations and the statistical summary for winter, summer and monsoon seasons are given in **Tables 3.7, 3.8 and 3.9** respectively (**Chapter 3**). The heavy metals i.e. Zn, Hg, Pb, Mn, Fe, Cu, Cr, Cd, As and Al have been identified as toxic substances causing adverse effects on human drinking waters. The water quality may even alter naturally, but contamination due to anthropogenic activities is the usual factor impairing water quality. The human practices leading to water pollution has already become a giant societal concern (Claude, 2000). Goel (2006) categorized the adverse effects of water pollution as physicochemical and biological effects of pollution. These trace metals are selected in this study for analysis as they are good up to some extent, but become toxic and have harmful effects on human beings, if exceeds the limit.

Water quality Index (WQI) represents the state of complex water quality data in a simple numerical value, which can be easily understood and used by public. It expresses overall water quality based on several water quality parameters. A WQI value less than 100 is considered usable for a specific application, considering the relevant permissible limits for each influential parameter. The WQI for all the sampling sites over UGC, Roorkee during all the three seasons is also determined by considering the physicochemical parameters and toxic trace metals separately as well as in combined form, of which, the later represents the overall water quality. The computation procedure and explanations of WQI is presented in **Section 3.5** of **Chapter 3** (Materials and Methods). The standards and guidelines by Bureau Indian Standards (IS 10500: 2012), are presented in **Table 3.12** of **Chapter 3**, which are used for taking the limiting values of different parameters to compute WQI for human drinking.

6.3 Results and Discussions

6.3.1 Physicochemical Parameters

The physicochemical parameters relevant to human drinking are considered and compared with respect to the authentic international standards/guidelines. These parameters are pH, electrical conductivity, total dissolved solids, total alkalinity, total hardness, cations (Sodium, Potassium, Magnesium and Calcium), anions (Chlorine, sulfate and Nitrate), dissolved oxygen, chemical oxygen demand and Boron. Any alterations in these parameters may significantly affect the suitability of water for human drinking purposes. Therefore, it is necessary to compare the results obtained with the reliable standards. The condition of UGC water in terms of these parameters (analyzed on field and at laboratory) at all the eighteen sampling sites from November 2014 to October 2015, are presented in **Tables 6.1, 6.2 and 6.3** for winter, summer and monsoon seasons respectively. These results were compared to the guidelines by Bureau Indian Standards (IS 10500: 2012), Indian Council Medical Research ICMR (2012), World Health Organization (WHO, 2004) and Environmental Protection Agency (EPA, 2001), to assess suitability for human drinking in all sampling sites of the UGC, Roorkee. The allowable limits of these parameters by the aforementioned standards are presented in **Table 6.4**.

Table 6.1: Observed values of the physicochemical parameters for winter season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
pH	8.300	8.400	8.400	7.100	6.800	8.300	6.900	8.300	8.300	8.300	8.200	8.300	8.300	8.300	8.400	8.300	8.300	8.300	6.800	8.400	8.083	0.534
EC	200.000	187.000	181.000	1316.000	984.000	193.000	985.000	199.000	185.000	182.000	183.000	195.000	186.000	238.000	243.000	242.000	241.000	195.000	181.000	1316.000	351.944	348.878
TDS	128.000	120.000	121.000	826.000	637.000	124.000	636.000	127.000	118.000	116.000	117.000	125.000	119.000	152.000	156.000	155.000	154.000	125.000	116.000	826.000	225.333	221.914
TA	76.250	76.250	83.500	257.500	260.500	79.750	215.250	75.250	73.000	78.500	89.750	83.750	84.750	82.750	81.500	86.500	86.250	86.750	73.000	260.500	108.764	63.185
TH	57.800	64.000	67.500	219.000	364.300	64.300	220.800	60.300	61.800	63.300	60.800	64.000	58.800	56.500	66.800	55.500	58.500	59.800	55.500	364.300	95.767	84.338
Ca	42.000	46.000	41.500	121.000	335.250	43.250	137.500	37.750	39.000	41.000	44.250	36.250	36.000	35.500	44.000	33.000	33.000	34.250	33.000	335.250	65.583	73.458
Mg	15.750	21.500	22.500	98.000	29.000	21.000	83.250	22.500	22.750	22.250	22.250	24.500	25.250	21.000	22.750	28.250	27.500	28.000	15.750	98.000	31.000	22.074
Na	2.825	3.200	2.850	42.300	54.800	4.450	43.000	3.950	2.775	3.175	3.350	3.175	3.175	3.250	3.500	3.525	3.275	3.550	2.775	54.800	10.563	16.808
K	1.400	1.550	1.500	14.650	31.175	2.425	22.250	1.450	1.550	2.550	1.875	1.800	1.975	1.900	2.675	1.950	1.950	2.875	1.400	31.175	5.417	8.451
Cl	16.000	10.750	14.250	117.500	345.000	14.250	148.000	11.500	16.250	15.000	15.250	14.000	18.000	15.750	24.000	11.750	14.750	14.750	10.750	345.000	46.486	83.802
SO_4	94.500	96.750	97.250	89.000	93.500	100.750	176.250	98.000	101.250	102.000	100.000	104.500	100.000	103.250	115.000	103.750	103.000	116.000	89.000	176.250	105.264	18.899
NO_3	4.300	3.875	4.650	1.687	2.360	5.825	2.625	5.975	3.900	3.775	4.150	4.025	2.975	3.350	4.900	3.075	3.000	3.000	1.687	5.975	3.747	1.131
DO	9.720	9.690	9.670	2.160	1.540	9.750	2.110	9.870	9.770	9.690	9.640	9.700	9.510	9.740	9.640	9.850	9.680	9.500	1.540	9.870	8.402	2.979
COD	25.17	39.01	32.98	202.06	491.09	260.88	28.89	22.39	31.59	16.74	26.30	18.48	22.42	16.10	48.53	27.49	22.14	30.49	16.10	491.09	75.71	123.45
B	0.453	0.568	0.665	0.936	0.988	0.688	0.947	0.828	0.831	0.831	0.832	0.831	0.836	0.946	1.531	0.836	0.833	0.884	0.453	1.531	0.848	0.218

Table 6.2: Observed values of the physicochemical parameters for summer season

Parameter (mg/L)	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**Min**	**Max**	**Avg**	**SD**
pH	7.800	7.700	7.800	7.400	7.100	7.600	7.300	7.800	7.800	7.800	7.700	7.700	7.600	7.700	7.700	8.000	7.800	7.700	7.100	8.000	7.667	0.211
EC	198.000	201.000	202.000	1226.000	1237.000	209.000	1029.000	208.000	180.000	195.000	164.000	180.000	243.000	161.000	249.000	168.000	196.000	170.000	161.000	1237.000	356.444	374.537
TDS	127.000	129.000	129.000	653.000	713.000	134.000	679.000	133.000	115.000	124.000	105.000	115.000	155.000	103.000	160.000	108.000	125.000	108.000	103.000	713.000	217.500	214.394
TA	52.750	62.530	72.500	100.850	177.250	66.500	110.500	65.250	67.750	69.750	71.250	70.250	74.250	70.750	90.250	88.550	72.500	70.250	52.750	177.250	80.760	27.856
TH	64.500	67.800	71.500	202.300	247.800	67.800	224.500	65.800	65.000	66.300	65.300	65.300	66.300	65.500	76.000	66.800	64.800	65.500	64.500	247.800	93.267	61.123
Ca	43.000	43.500	44.200	132.500	173.750	42.500	136.250	42.000	45.500	42.250	42.000	42.250	43.750	44.250	53.750	41.750	43.250	42.000	41.750	173.750	61.025	40.645
Mg	21.500	28.000	23.500	69.750	74.000	25.250	88.250	23.750	19.500	24.000	23.250	23.000	22.500	21.250	22.250	25.000	21.500	22.500	19.500	88.250	32.153	21.134
Na	1.175	1.900	2.800	12.400	16.800	2.450	13.320	1.050	1.475	2.900	3.250	3.325	1.975	2.450	1.900	2.075	2.075	2.075	1.050	16.800	4.189	4.704
K	1.650	2.225	1.675	20.250	13.000	1.475	28.075	1.225	1.400	1.850	1.225	1.500	1.650	1.925	4.750	1.450	1.450	1.650	1.225	28.075	4.913	7.639
Cl	15.750	16.750	17.000	119.000	169.000	16.750	141.250	16.500	16.250	17.000	17.500	17.500	17.500	17.750	22.750	19.750	18.000	16.200	15.750	169.000	38.456	48.933
SO_4	219.750	143.750	126.000	209.500	205.250	86.500	193.750	105.250	117.000	92.000	85.500	82.250	85.500	79.750	94.250	84.000	76.250	87.000	76.250	219.750	120.736	50.746
NO_3	4.500	6.250	4.150	4.692	5.062	3.625	6.542	3.725	3.875	3.900	4.075	3.500	3.850	3.600	9.875	3.800	4.050	4.150	3.500	9.875	4.623	1.566
DO	8.770	9.050	9.020	2.510	1.520	8.950	2.240	9.020	9.120	9.260	9.220	9.280	9.280	9.120	9.380	8.760	8.760	8.900	1.520	9.380	7.898	2.685
COD	2.98	3.09	3.55	218.73	295.98	170.75	18.86	3.00	8.73	20.88	21.21	16.61	29.26	6.98	15.85	4.55	6.15	5.24	2.98	295.98	47.35	86.47
B	0.525	0.612	0.652	1.252	1.352	0.663	1.253	0.664	0.725	0.828	0.827	0.828	0.872	0.923	0.846	0.854	0.835	0.845	0.525	1.352	0.853	0.226

Table 6.3: Observed values of the physicochemical parameters for monsoon season

Parameter (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	SD
pH	7.300	7.200	7.000	7.100	7.300	7.300	7.500	7.200	7.100	7.400	7.300	7.400	7.300	7.200	7.100	7.400	7.500	7.400	7.000	7.500	7.278	0.144
EC	166.000	198.000	153.000	1020.000	667.000	205.000	1064.000	224.000	209.000	213.000	256.000	215.000	246.000	250.000	240.000	200.000	213.000	219.000	153.000	1064.000	331.000	281.008
TDS	106.000	127.000	98.000	734.000	427.000	131.000	681.000	143.000	133.000	136.000	168.000	142.000	158.000	160.000	153.000	127.000	136.000	140.000	98.000	734.000	216.667	192.078
TA	58.750	63.000	63.000	335.000	179.250	62.750	208.750	63.250	61.750	62.250	61.750	62.250	61.750	61.750	138.250	78.750	63.350	64.250	58.750	335.000	97.214	74.205
TH	78.000	78.300	77.000	184.000	178.700	70.300	157.800	73.000	77.300	86.800	82.500	86.000	78.800	72.500	118.800	92.300	87.500	83.800	70.300	184.000	97.967	36.654
Ca	49.750	50.750	51.750	124.450	113.750	52.000	111.750	53.250	54.000	54.250	55.500	54.750	56.000	55.000	68.000	57.000	57.210	55.250	49.750	124.450	65.245	24.077
Mg	28.250	27.550	25.250	59.550	64.900	18.300	46.050	19.750	23.300	32.550	27.000	31.250	22.800	17.500	50.800	35.300	30.290	28.550	17.500	64.900	32.719	13.768
Na	2.200	2.625	2.350	49.125	57.675	3.175	48.200	3.025	2.850	3.275	3.175	3.300	3.400	3.450	10.950	3.050	3.600	3.575	2.200	57.675	11.611	18.615
K	2.850	2.750	2.550	16.350	10.475	2.950	18.150	2.925	3.025	3.300	3.600	3.275	3.300	3.375	11.050	3.400	3.400	3.525	2.550	18.150	5.569	4.918
Cl	22.250	22.550	23.500	103.500	95.750	23.650	120.750	24.750	24.800	24.850	24.950	23.750	25.250	24.950	39.500	27.250	26.250	24.950	22.250	120.750	39.067	31.633
SO_4	110.500	114.750	118.250	139.750	136.750	119.250	144.550	120.750	122.250	127.250	130.250	128.250	132.750	131.750	136.200	136.000	138.750	129.250	110.500	144.550	128.736	9.420
NO_3	1.075	1.500	1.625	3.200	3.825	1.100	5.325	1.325	1.325	1.175	1.175	1.150	1.025	1.200	1.425	1.000	1.075	1.075	1.000	5.325	1.700	1.185
DO	8.560	8.560	8.520	2.510	1.880	8.400	2.190	8.560	8.520	8.440	8.610	8.520	8.280	8.440	8.180	8.520	8.360	8.480	1.880	8.610	7.418	2.409
COD	12.97	12.81	20.88	96.00	272.54	205.19	19.23	24.50	11.54	12.80	30.94	11.22	41.16	48.26	58.66	13.02	7.80	38.47	7.80	272.54	52.11	72.36
B	0.671	0.727	0.707	0.911	0.912	0.708	0.952	0.735	0.747	0.818	0.816	0.816	0.815	0.837	0.867	0.925	0.814	0.827	0.671	0.952	0.811	0.082

Table 6.4: Guidelines and Standards for physicochemical parameters of canal surface water relevant to human drinking

Parameter	Units	BIS (IS 10500: 2012)		ICMR (2012)		WHO (2004)	EPA (2001)
		Desirable Limit	Permissible Limit	Desirable Limit	Permissible Limit	Permissible Limit	Permissible Limit
pH	1-14	6.5-8.5	N. R.	6.5-8.5	5.5 - 8.5	6.5-8.5	5.5 - 8.5
EC	µS/cm	1000	2000	1400	1000	1400	1000
TDS	mg/L	500	2000	500-1500	N. R.	500-1500	-
TA	mg/L	200	600	200	400	200	400
TH	mg/L	200	600	200	500	500	200
Ca	mg/L	75	200	75	N.R	75	-
Mg	mg/L	30	100	30	N. R.	30	-
Na	mg/L	100	200	200	200	200	200
K	mg/L	10	10	12	-	12	-
Cl	mg/L	250	1000	250	250	250	250
SO_4	mg/L	200	400	250	200	250	200
NO_3	mg/L	45	100	50	50	50	50
DO	mg/L	4	6	5	-	5	-
COD	mg/L	10	-	10	40	10	40
B	mg/L	0.5	1	0.5	2	0.5	2

For BIS (2012) and ICMR (1975), a desirable as well as a permissible limit is given in **Table 6.4**. The permissible limits, in these cases, are generally referred to the condition when no alternative source is available. For some cases, N. R. (No Relaxation) is mentioned, which implies that there is no difference between the desirable limit and permissible limit. A brief description of the results obtained and comparison with the authentic standards for individual physicochemical parameters are presented below.

pH

The pH value of the water samples ranged from 6.8 to 8.4 with an average value of 8.1 and SD of 0.53 during the winter season, from 7.1 to 8.0 with an average value of 7.7 and SD of 1.08 during the summer season, and from 7.0 to 7.5 with an average of 7.3 and SD of 0.1 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by BIS (IS 10500: 2012), ICMR (2012) and WHO (2004), the pH values were within the maximum allowable limits of the standards during all the seasons at all the stations and thus, the UGC water was suitable for human consumption (**Figure 6.1 and Table 6.4**).

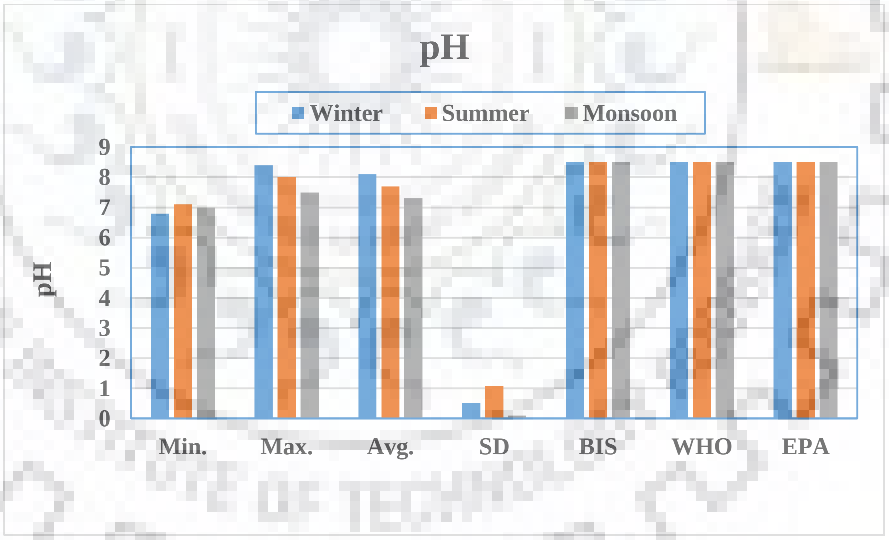


Figure 6.1: Variation of pH Values in winter, summer and monsoon seasons for various samples

Electrical Conductivity (EC)

The EC value of the water samples from the UGC varied between 181 to 1316 µS/cm with an average of 351 µS/cm and ± SD of 348.9 during the winter season; it varied between 161 to 1237 µS/cm with an average of 356 µS/cm ad SD of 375 µS/cm during the summer season; and from 153 to 1064 µS/cm with an average of 331 µS/cm and SD of 281 during the monsoon season (**Tables**

6.1, 6.2 and 6.3). According to the guidelines by BIS (IS 10500: 2012) and WHO (2004), EC was within the permissible limits and thus, UGC water was suitable for human drinking purpose. However, during all the three seasons, results were above the permissible limits of the EPA (2001) guidelines (**Figure 6.2 and Table 6.4**).

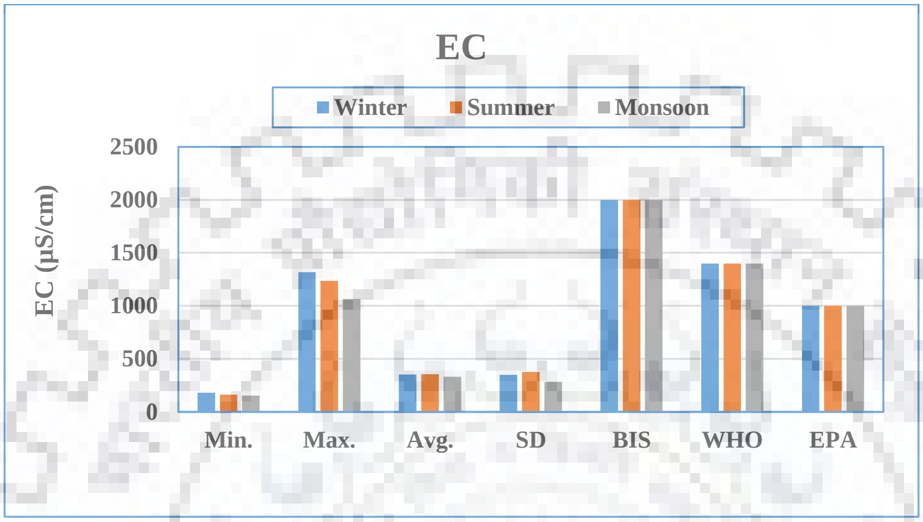


Figure 6.2: Variation of EC (μS/cm) in winter, summer and monsoon seasons for various samples

Total Dissolved Solids (TDS)

The TDS value of the UGC, Roorkee varied from 116 to 826 mg/L with a mean of 225 mg/L and ± SD of 222 during the winter season; from 103 to 715 mg/L with a mean of 218 mg/L and SD of 214 during the summer season; and from 98 to 734 mg/L with a mean of 217 mg/L and SD of 192 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by BIS (IS 10500: 2012), ICMR (2012) and WHO (2004), TDS of the UGC was within the permissible limits during all the seasons (**Figure 6.3 and Table 6.4**) and it was therefore suitable for human drinking.

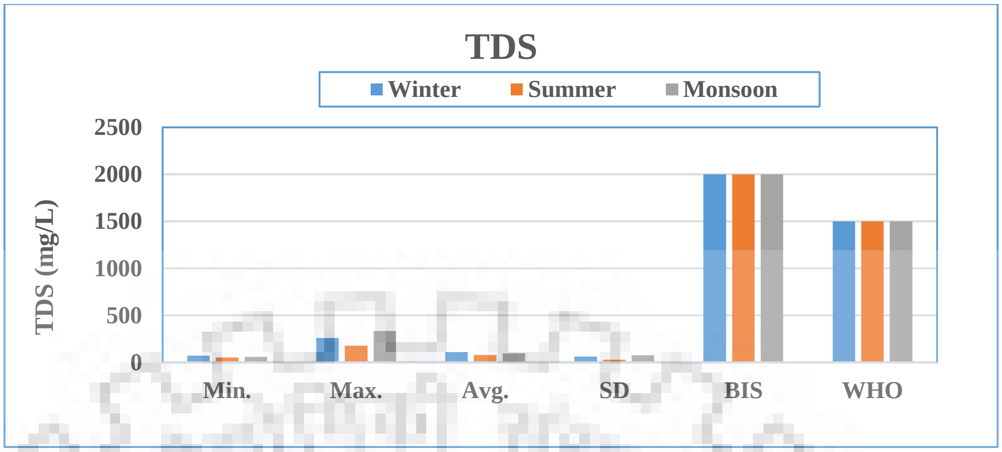


Figure 6.3: Variation of TDS Concentration (mg/L) in winter, summer and monsoon seasons for various samples

Total Alkalinity (TA as $CaCO_3$)

The TA value of the collected water samples ranged between 73 to 260.5 mg/L having respective mean and SD values of 108.7 mg/L and 63.2 respectively during the winter season, between 52.7 to 177.3 mg/L having respective mean and SD values of 80.7 mg/L and 27.8 during the summer season, and between 58.75 to 335 mg/L having respective mean and SD values of 97.2 mg/L and 74.2 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines of BIS (IS 10500: 2012) and EPA (2001), TA values were within the permissible limits during all the seasons and therefore, it was suitable for human drinking. However, it was above the permissible limits by the WHO (2004) Standards during winter and monsoon seasons (**Figure 6.4 and Table 6.4**).

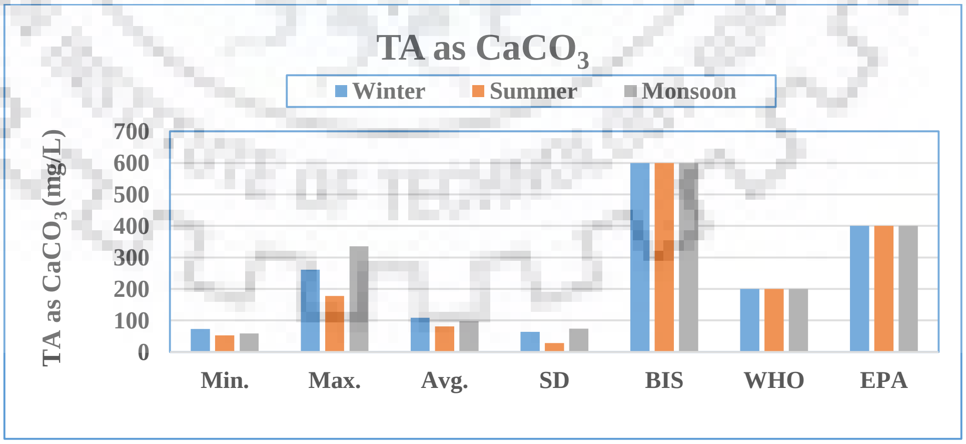


Figure 6.4: Variation of TA (as mg/L $CaCO_3$) in winter, summer and monsoon seasons for various samples

Total Hardness (TH as $CaCO_3$)

The TH value of the water samples of the UGC ranged from 55.5 to 364.3 mg/L with an average of 95.7 mg/L and SD of 84.3 during the winter season, from 64.5 to 217.8 mg/L with an average of 93.26 mg/L and SD of 61.12 during the summer season, and from 70.3 to 184 mg/L with an average of 98 mg/L and SD of 36.6 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines of BIS (IS 10500: 2012), ICMR (2012) and WHO (2004), all values were under the permissible limits and thus, UGC water was suitable for human drinking. However, it was above the permissible limits of EPA (2001) for winter and summer seasons (**Figure 6.5 and Table 6.4**).

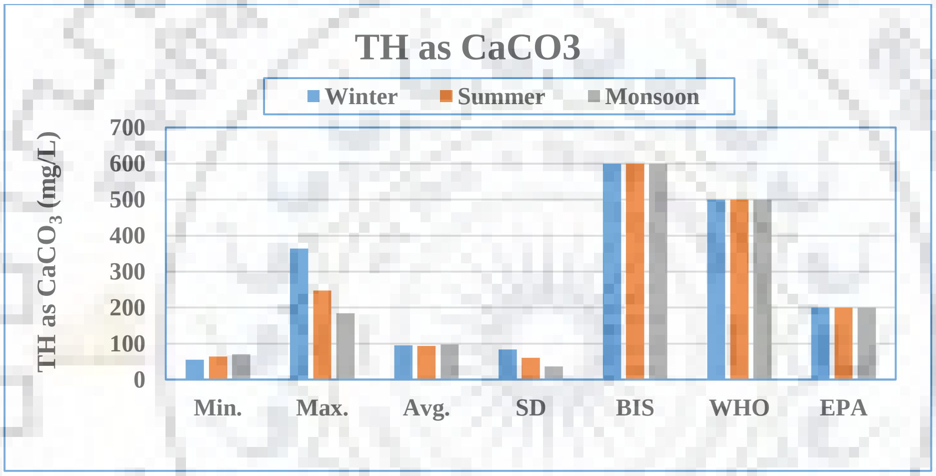


Figure 6.5: Variation of TH (as mg/L $CaCO_3$) in winter, summer and monsoon seasons for various samples

Calcium Hardness (Ca as $CaCO_3$)

The Ca values of the water samples from UGC, Roorkee varied from 33 to 335.25 mg/L with an average value of 65.58 mg/L and SD of 73.46 during the winter season, from 42 to 173.75 mg/L with an average value of 61.02 mg/L and SD of 40.65 during the summer season; and it varied from 49.75 to 124.45 mg/L with an average value of 65.25 mg/L and ± SD value of 24.08 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by BIS (IS 10500: 2012), the results were above the permissible limits during only winter season and hence, not suitable for human drinking. Also, it was above the permissible limits of the WHO (2004) Standards during all the seasons (**Figure 6.6 and Table 6.4**). Therefore, the UGC canal water was not suitable for human consumption.

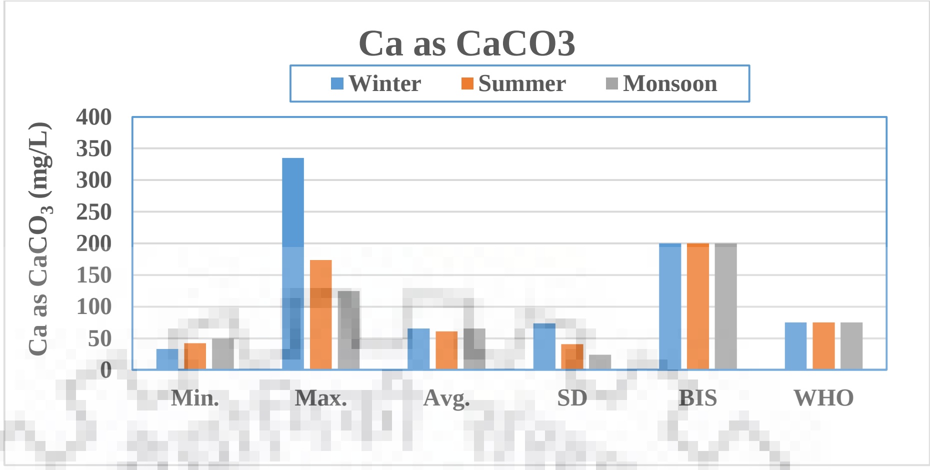


Figure 6.6: Variation of Ca Hardness (as mg/L CacO$_3$) in winter, summer and monsoon seasons for various samples

Magnesium hardness (Mg as CaCO$_3$)

The Mg values of the canal ranged from 15.75 to 98 mg/L with an average of 31 mg/L and SD of 22.07 during the winter season, from 19.5 to 88.25 mg/L with an average of 32.15 mg/L and ± SD of 21.13 during the summer season, and from 17.5 to 64.9 mg/L with an average of 32.72 mg/L and SD of 15.76 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines of BIS (IS 10500: 2012), all values were within the permissible limits. But, the results were above the permissible limits of the WHO (2004) Standards during all the seasons (**Figure 6.7 and Table 6.4**) and thus, it was not suitable for human drinking.

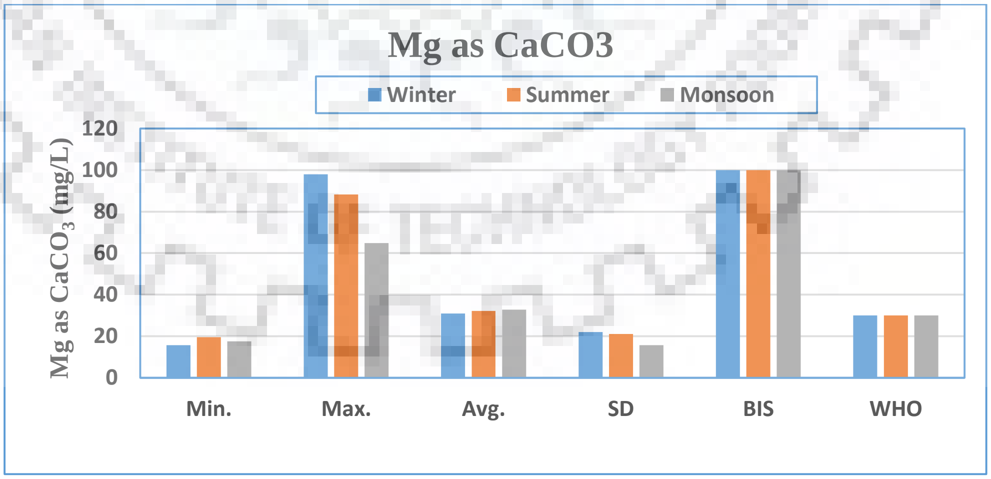


Figure 6.7: Variation of Mg Hardness (as mg/L CacO$_3$) in winter, summer and monsoon seasons for various samples

Sodium (Na)

The Na values of the canal ranged from 2.775 to 54.8 mg/L with an average of 10.56 mg/L and SD of 16.806 during the winter season, from 1.05 to 16.8 mg/L with an average of 4.188 mg/L and SD of 4.704 during the summer season, and from 2.2 to 57.68 mg/L with an average of 11.61 mg/L and SD of 18.62 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by BIS (IS 10500: 2012), ICMR (2012), EPA (2001) and WHO (1984, 2004), all values were within the permissible limits during all the seasons (**Figure 6.8 and Table 6.4**) and hence, UGC water is suitable for human drinking.

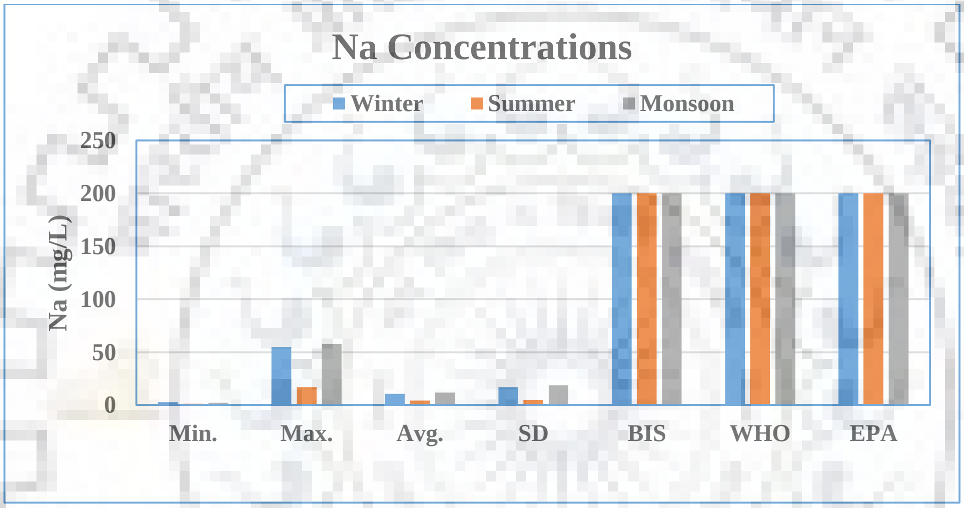


Figure 6.8: Variation of Na concentration (mg/L) in winter, summer and monsoon seasons for various samples

Potassium (K)

The K values of the canal ranged from 1.4 to 31.175 mg/L with an average of 5.417 mg/L and SD of 8.451 during the winter season, from 1.4 to 28.075 mg/L with an average of 4.913 mg/L and SD value of 7.639 during the summer season, and from 2.55 to 18.15 mg/L with an average of 5.569 mg/L and SD of 4.92 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by BIS (IS 10500: 2012) and WHO (2004), all values were above the maximum allowable limits during all three seasons (**Figure 6.9 and Table 6.4**) and thus, it was not suitable for human drinking.

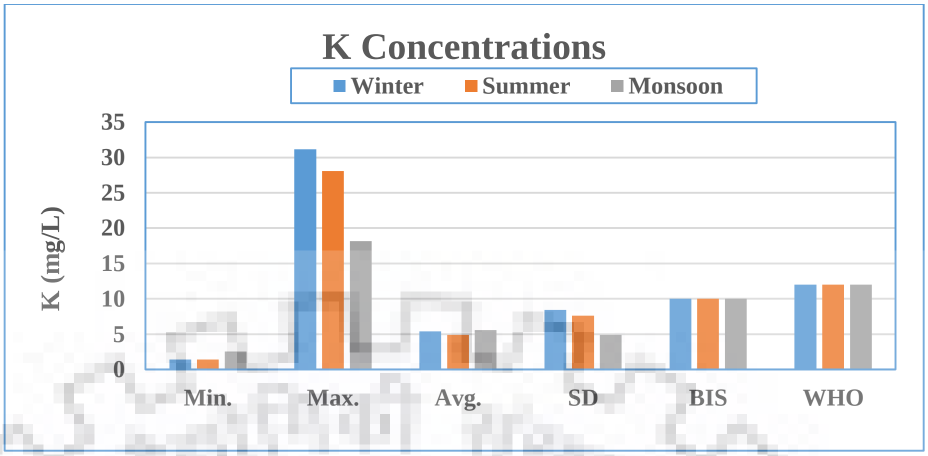


Figure 6.9: Variation of K concentration (mg/L) in winter, summer and monsoon seasons for various samples

Chloride (Cl)

The Cl values of the canal ranged from 10.75 to 345 mg/L with an average of 4651 mg/L and SD of 83.8 during the winter season, from 15.75 to 169 mg/L with an average of 38.46 mg/L and SD of 48.93 during the summer season, and from 22.25 to 120.75 mg/L with an average of 39.07 mg/L and SD of 31.63 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by BIS (IS 10500: 2012) and ICMR (2012), all values are within the permissible limits and hence, it was suitable for human drinking. However, during the winter season results were above the permissible limits of EPA (2001) and WHO (2004) Standards (**Figure 6.10 and Table 6.4**).

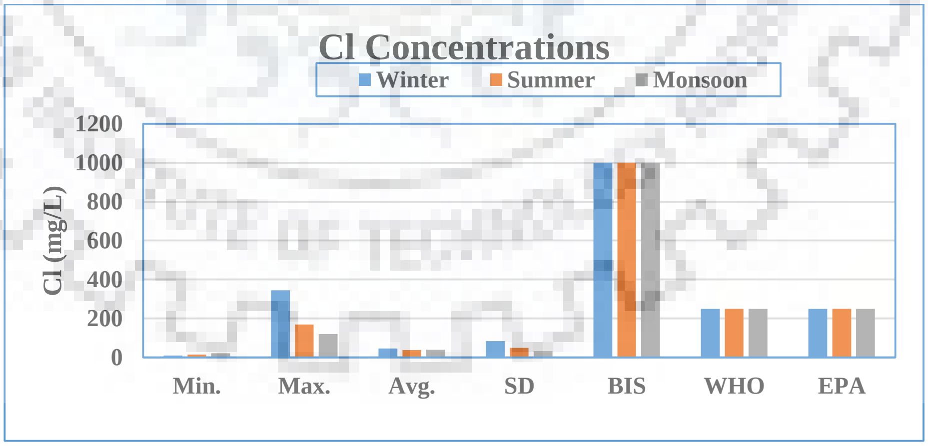


Figure 6.10: Variation of Cl concentration (mg/L) in winter, summer and monsoon seasons for various samples

Sulfate (SO_4)

The SO_4 values of the UGC ranged from 93.5 to 176.3 mg/L with an average of 105.3 mg/L and SD of 18.9 during the winter season, from 76.25 to 219.7 mg/L with an average of 120.7 mg/L and SD of 50.8 during the summer season, and from 110.5 to 144.6 mg/L with an average of 128.7 mg/L and SD of 9.4 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines of BIS (IS 10500: 2012), ICMR (2012) and WHO (2004), all values were within the permissible limits of the standards in all seasons, thus it was suitable for human consumption. However, during summer season results were above the permissible limits of EPA (2001) Standards (**Figure 6.11 and Table 6.4**).

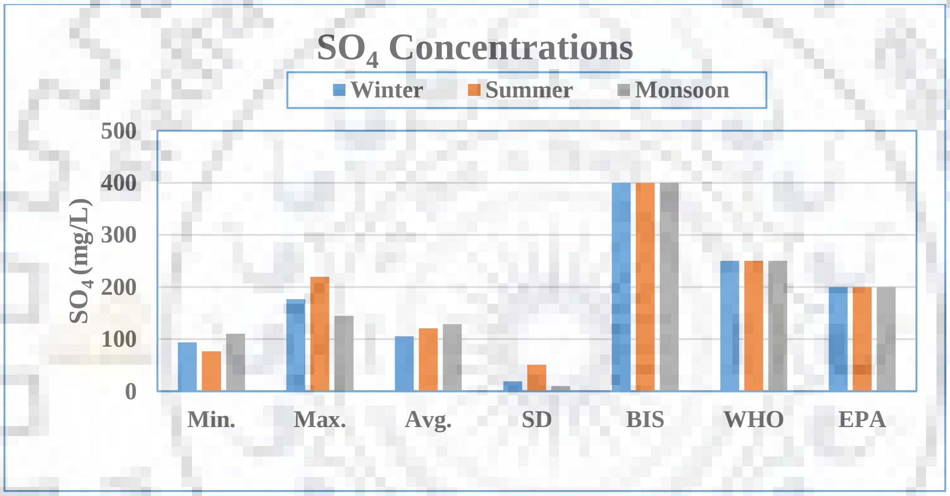


Figure 6.11: Variation of SO_4 concentration (mg/L) in winter, summer and monsoon seasons for various samples

Nitrate (NO_3)

The Cl value of the UGC ranged from 1.69 to 5.98 mg/L with an average of 3.75 mg/L and SD of 1.13 during the winter season, from 3.5 to 9.88 mg/L with an average of 4.62 mg/L and SD of 1.57 during the summer season, and from 1.0 to 5.33 mg/L with an average of 1.7 mg/L and SD of 1.19 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by BIS (IS 10500: 2012), ICMR (2012), EPA (2001) and WHO (2004) Standards, all values are within the permissible limits during all seasons (**Figure 6.12 and Table 6.4**) and hence, it was suitable for human consumption.

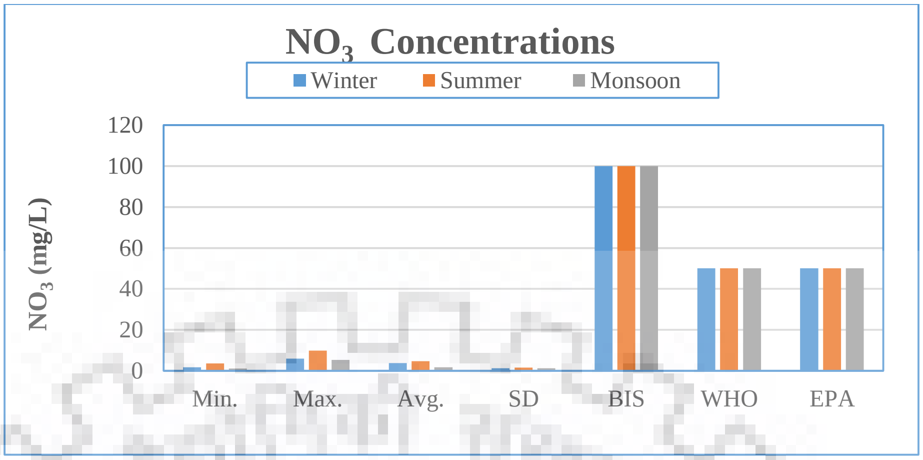


Figure 6.12: Variation of Nitrate concentration (mg/L) in winter, summer and monsoon seasons for various samples

Dissolved Oxygen (DO)

The DO value of the UGC ranged from 1.54 to 9.87 mg/L with an average of 8.4 mg/L and SD of 2.9 during the winter season, from 1.52 to 9.28 mg/L with an average of 7.9 mg/L and SD of 2.68 during the summer season, and from 1.88 to 8.56 mg/L with an average of 7.42 mg/L and SD of 2.41 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines of BIS (IS 10500: 2012), ICMR (2012) and WHO (2004) Standards, most of the values were below the permissible limits of the standards during all three seasons (**Figure 6.13 and Table 6.4**) and hence, it was not suitable for human consumption at these minimum DO values.

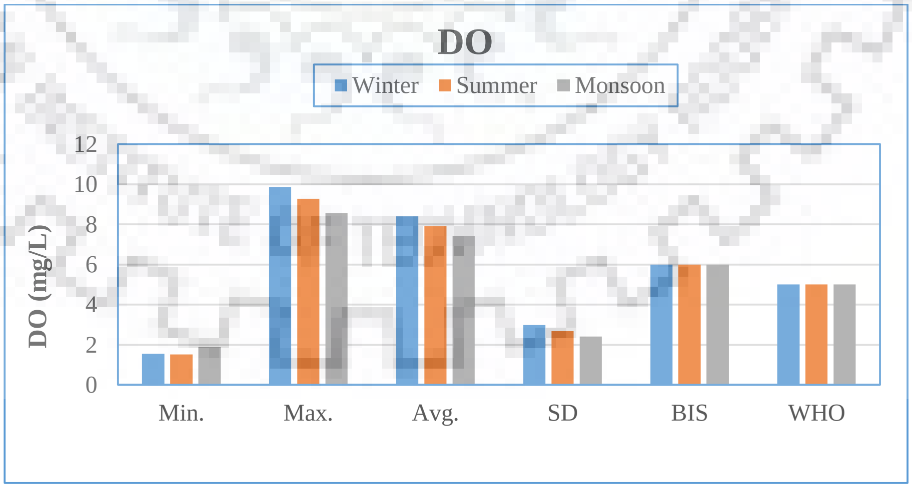


Figure 6.13: Variation of Dissolved Oxygen concentration (mg/L) in winter, summer and monsoon seasons for various samples

Chemical Oxygen demand

The COD of the canal ranged from 2.52 to 49.1 mg/L with a mean value of 75.71 mg/L and SD of 123.55 mg/L during the winter season; ranged from 2.98 to 295.98 mg/L with a mean value of 47.35 mg/L and SD of 86.47 during the summer season and it ranged from 7.8 to 295.98 mg/L with a mean value of 52.11 mg/L and SD of 72.36 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by BIS (IS 10500: 2012), EPA (2001) and WHO (2004), during all the seasons, the COD values were not within the permissible limits and hence, it was not suitable for human drinking purpose (**Figure 6.14 and Table 6.4**). The reason for high COD values is dead bodies, perished food and vegetables, grasses and leaves, cow dungs, domestic sewages and Hyacinth weed growing on the canal.

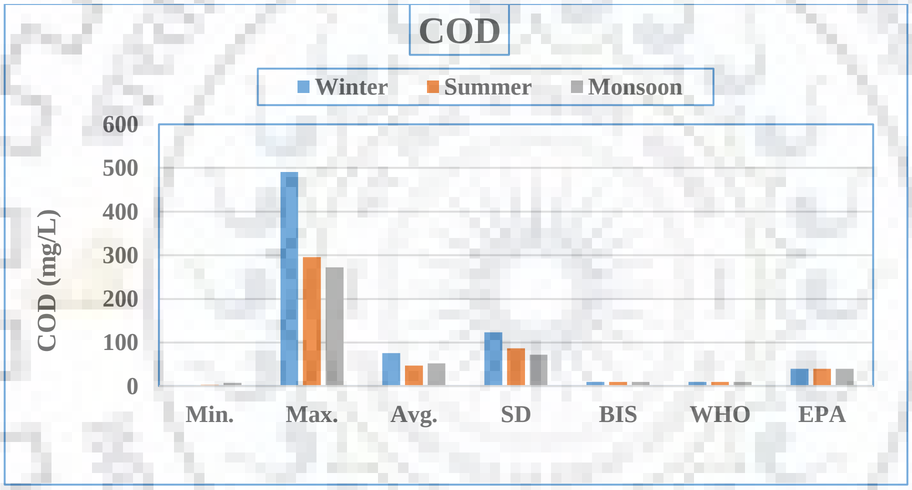


Figure 6.14: Variation of Chemical Oxygen Demand concentration (mg/L) in winter, summer and monsoon seasons for various samples

Boron (B)

The B of the canal ranged from 0.433 to 1.531mg/L with a mean value of 0.848 mg/L and SD of 0.218 mg/L during the winter season; ranged from 0.525 to 1.352 mg/L with a mean value of 0.853 mg/L and SD of 0.226 during the summer season; it ranged from 0.671 to 0.952 mg/L with a mean value of 0.811mg/L and SD of 0.086 during the monsoon season (**Tables 6.1, 6.2 and 6.3**). According to the guidelines by EPA (2001) during all seasons, the values of B were within the permissible limits of the standards. However, the concentration of B was above the permissible limits of BIS (IS 10500: 2012) during winter and summer season. Similarly, based on WHO

(2004) guidelines, B was above the maximum allowable limit during all the three seasons and thus, UGC water was not suitable for drinking purpose (**Figure 6.15 and Table 6.4**).

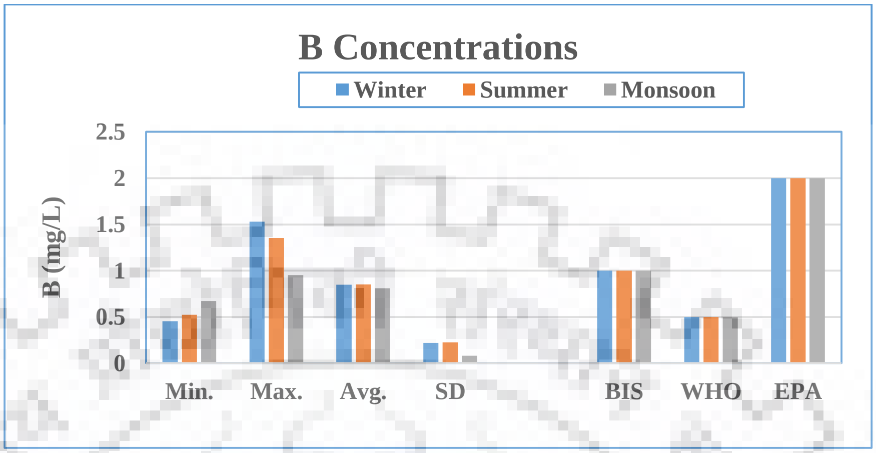


Figure 6.15: Variation of Born, (mg/L) in winter, summer and monsoon seasons for various samples

6.3.2 Toxic Trace Metals

The recommended maximum concentration (permissible limit) of toxic trace metals considered for this study relevant to human drinking, given by the reliable international standards/guidelines are presented in **Table 6.5**. These metals are Aluminium, Arsenic, Cadmium, Chromium, Copper, Iron, Mercury, Manganese, Lead and Zinc. Any alterations in these metals, specially at concentrations above the allowable limit may impart toxicity to water and thus, may be detrimental to human health. The results obtained from this study i.e. concentration of the trace metals were compared to the guidelines by Bureau Indian Standards (IS 10500: 2012), Indian Council Medical Research ICMR (2012), World Health Organization (WHO, 2004) and Environmental Protection Agency (EPA, 2001), to assess suitability of water for human drinking in all sampling sites of the UGC, Roorkee.

Table 6.5: Guidelines and Standards for toxic trace metals in canal surface water relevant to human drinking

Parameter	Units	BIS (IS 10500: 2012)		ICMR (2012)		WHO (2004)	EPA (2001)
		Desirable Limit	Permissible Limit	Desirable Limit	Permissible Limit	Permissible Limit	Permissible Limit
Al	mg/L	0.03	0.2	-	-	0.2	0.2
As	mg/L	0.01	No relaxation	-	0.05	0.05	0.05
Cd	mg/L	0.003	No relaxation	-	0.01	0.003	0.05
Cr	mg/L	0.05	No relaxation	-	-	0.05	0.05
Cu	mg/L	0.05	1.5	0.05	1.5	1	0.05
Fe	mg/L	0.3	No relaxation	0.1	1	0.3	0.2
Hg	mg/L	0.001	No relaxation	-	0.001	0.001	0.001
Mn	mg/L	0.1	0.3	0.1	0.5	0.5	0.05
Pb	mg/L	0.05	No relaxation	-	0.5	0.01	0.05
Zn	mg/L	5	15	0.1	5	5	3.0

A brief description of the results and their comparison with the allowable concentration levels for individual trace metals are presented below.

Aluminum (Al)

The Al of the canal ranged from 0.1311 to 2.3274 mg/L with a mean value of 0.5249 mg/L and SD of 0.707 mg/L during the winter season; ranged from 0.1342 to 1.1652 mg/L with a mean value of 0.642 mg/L and SD of 0.214 during the summer season and it ranged from 0.1311 to 1.1751 mg/L with a mean value of 0.407 mg/L and SD of 0.346 during the monsoon season. According to the guidelines by BIS (IS 10500: 2012), EPA (2001) and WHO (2004), during all the seasons, the Al values were above the permissible limits and hence, it was not suitable for human drinking purpose (**Figure 6.16 and Table 6.5**).

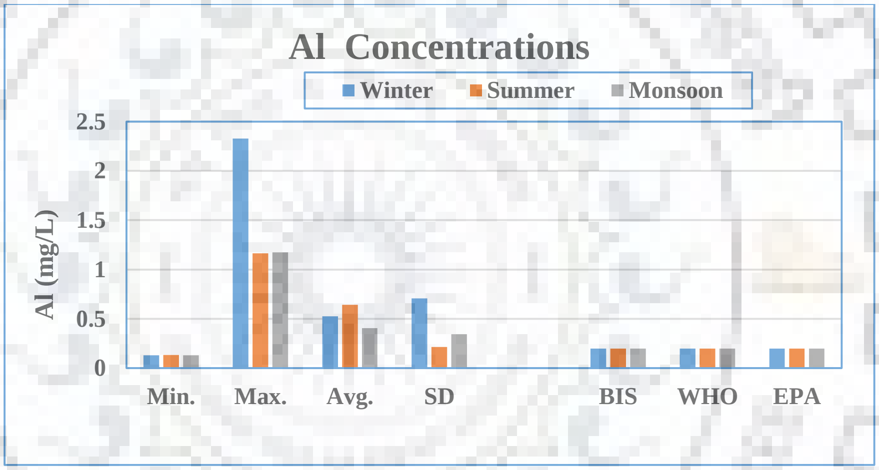


Figure 6.16: Variation Aluminum in winter, summer and monsoon seasons for various samples

Arsenic (As)

The concentration of As in the samples collected from UGC, Roorkee, varied from 0.002 mg/l to 0.014 mg/l with an average of 0.0045 mg/l and ± SD of 0.0038 for winter season, from 0.002 mg/l to 0.013 mg/l with an average of 0.0041 mg/l and SD of 0.0035 for summer season, and from 0.002 mg/l to 0.017 mg/l with an average of 0.0051 mg/l and SD of 0.0042 for monsoon season. According to the guidelines by ICMR (2012), EPA (2001) and WHO (2004), during all three seasons, the As values were within the allowable limits. However, as per BIS (IS 10500: 2012), the sites S4, S5 and S7 exceeded the permissible limits (**Figure 6.17 and Table 6.5**).

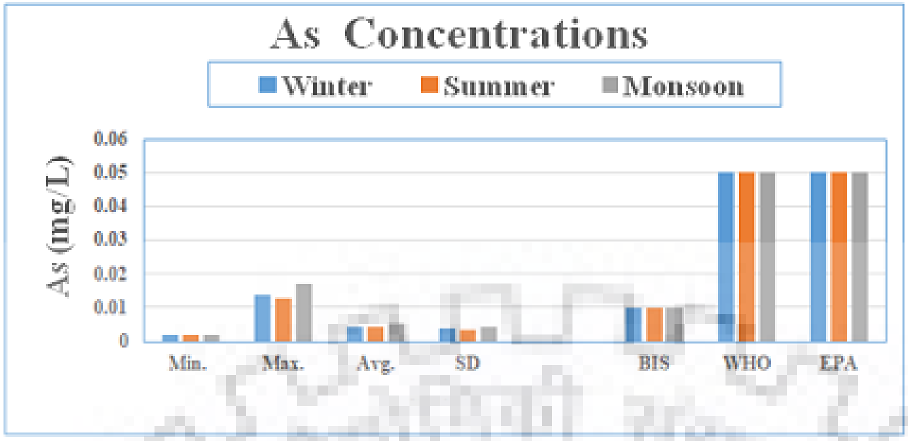


Figure 6.17: Variation of Arsenic (mg/L) in winter, summer and monsoon seasons for various samples

Cadmium (Cd)

The Cd of the UGC water ranged from 0.001 to 0.0185 mg/L with a mean value of 0.004 mg/L and SD of 0.004 mg/L during the winter season; ranged from 0.002 to 0.008 mg/L with a mean value of 0.005 mg/L and SD of 0.001 during the summer season and it ranged from 0.001 to 0.005 mg/L with a mean value of 0.0031 mg/L and SD of 0.001 during the monsoon season. According to the guidelines by EPA (2001) and ICMR (2012) during all the seasons, the values of Cd were within the permissible limits of the standards. However, all values of Cd were above the permissible limits of BIS (IS 10500: 2012) and WHO (2004) and it was not suitable for human drinking (**Figure 6.18 and Table 6.5**).

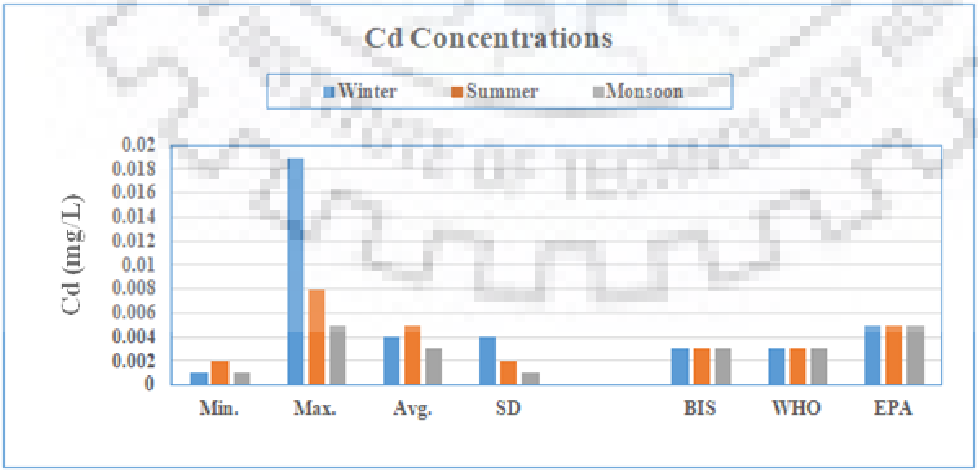


Figure 6.18: Variation of Cadmium, (mg/L) in winter, summer and monsoon seasons for various samples

Chromium (Cr)

The Cr of the UGC water ranged from 0.0211 to 0.0185 mg/L with a mean value of 0.004 mg/L and SD of 0.02 mg/L during the winter season; ranged from 0.0211 to 0.098 mg/L with a mean value of 0.046 mg/L and SD of 0.023 during the summer season and it ranged from 0.0201 to 0.055 mg/L with a mean value of 0.033 mg/L and SD of 0.01 during the monsoon season. According to the guidelines by BIS (IS 10500: 2012), EPA (2001), ICMR (2012) and WHO (2004), during all the seasons, the Cr values were not within the permissible limits and thus, it was not suitable for human drinking (**Figure 6.19 and Table 6.5**).

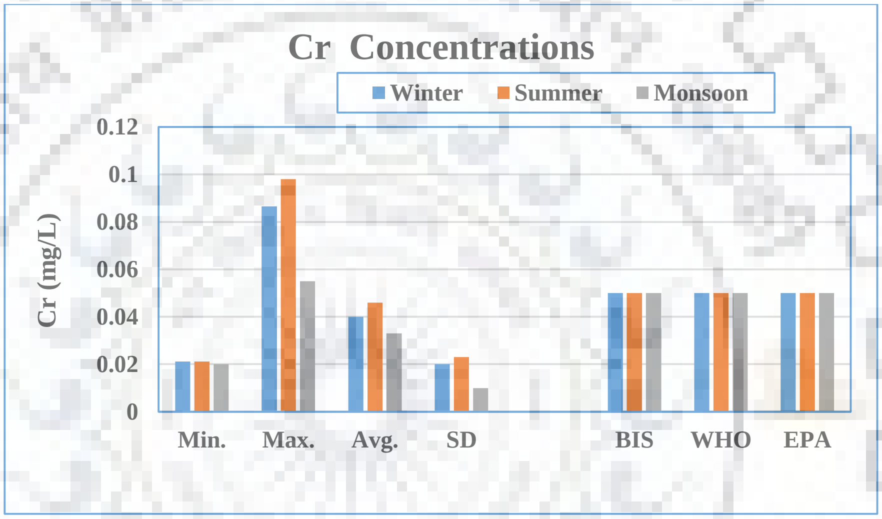


Figure 6.19: Variation of Chromium, (mg/L) in winter, summer and monsoon seasons for various samples

Copper (Cu)

The Cu of the UGC water ranged from 0.02 to 0.092 mg/L with a mean value of 0.054 mg/L and SD of 0.018 mg/L during the winter season; ranged from 0.023 to 0.176 mg/L with a mean value of 0.057 mg/L and SD of 0.077 during the summer season and it ranged from 0.02 to 0.069 mg/L with a mean value of 0.038 mg/L and SD of 0.013 during the monsoon season. According to the guidelines by BIS (IS 10500: 2012) and WHO (2004), during all the seasons, the values of Cu were within the permissible limits and thus, it was suitable for human drinking. However, during all seasons, Cu values were above the permissible limits of EPA (2001) and ICMR (2012) guidelines (**Figure 6.20 and Table 6.5**).

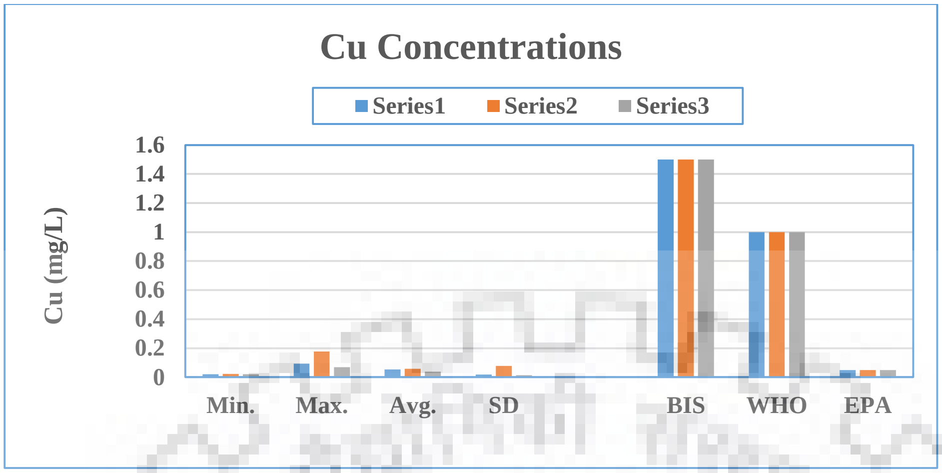


Figure 6.20: Variation of Copper, (mg/L) in winter, summer and monsoon seasons for various samples

Iron (Fe)

The Fe of the UGC water ranged from 1.151 to 3.922 mg/L with a mean value of 2.976 mg/L and SD of 0.641 mg/L during the winter season; from 1.151 to 3.016 mg/L with a mean value of 2.4286 mg/L and SD of 0.392 during the summer season and from 1.299 to 2.4382 mg/L with a mean value of 1.88 mg/L and SD of 0.354 during the monsoon season. According to the guidelines by BIS (IS 10500: 2012), EPA (2001), ICMR (2012) and WHO (2004), during all the seasons, the Fe values were not within the permissible limits and thus, it was not suitable for human consumption (**Figure 6.21 and Table 6.5**).

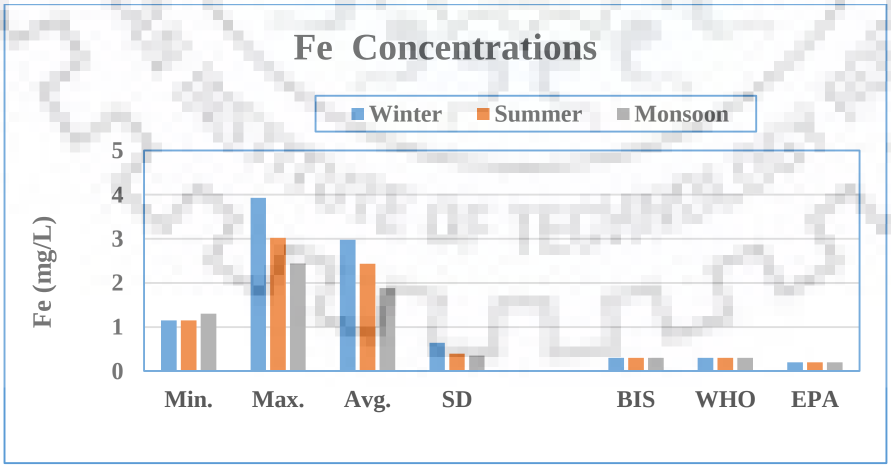


Figure 6.21: Variation of Iron, (mg/L) in winter, summer and monsoon seasons for various samples

Manganese (Mn)

The Mn of the UGC water ranged from 0.035 to 0.214 mg/L with a mean value of 0.103 mg/L and SD of 0.056 mg/L during the winter season; ranged from 0.083 to 0.179 mg/L with a mean value of 0.131 mg/L and SD of 0.0.027 during the summer season and it ranged from 0.062 to 0.141 mg/L with a mean value of 0.114 mg/L and SD of 0.020 during the monsoon season. According to the guidelines by BIS (IS 10500: 2012) and WHO (2004), during all the seasons, the Mn values were within the permissible limits and therefore, it was not suitable for human consumption. However, during all seasons, Mn values were above the permissible limits of EPA (2001) guidelines (**Figure 6.22 and Table 6.5**).

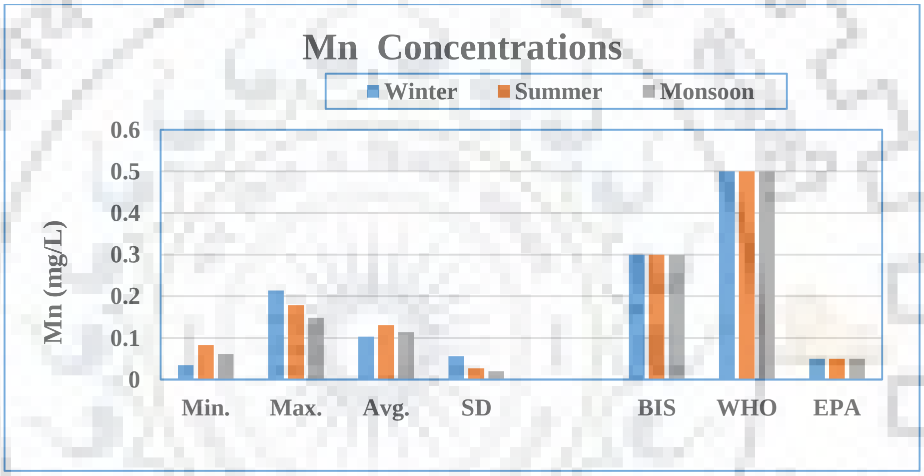


Figure 6.22: Variation of Manganese, (mg/L) in winter, summer and monsoon seasons for various samples

Mercury (Hg)

The Hg of the canal ranged from 0.0011 to 0.0211 mg/L with a mean value of 0.0052 mg/L and SD of 0.0066 during winter season, from 0.0012 to 0.0199 mg/L with a mean value of 0.0049 mg/L and SD of 0.0061 during summer season, and from 0.0011 to 0.0222 mg/L with a mean value of 0.0062 mg/L and ± SD of 0.0071 during monsoon season. According to the guidelines by BIS (IS 10500: 2012), EPA (2001), ICMR (2012) and WHO (2004), during all the seasons, the Hg values were not within the permissible limits and therefore, it was not suitable for human consumption (**Figure 6.23 and Table 6.5**).

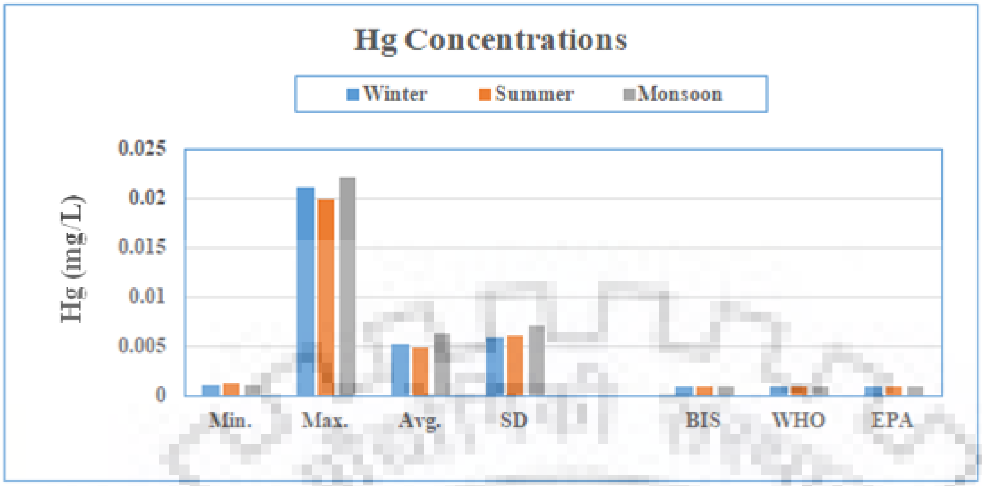


Figure 6.23: Variation of Mercury (mg/L) in winter, summer and monsoon seasons for various samples

Lead (Pb)

The Pb of the UGC water ranged from 0.0116 to 0.0569 mg/L with a mean value of 0.029 mg/L and SD of 0.012 mg/L during the winter season; ranged from 0.0221.98 to 0.0989 mg/L with a mean value of 0.035 mg/L and SD of 0.017 during the summer season and it ranged from 0.0111 to 0.045 mg/L with a mean value of 0.023 mg/L and SD of 0.01 during the monsoon season. According to the guidelines by BIS (IS 10500: 2012), EPA (2001), ICMR (2012) and WHO (2004), during all the seasons, the Pb values were not within the permissible limits and hence, it was not suitable for human consumption (**Figure 6.24 and Table 6.5**).

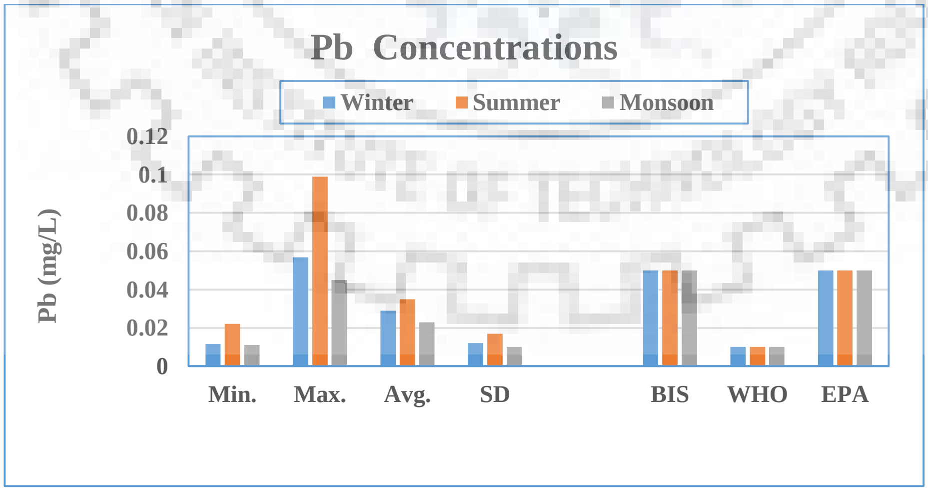


Figure 6.24: Variation of Lead, (mg/L) in winter, summer and monsoon seasons for various samples

Zinc (Zn)

The Zn of the UGC water ranged from 0.0723 to 2.014 mg/L with a mean value of 1.061 mg/L and SD of 0.521 mg/L during the winter season; ranged from 0.57 to 3.1405 mg/L with a mean value of 1.28 mg/L and SD of 0.773 during the summer season and from 0.37 to 1.954 mg/L with a mean value of 0.87 mg/L and SD of 0.478 during the monsoon season. According to the guidelines by BIS (IS 10500: 2012), EPA (2001) and WHO (2004), during all the seasons and stations, the Zn values were within the permissible limits and hence, it was suitable for human drinking (**Figure 6.25 and Table 6.5**).

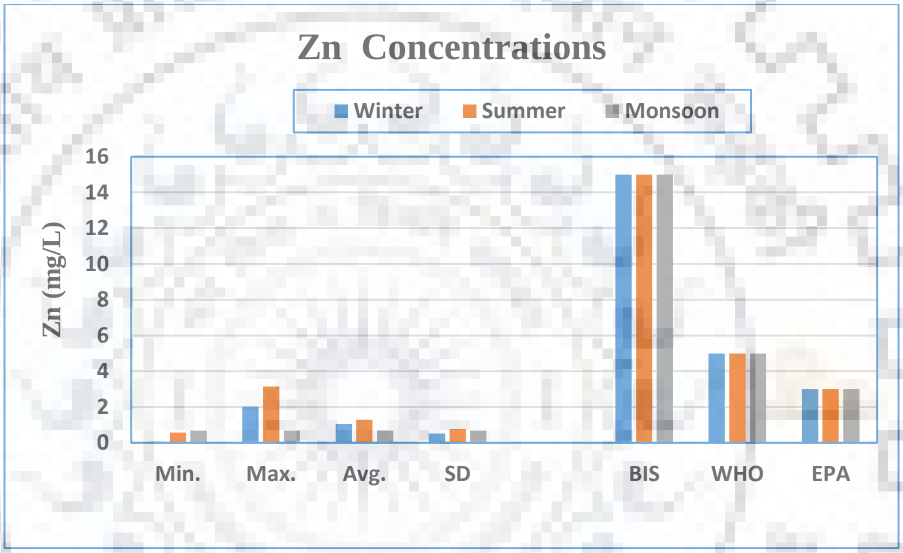


Figure 6.25: Variation of Zinc, (mg/L) in winter, summer and monsoon seasons for various samples

The UGC water constituents in terms of toxic trace metals are moderately variable in the three seasons during November 2014 to October 2015. Based on the average values of trace metal concentrations in mg/l, it can be observed that, Fe and Cd are the most and least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Cr > Pb > Hg > As > Cd, during winter season; similarly Fe and As are the most and least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Cr > Pb > Cd > Hg > As, during the summer season; Fe and Cd are the most and least concentrated of the metals in the order of: Fe> Zn > Al > Mn > Cu > Cr > Pb > Hg > As > Cd during the monsoon season.

6.3.3 Water Quality Index

WQI is a robust measure to express the condition of water quality. A WQI value of zero represents absolute absence of pollutants; when WQI < 100 shows that the water is under consideration and fits for utilization and when WQI > 100 indicates its unsuitability for use (Gadekar et al. 2012; Pandey, 2014). The weighted arithmetic of WQI is computed to assess the water quality of the UGC, Roorkee, to classify the water quality based on the degree of purity by using the standard variables.

Table 6.6: An Example for calculation of WQI for Human drinking (site S1)

Parameter	Measured value (V_{actual}) for site S1	Permissible Limit for Human	Relative Weight (Wi)	Quality Rating (Q_i)	Weighted value
pH	8.3	6.5 – 8.5	0.667	86.667	57.778
DO	9.72	4.00	0.250	46.038	11.509
TDS	128	2000	0.001	6.400	0.003
TA	76.25	600	0.002	12.708	0.021
TH	57.8	600	0.002	9.633	0.016
Ca	42	200	0.005	21.000	0.105
Mg	15.75	30	0.033	52.500	1.75
Na	2.825	200	0.005	1.413	0.007
Cl	16	1000	0.001	1.600	0.002
SO_4	94.5	400	0.003	23.625	0.059
NO_3	4.3	45	0.022	9.556	0.212
B	0.453	1	1	45.300	45.3
Al	0.532	0.2	5	266.000	1330
As	0.002	0.05	20	4.000	80
Cd	0.001	0.003	333.333	33.333	11111.111
Cr	0.021	0.05	20	42.200	844
Cu	0.047	1.5	0.667	3.133	2.089
Fe	1.151	0.3	3.333	383.667	1278.889
Hg	0.0021	0.001	1000	210	210000
Mn	0.035	0.3	3.333	11.667	38.889
Pb	0.012	0.01	100.000	116.000	11600
Zn	0.567	15	0.067	3.783	0.252
			$\sum Wi$ = 1487.174		$\sum WiQi$ = 236354.411
$\sum WiQi / \sum Wi$ = 158.93					

An example (for site S1) of calculation of WQI for human drinking is provided in **Table 6.6**. The WQI results for all sites considering the physicochemical parameters are presented in **Table 6.7** and that of considering toxic trace metals are also presented in **Table 6.8**. The overall WQI at all the sites considering both physicochemical and toxic trace metals together, for all the three seasons are presented in **Table 6.9**.

The detailed calculation procedure of WQI considering 22 parameters (12 physicochemical and 10 toxic trace metals) over site S1 during winter season is provided in **Table 6.6**. It can be observed that the relative weight of a parameter is reciprocal to its permissible limit. Thus, the relative weight of Mercury (Hg) is very high (equal to 1000) compared to all other parameters, owing to its lowest permissible limit. The WQI value obtained by the weighed arithmetic method is 158.93, which exceeds the limiting value of WQI to be suitable for the specific purpose. Thus, the water from S1 during winter season was not suitable for human drinking.

Table 6.7: WQI of Physicochemical parameters for Human drinking purpose

Site Code	Winter	Summer	Monsoon
S1	48.02	52.36	60.49
S2	57.04	57.93	63.79
S3	63.9	60.87	61.21
S4	93.94	114.85	88.76
S5	96.43	122.22	91.35
S6	64.76	60.76	62.56
S7	94.83	116.31	93.29
S8	74.39	61.69	63.75
S9	74.71	65.45	64.38
S10	74.80	72.71	71.79
S11	74.43	72.11	70.40
S12	74.96	72.04	71.42
S13	75.64	74.52	70.54
S14	82.58	78.76	70.86
S15	124.11	73.31	75.46
S16	75.31	76.49	79.3
S17	75.32	73.82	72.02
S18	79.20	73.82	72.04
Min	48.02	52.36	60.49
Max	124.11	122.22	93.29
Avg	78.83	77.73	72.86
SD	16.83	20.28	10.03

The WQI values obtained at all the sampling sites in different seasons (winter, summer and monsoon), considering only physicochemical parameters for human drinking purpose are presented in **Table 6.7.** The WQI ranged from 48.02 to 124.11 with a mean of 78.83 and SD of 16.83 for winter season, from 52.36 to 122.22 with an average of 77.73 and SD of 20.28 for summer season, and from 60.49 to 93.29 with the average value of 72.86 and SD value of 10.03 for monsoon season. It can be noticed that the site S1 had lowest WQI values during all the seasons. On the other hand, sites S15, S5 and S7 had the highest WQI value during winter, summer and monsoon season respectively. Moreover, the sites S4, S5 and S7 possessed higher values during all three seasons compared to other sites, taking only physicochemical parameters. However, for only summer season, WQI values for these sites exceeded 100. The average WQI is similar during all the three seasons. For site S15, WQI value was 124.11 during winter season, but it was very close to the average of 18 samples for summer and monsoon season.

Table 6.8: WQI of toxic trace metals for Human drinking purpose

Site Code	Winter	Summer	Monsoon
S1	159	173	158.1
S2	220.7	228.9	214.5
S3	230.2	243.4	222.1
S4	1369.8	1387.1	1356.1
S5	1325.1	1351.2	1288.7
S6	263.9	278.8	262.7
S7	1486.99	1519.5	1486.01
S8	178.7	193.2	176.9
S9	104.7	127.7	104.3
S10	219.9	242.3	228
S11	295.6	282.7	268.4
S12	291.5	316.6	302.1
S13	302.4	220.2	190.2
S14	191.2	228.2	197.2
S15	133.4	155	130.7
S16	118.7	160.3	136.1
S17	184.3	208.7	198.3
S18	208.8	213.6	190.6
Min	104.67	127.71	104.28
Max	1486.99	1519.46	1486.01
Avg	443.83	458.87	435.07
SD	459.72	463.95	455.81

The WQI values obtained at all the sampling sites in different seasons (winter, summer and monsoon), considering only toxic trace metals for irrigation purpose are presented in **Table 6.8.** The WQI ranged from 104.67 to 1486.99 with a mean of 443.83 and SD of 459.72 for winter season, from 127.71 to 1519.46 with the average value of 458.87 and SD of 463.95 for summer season, and from 104.28 to 1486.01 with the average value of 435.07 and SD value of 455.81 for monsoon season. It can be noticed that the site S7 had highest WQI, whereas S9 had lowest WQI values during all the three seasons. But, since the lowest WQI considering the toxic trace metals is above 100 in all the seasons, the UGC water is highly unsuitable for human drinking purposes.

Table 6.9: WQI of physicochemical and toxic trace metals for Human drinking purpose

Site Code	Winter	Summer	Monsoon
S1	158.93	172.85	158.03
S2	220.57	228.78	214.39
S3	230.08	243.25	221.91
S4	1368.6	1385.83	1354.89
S5	1323.9	1349.96	1287.59
S6	263.69	278.57	262.46
S7	1485.64	1518.1	1484.66
S8	178.59	193.09	176.82
S9	104.64	127.65	104.24
S10	219.79	242.16	227.84
S11	295.39	282.46	268.18
S12	291.32	316.35	301.88
S13	302.18	220.02	190.04
S14	191.11	228.07	197.11
S15	133.35	154.91	130.61
S16	118.64	160.21	136.06
S17	184.17	208.6	198.20
S18	208.71	213.51	190.51
Min	104.64	127.65	104.24
Max	1485.64	1518.1	1484.66
Avg	443.48	458.51	434.71
SD	459.28	463.52	455.38

From **Table 6.9**, it can be noticed that the overall WQI values (considering both physicochemical parameters and toxic trace metals) of the UGC water sites ranged from 104.64 to 1485.64 with a mean of 443.48 and SD of 459.28 for winter season, from 127.65 to 1518.1 with an average of 458.51 and SD of 463.52 for summer season, and from 104.24 to 1484.66 with the average value of 434.71 and SD value of 455.38 for monsoon season. The site S7 possessed highest value of WQI throughout all the seasons, which is indicative of highest pollution amongst all the sites. On the other hand, S9 was the least polluted site in all the seasons, based on WQI values. However, the limiting value for the water to be suitable for human drinking is 100. The minimum WQI value among all the sites is beyond this threshold for all the seasons. This reflects that the surface canal water at all the sampling sites is unsuitable for human drinking purpose. Moreover, it can be observed that, except S4, S5 and S7, the WQI values are less than the average of 18 samples. For these three sites, the WQI values are in the range of 1287.59 to 1518.1, showing the extent of pollution. It will cause severe health hazard, if used for drinking purpose. The high value of the WQI may be attributed to dumping of industrial effluents, domestic sewages, and mining etc. The human activities such as swimming, dipping, dumping of idols, washing clothes, defecating, cattle wadding, domestic sewages and disposing solid materials are common and could be the sources of pollution which makes water unfit for human drinking.

6.4 Conclusions

The Upper Ganga Canal water was evaluated for human drinking purpose. A total of 18 sampling sites were located in Upper Ganga Canal. Based on the analysis, following conclusions are drawn from the present study:

1. Based on guidelines and Standards by BIS (IS 10500: 2012), ICMR (2012), WHO (2004) and EPA (2001), it was found that the physicochemical parameters viz., Ca, K, B, DO and COD were above the permissible limits for human drinking purpose.
2. Most of the trace metals in UGC water possess higher concentration compared to the permissible limits of the standards/guidelines considered for human drinking purposes. The higher concentration of these metals imparts toxicity to the water and hence, is not utilizable for drinking purposes.
3. The overall WQI values of the UGC water sites ranged from 104.64 to 1485.64 with a mean of 443.48 for winter season; from 127.65 to 1518.1 with an average of 458.51 for summer season; and from 104.24 to 1484.66 with the average value of 434.71 for monsoon season. Hence, it is not suitable for human drinking.

CHAPTER 7

NUMERICAL MODELING OF SEWAGE POLLUTANT DISPERSION

In this chapter, the numerical modeling of sewage pollutant dispersion of Upper Ganga Canal using Computational fluid Dynamics (CFD) is presented. A numerical model of Upper Ganga Canal from old canal bridge to Ganeshpur bridge, Roorkee, has been developed to simulate water flow in the canal with the inflow of pollutants from sewages at five different locations in the Upper Ganga Canal model. Influence of opening of various sewage as well as sewage velocities on the change in concentration of canal water is investigated. The study is augmented by analyzing the insertion of solid particle pollutants from the sewage inflow. The density and size of the solid particles was varied during the analysis. The ANSYS Fluent 16.0 software is used to accomplish this numerical modeling work.

7.1 Introduction

The Ganga River serves irrigation and drinking purposes in 11 states and to almost 40% of the population in India. Despite the fact that Ganga River is a major source of water for drinking and agriculture and has significant environmental values in India, this precious asset is getting degraded due to effluent discharge from different organizations and communities (Rai, 2013; Ensink et al., 2010). The Ganga River was ranked among the five most polluted rivers of the world in 2007 (NRCD, 2009). The pollution can also be seen in the Upper Ganga Canal, which is crucially affecting the water quality of canal water at Roorkee for irrigation and drinking purposes (Kumar and Chopra, 2012; and Kumar et al., 2015). The increase in population, food production demand, rising standard of living, growth of industrialization and urbanization, increases the demand for clean and safe water (Matta, 2015). Moreover, disposal of sewages is the major source of pollutant (wastewater) and contamination, specifically in Upper Ganga Canal at Roorkee.

Many sewers are opened in the Ganga canal directly without any treatment in Roorkee city only (Rai, 2013). One major sewer opening in the canal is at Piran Kalyar at old canal. Then after Piran Kalyar there are five villages on the left side of the canal through which a major sewer is joining the canal near Saini Sonki and one sewer is entering the canal from the right side at Civil Lines of Roorkee city (Matta et al., 2017). During field visits, the solid sediments and sewage dumping into the canal was observed at many places**.** This is the reason that the Upper Ganga canal region near Roorkee city has been taken for consideration with similar sewer entries in the canal as an effort in the direction of studying the behavior, effect and extent of pollution caused by sewer entries.

Several literatures have been found for experimental investigation of water quality for irrigation purposes at different canals and rivers (Rai, 2013; Keupers and Willems, 2017). However, numerical investigations analyzing the canal water flow behavior with pollutant dispersion has rarely been reported. Few investigators have reported the flow behavior of water by mathematical modelling. Buccolieri et al. (2010) analyzed the flow behavior in a portion of the Canal Grande (Grand Canal) in Venice (Italy). Drolc and Končan (1996) developed a model to predict the dissolved oxygen concentration at different flows in the river. No study has been found to conduct numerical investigation of change in water quality/concentration due to liquid pollutants and/or solid particle pollutants for Upper Ganga Canal at Roorkee. Hence, from the reported literature, it is found that very less attention were paid towards the numerical assessment of water quality on the inclusion of sewage as well as the velocity at which sewage pollutants are discharged into the canal.

In the present investigation, numerical simulations of fluid (water) flow in the canal have been analyzed with the inflow of pollutants from various sewages in the Upper Ganga Canal model. The study has been performed with the analysis of the influence of opening various sewage as well as sewage velocities on the change in concentration of canal water. The study has been augmented by analyzing the insertion of solid particle pollutants from the sewage inflow, where density and size of the solid particles have been varied during the analysis. Fluid flow equations have been discretized simultaneously with species transport equations for predicting the change in water concentration by sewage inflow. The path and flow of solid particles have been tracked by solving discrete phase model equations using finite volume method.

7.2 Methods

The numerical investigation has been carried out over Upper Ganga Canal using Computational fluid dynamics (CFD) tool Ansys Fluent. The geometry of the canal (from UGC Bridge Roorkee, Civil Line to Ganga Canal Bridge near to Ganeshpur) has been prepared using design modeller of Ansys 16.0. The fluid flow in the canal water has been studied with the individual opening of the sewage inlets at different velocities. The pollutant discharged into the canal from different sewage inlets and their effect on the mass fraction has been calculated using the turbulence model, species transport model and mixing model.

7.2.1. Brief Description of CFD

Computational fluid dynamics (CFD) is an efficient tool that uses numerical methods and algorithms to model the actual properties of fluids. It optimizes the design parameters thus reducing a requirement of the expensive testing of numerous prototypes. It is an effective visualization tool to monitor flow patterns that reveals the flow physics which is difficult and expensive to obtain experimentally. Governing equations are set to characterize fluid flow physics and behavior. It is not always feasible to apply computation methods to solve real world problems as there are many variables involved in its physics. Computational fluid dynamics includes making a computational mesh to convert the continuous fluid medium to a discrete domain. The developed governing equations can then be applied to each discrete domain, the properties of each domain is in relation with its neighbor domain elements so all the computational domain is solved using numerical analysis for a complete solution of the full flow field. CFD analysis also has its limitations. Its accuracy bank on different factors such as superiority and correctness of meshed geometry, the extent to which the modelled equations matches the physics of fluid flow to be modeled, the explanation of the results, and the boundary conditions used or the order of residuals.

Three fundamental principles govern the physics of any fluid flow: 1) Conservation of mass; 2) Conservation of Momentum; 3) Newton’s Conservation of energy. These basic principles can be communicated in mathematical equations form either as partial differential equations or integral equations. To solve the numerical solutions of computational domain, governing equations are used, which are explained in detail in **Section 3.7 of Chapter 3.**

7.2.2 Turbulence Model

Most of the fluid flows are turbulent which occur in our daily life. Distinctive examples of turbulent fluid flow are: the river, fluid flow in the ocean, canal water flow, flow of fluid in wash basins etc. It is difficult to define turbulent flow in few lines, but it has a number of characteristic features which help in recognizing its regime such as irregularity, diffusivity, large Reynolds numbers, 3- Dimensional, Dissipation and Continuum. Modeling of turbulent flow is the development of a model and its use to estimate the turbulence effects. A turbulent fluid flow has characteristic structures of different time and length scales, which all intermingle with each other. To focus on modeling of large-scale and mean flow features of the flow the average the governing equations is obtained for the flow, but for most accurate results the small length scales and fluctuations should also be considered. When the flow is turbulent, the instantaneous flow variables (for example pressure and velocity) should be reduced to average and RMS value. One reason to decompose the variables is that when flow quantities are measured, more emphasis is made upon average values rather than their time responses. Second reason is that Navier-Stokes equation when numerically solved, a refined grid is needed to resolve all turbulent length scales and also need a fine resolution for time scale since turbulent flow is unsteady in nature.

There are many model available for turbulence fluid flow among these, K-epsilon (k-ε) model is the very common model used for turbulence in CFD to map average flow characteristics. It comprises of two partial differential equations which provides an account of turbulence. The reason behind development of the model was to replace the Prandtl's mixing-length model, also to look for an alternative to algebraically proposing length scales in moderate to high turbulent flows. The classic k-ε equations comprise of lot of unmeasurable expressions so to bring practical approach in the model, the standard model **(**Launder and Spalding, 1974) is opted which is founded on our knowledge of the fluid flow processes, thus reducing unknowns and developing the equations used in most of the fluid flow applications encountering turbulence. The partial differential equations for turbulent kinetic energy (k) and dissipation rate (ε) along with the governing equation to obtain mass fraction of sewage pollutant can be referred from **Section 3.7 of Chapter 3.**

7.2.3 Species Transport Model

Species transport in homogenous multi component model assumes that all the species are mixed on a molecular level and do not attempt to calculate any slip between the phases. Instead of any mixing this is assumed to come from turbulent diffusion. One set of governing equations plus a species transport equation is solved. This method solves the conservation equations for convection, diffusion, and response sources for more than one aspect species..

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla.(\rho \vec{v} Y_i) = -\nabla.\vec{J_i} + R_i + S_i \qquad (7.1)$$

This conservation equation describes the diffusion and convection of the mass fraction, of a species where Y_i. Called production rate by chemical reaction, and S_i called rate of creation due to effect of the dispersed phase and input sources. The diffusion flux Ji occurs due to concentration. Fick's law is the default:

$$\vec{J}_I = -\rho D_{i,m}\nabla Y_I - D_{T,i}\frac{\nabla T}{T} \tag{7.2}$$

Where $D_{i,m}$ stands for mass diffusion coefficient and $D_{T,i}$ is thermal diffusion coefficient. This approximation is conventionally good. With turbulence, accommodation is necessary as mixing must be explicitly included as function of turbulence at shorter length scales.

7.2.4 Mixture Model

The mixture model is defined with two of multiphase (fluid or particulate). The mixture model is a simple model for multiphase flows where phases move at unlike velocities. Homogenous multiphase flows can also be modeled using this model in which phases have very strong coupling. Using the Eulerian model, the phases can be treated as intermingling continua. The model solves the continuity equation for the mixture, the mixture momentum equation, the energy equation for the mixture, and equation of volume fraction for the subsidiary phases and suggests relative velocities of the dispersed phase. The mixture model proved as a good alternate of the Eulerian model for multiphase in numerous applications. A complete multiphase model may not be applicable when particulate phases are widely spread or when governing laws of interphase not known. Application of the mixture model consist of particle-laden which flows with less loading, sedimentation, flows having bubbles, and cyclone separators. The model can be applied without relative motion of the dispersed phase to model homogenous multiphase flow. The continuity equation for the mixture is

$$\frac{\partial(\rho_m)}{\partial t} + \nabla.(\rho_m \overrightarrow{v_m}) = \dot{m} \tag{7.3}$$

Where, v_m is mass-averaged velocity.

$$\overrightarrow{\mathrm{v_m}} = \frac{\sum_{k=1}^{n}\alpha_k\ \rho_k\ \overrightarrow{\mathrm{v_k}}}{\rho_m} \tag{7.4}$$

And, ρ_m is mixture density, given by:

$$\rho_m = \sum_{k=1}^{n} \alpha_k \ \ \rho_k \tag{7.5}$$

α_k stands for volume fraction of phase k and m is mass transfer because of cavitation or user-defined sources of mass. The equation of momentum balance for mixture can be obtained by adding individual momentum balance equation of all phases, expressed as:

$$\frac{\partial}{\partial t}(\rho_m \vec{v}_m) + \nabla \cdot (\rho_m \vec{v}_m \vec{v}_m) = -\nabla p + \nabla . \left[\mu_m \left(\nabla \overrightarrow{v_m} + \nabla \overrightarrow{v_m^T} \right)\right] + \rho_m \vec{g} + \vec{F} + \nabla . \left(\sum_{k=1}^{n} \alpha_k \, \rho_k \, \vec{v}_{dr,k} \, \vec{v}_{dr,k} \right) \tag{7.6}$$

where n is the number of phases, and F is a body force, μ_m is the viscosity of the mixture

$$\mu_m = \sum_{k=1}^{n} \alpha_k \, \mu_k \tag{7.7}$$

Volume Fraction Equation for the Secondary Phases

In the continuity equation for subsidiary phase p, the equation of volume fraction is calculated as:

$$\frac{\partial}{\partial t}(\alpha_p \rho_p) + \nabla . (\alpha_p \rho_p \vec{v}_m) = -\nabla . (\alpha_p \rho_p \vec{v}_{dr,p}) \tag{7.8}$$

where $\alpha_k$the volume fraction of secondary is phase p and $v_{dr,p}$ is the drift velocity of phase.

7.2.5 Solid Particle Trajectory Calculation

In a quiescent fluid, solid particle pollutants are small enough and obey Stokes law, the terminal rising velocity of the particles,V_s may be given by Stokes relation (Jha and Dash, 2002).

$$V_s = \frac{g(\rho - \rho_p)d^2}{18\mu} \tag{7.9}$$

However, when the liquid has motion, the velocityV_s becomes an additional vertical component to the fluid velocity. The particles that reache to the bottom surface of the canal by settling down were assumed to be trapped at the base. Solid particle pollutant trajectories have been calculated using Lagrangian particle tracking method, which solves a transport equation for each particle as it travels through. The mean local particle velocity component is needed to obtain the particle path.

The detailed methodology and equations to obtain this mean local particle velocity is described in **Section 3.7 of Chapter 3.**

7.2.6 Model Description

To achieve the defined objectives numerical investigations have been carried out using CFD tool Ansys Fluent. The computational domain has been prepared owing the dimensions of Ganga Canal from UGC Bridge, Roorkee Civil Line to Ganga Canal Bridge Near, Ganeshpur. Total five sewage inlets have been observed in the canal area undertaken. Hence, five sewage inlets have also been used in the computational domain. The computational domain i.e. model geometry developed based on geometrical data obtained Upper Ganga Canal between old canal bridge to Ganeshpur bridge, Roorkee, used for the analysis is shown **in Figure 3.2 of Chapter 3**. The dimensions of the canal modelled are length 1397.715 m, depth 8 m and width 60 m. The inlet of the each sewage is taken as circular inlet of diameter 0.4 m, 0.5 m away from the canal wall. Further, geometry has been subdivided into 85440 elements with structured hexahedron meshing. The mesh developed into the geometry can be visualized from the **Figure 3.3 of Chapter 3**. The three-dimensional mesh geometry of the canal is shown in **Figure 7.1.**

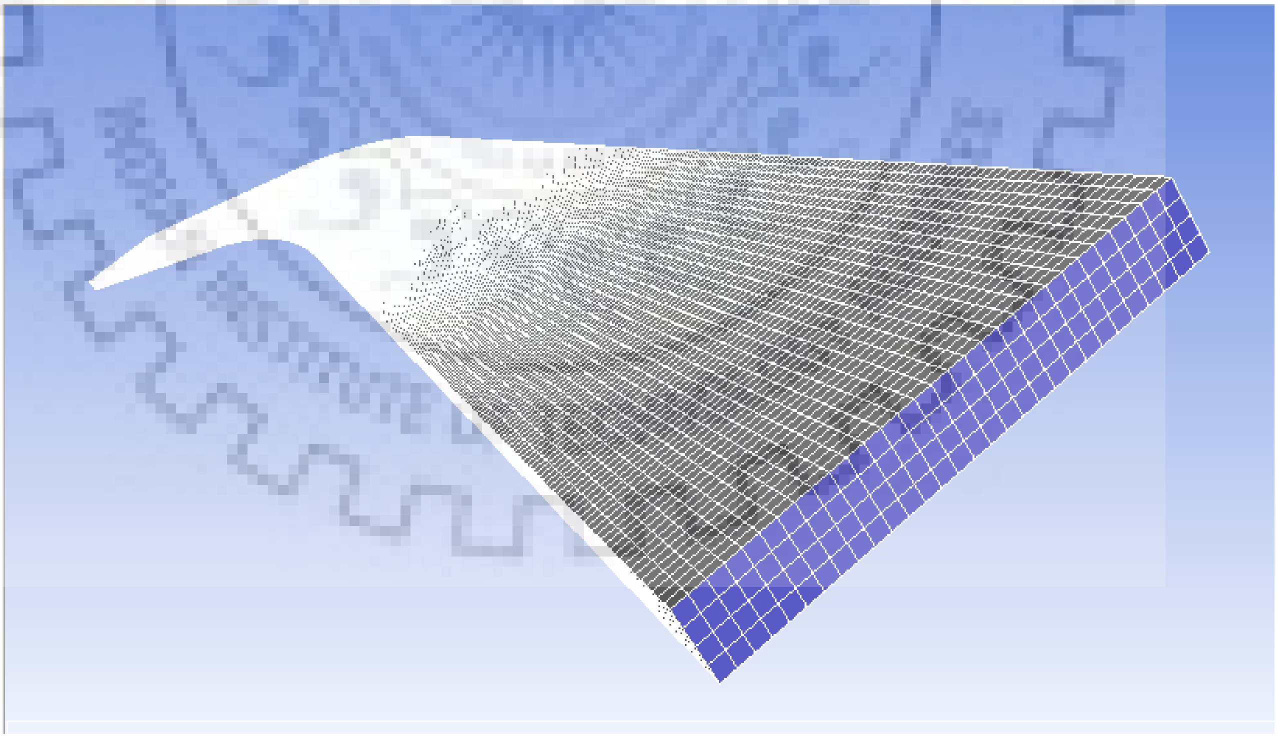


Figure 7.1 Three dimensional mesh geometry of canal

7.2.7 Boundary Condition and Material Properties

Four types of boundary conditions were used in this study, as detailed below:

1. Inlet velocity: Velocity perpendicular to the inlet plane of the model of the canal is specified to achieve a specific flow rate.
2. Outflow: An outflow boundary condition is specified at an outlet of the canal to achieve a specified fraction of the total inflow throughout the cross section of the outlet.
3. Sewage inlet: Five sewage inlets are given in the model of the canal, one on the right side and four on the left side of the canal having variation in average inlet velocities from 0.2, 0.4 and 0.6 m/s (common for all sewage inlets for each variation).
4. Walls: All surfaces of the canal; bottom, top, left hand side wall and right hand side wall are treated as non-slip walls. On these surfaces, velocity is kept zero.
5. Slip wall: The water surface is treated as a flat, zero shear stress wall that allows water to freely slip on the surface.

Table 7.1 Boundary Condition and Material Properties Used

Boundary condition /Process parameters	**Value**
Length of canal modelled (m)	1397.715
Width of canal (m)	60
Depth of canal (m)	8
Sewage inlet diameter (m)	0.4
Velocity at old canal bridge near civil line (m/s)	0.981
Average Sewage velocity (m/s)	0.2, 0.4 and 0.6
Density of water (kg/m3)	998.2
Density of sewage pollutant (kg/m^3)	1300
Mass diffusivity of mixture (m^2/s)	2.88×10^{-9}
Density of solid particle (kg/m^3)	1200, 1500, 2000
Diameter of solid particle (m)	0.00015, 0.00008, 0.000023, 0.000008, 0.0000023

All the fluid flow equations are discretized and solved simultaneously using solver of Ansys Fluent 16.0. The conservation equations for convection and diffusion for the mass fraction of sewage pollutant has been solved using user defined scalars of fluent module. As sewage pollutant are injected vertical to the fluid flow of canal water, mixing (diffusion) starts due to concentration gradient (according to Fick's law). Sewage pollutant is simultaneously dispersed due to mixing of sewage pollutant in canal water and the rate of mass fraction of sewage pollutant is decreased for one sewage opening side of canal but for other side of canal it is increased. Second order implicit scheme has been used for discretization to achieve higher order of accuracy. Turbulence parameters were calculated using standard k–ε turbulence model. An asymmetric turbulence behaviour of fluid flow and mass fraction of sewage pollutant has been reported in literature, hence symmetric boundary condition has not been applied i.e. complete cross sectional geometry has been considered for numerical Investigation. Simulation was carried out in transient state till the steady state of fluid flow and mass fraction of sewage pollutant has been achieved at outlet of canal (Ganeshpur Bridge). It has been observed that after 1500 seconds of run, steady state condition is achieved. Owing to slow convergence, initial time step of 0.1seconds and 200 maximum iterations per time step has been employed. The solution convergence has been achieved with momentum residuals less than a value of 10^{-4}. Computation time of each simulation was approximately 1 days on a laptop of 8GB RAM and CORE i5 7th Gen processor.

7.2.8 Assumptions

Following are the assumption that are employed in this work:

1. Flow is assumed to be unsteady and incompressible.
2. Air and gas entrainment diffusion in water flow is neglected.
3. Properties of material is assumed to be constant irrespective to pressure or temperature.
4. Surface roughness is assumed to be negligible near the wall.
5. No Phase transformation during this process.
6. The surface of the canal is considered to be perfectly flat and cross section of the canal was considered to be rectangular.
7. The canal structure old bridge to Ganeshpur Bridge assumed to be bend at middle part of specified domain that is curvature.

8. The effect of natural convection is neglected while computing the velocity field in the canal.
9. No slip condition has been considered at wall.
10. Pressure velocity coupling has been considered (SIMPLE) for solution control.
11. Momentum, volume fraction of sewage pollutant, turbulence kinetic energy and turbulence dissipation rate is considered for first order upwind in solution control.

7.3 Result and Discussion

The detailed results of the numerical modeling using CFD are discussed below in detail.

7.3.1 Analysis Based on Species Transport Model

Mass transport study is done in fluid mechanics to obtain velocity field of flowing fluid in any control volume. Most of the transport phenomenon is probabilistic or statistical in nature because of erratic continuous motion of fluid particles. The governing laws which govern the transport phenomena are generally, continuity and Navier stokes equations, describe how the quantity being studied must be conserved. The continuity equation confirms the conservation of mass making the fluid flow valid and Navier-Stokes equations describes the relationship between fluid flux and the forces applied to the fluid. Mass Transfer in a system is governed by Fick's First Law. Diffusion flux is dependent on concentration gradient and the diffusivity of the substance in the flow going on from higher concentration to lower concentration. In the present study the sewage pollutant particles are getting mixed and transported along the stream flow of the canal. There are many phases involved in this kind of fluid flow phenomenon moreover, there is change in the concentration of one phase (sewage particles) due to physical phenomena like convection, diffusion and dispersion. To understand such a complex fluid flow situation for modelling the flow a very effective and efficient mass transport model was required. Species transport model is such kind of model technique which helps in determining the mass fraction of sewage at any spatial location in the flow field and at any interval of time.

7.3.2 Mixing of sewage pollutant with canal water

To show the mixing phenomena in the canal, mass fraction of sewage pollutant in the river Ganga canal water has been predicted. **Figure 7.2** shows the contour of sewage pollutant at the top surface of the canal. For the case, inlet velocities of all the sewages are kept constant at 0.4 m/s.

Looking precisely it can be seen that sewage pollutant are restricted in the region near the canal wall and moves along the canal water flow direction. The view is not able to clearly explain the mixing phenomena. Hence, the region near all the sewage inlets are scaled-up to have clear visualization, shown in **Figure 7.3**. It can be seen that near sewage inlet 1 and 2, mass fraction of sewage pollutant quickly reduces while moving in the direction of canal water flow. Moving away from the computational domain inlet (inlet of canal considered) the rate of reduction of mass fraction of sewage pollutant are gradually reduces (can be seen near sewage 3, 4 and 5). This decrease in rate of reduction in mass fraction of sewage pollutant is because of addition of previous sewage pollutant with the pollutant of next sewage and gradual increases the overall mass fraction of pollutant in the canal water.

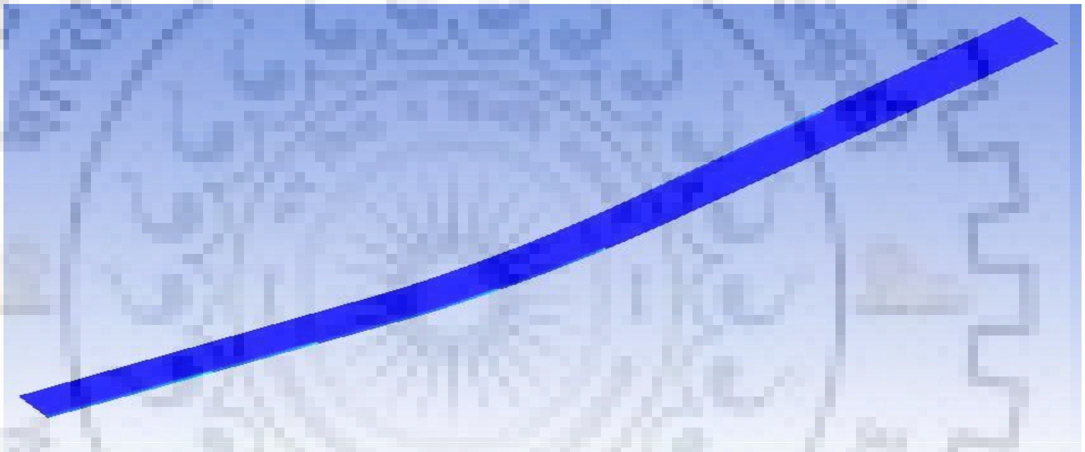
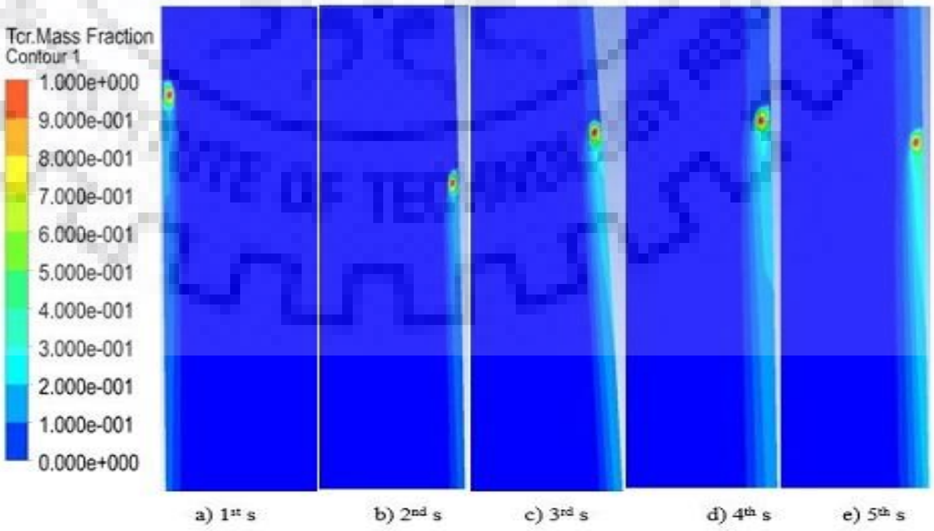


Figure 7.2 Contour of mass fraction of complete domain



a) 1st s b) 2nd s c) 3rd s d) 4th s e) 5th s

Figure 7.3 Contour of mass fraction of sewage pollutant at each inlet of sewage

Figures 7.2 and 7.3 shows the contour of mass fraction of sewage pollutant at the top surface of canal whereas, in **Figure 7.4,** it can be seen that mixing of sewage pollutant in upper Ganga canal near the walls of the canal occurs in the direction of flow. The figure indicates that the dispersion of pollutant increases towards the depth as we move from first sewage opening to last one when all sewage are simultaneously opened this is because of cumulative effect of upstream sewage openings on the respective sewages. Although the rate of dispersion of sewage pollutant from one source of sewage inlet reduces in the right side of the canal and finally constant value is obtained at outlet of canal (at Ganeshpur Bridge). While in left side of canal, rate of dispersion effect increases because of cumulative effect of upstream sewage pollutant after 2nd sewage inlet source and beyond.

Figure 7.4 Contour of mass fraction of sewage pollutant in both side of canal at each sewage inlet

To analyse the result quantitatively, the mass fraction of the pollutant has been tracked at the outlet of the computational domain (near to Ganeshpur Bridge).The predicted time dependency of mass fraction of sewage pollutant can be seen graphically in **Figure 7.5.** Sewages were opened successively one after another and then, the changes were observed. The observations that can be made from the **Figure 7.5** that equilibrium position of the mass fraction of sewage pollutant is achieved at the same time irrespective of the sewage openings. It is also observed that, the rate of mass fraction of sewage pollutant is gradually increasing because of successive opening of sewages although diffusion has occurred, however because of cumulative effect of sewage, the mass fraction of sewage increases at the outlet of canal.

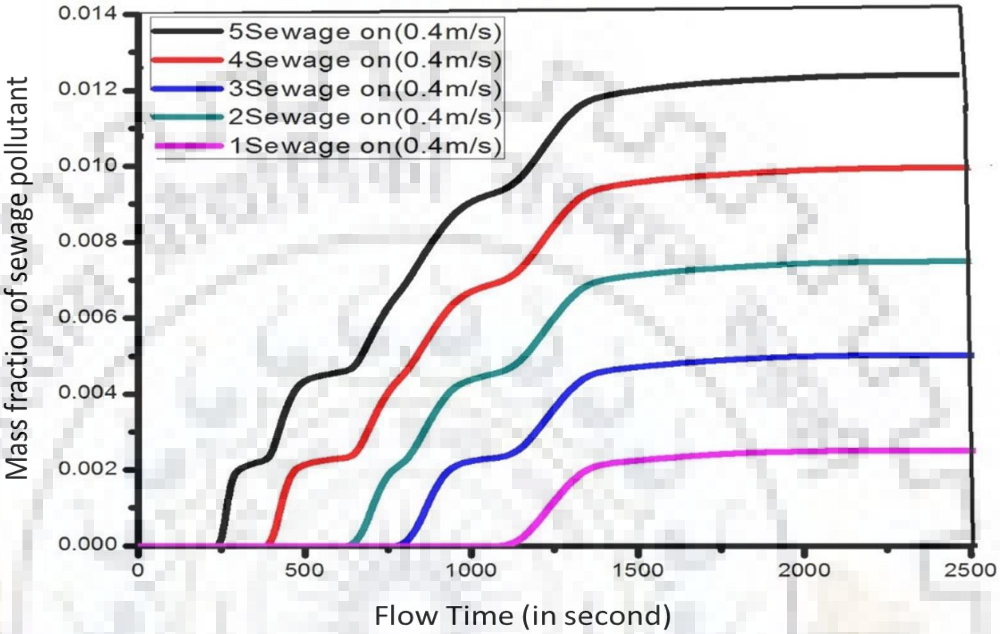


Figure 7.5 Variation of mass weighted average of sewage pollutant with flow time

7.3.3 Effect of sewage velocity

The contour diagrams **(Figures 7.2, 7.3 and 7.4)** indicates that dispersion of sewage pollutant at constant sewage velocity but the effect of sewage velocity on different parameters has also been analysed in **Figure 7.6.** It was observed that dispersion of sewage pollutant in to the upper Ganga canal increases with the increase of velocity of sewage flow. This observation that has been tracked at outlet of canal (at Ganeshpur Bridge) from **Figure 7.6** that most of the dispersion effect of sewage pollutant has been observed near the left wall and further increases with the velocity of sewage along the width but rate of mass fraction of sewage pollutant reduces and fraction of sewage pollutant is more concentred in left side at outlet near the wall of canal. Whereas, mass fraction of sewage is found very less in right side of canal due to less diffusion of pollutant.

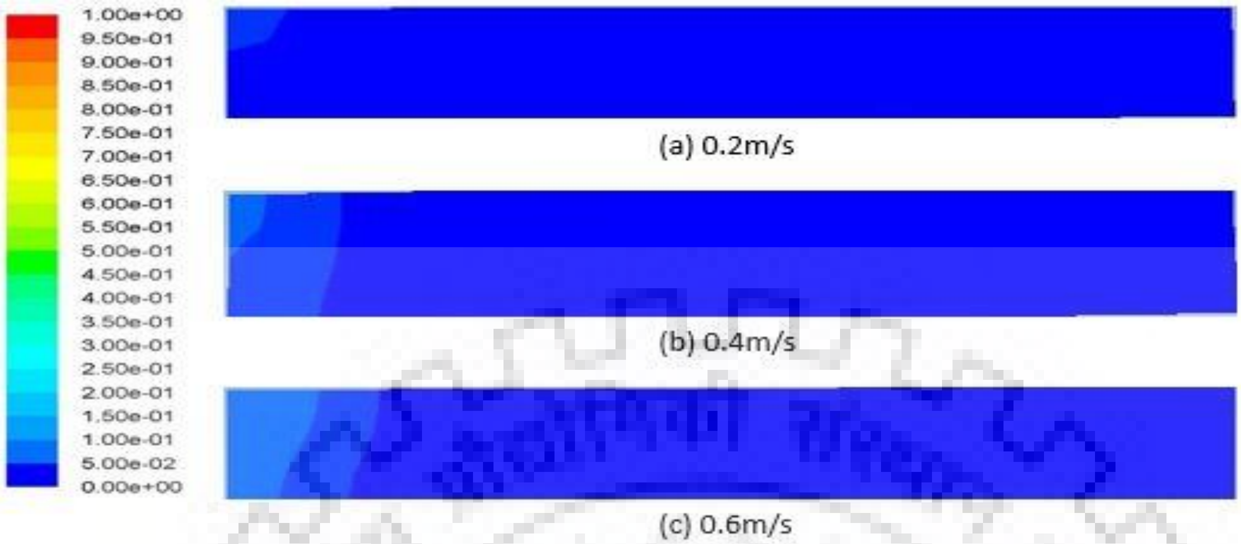


Figure 7.6 Contour of mass fraction of sewage pollutant at outlet of canal with five open sewage inlet with different velocities

To predict the flow behaviour of sewage pollutant from individual sewage inlet, path line has been developed as shown in **Figure 7.7**. These path lines indicate that effects of sewage pollutant from the top surface are increasing along the direction of fluid flow with the increase of velocity of sewage pollutant.

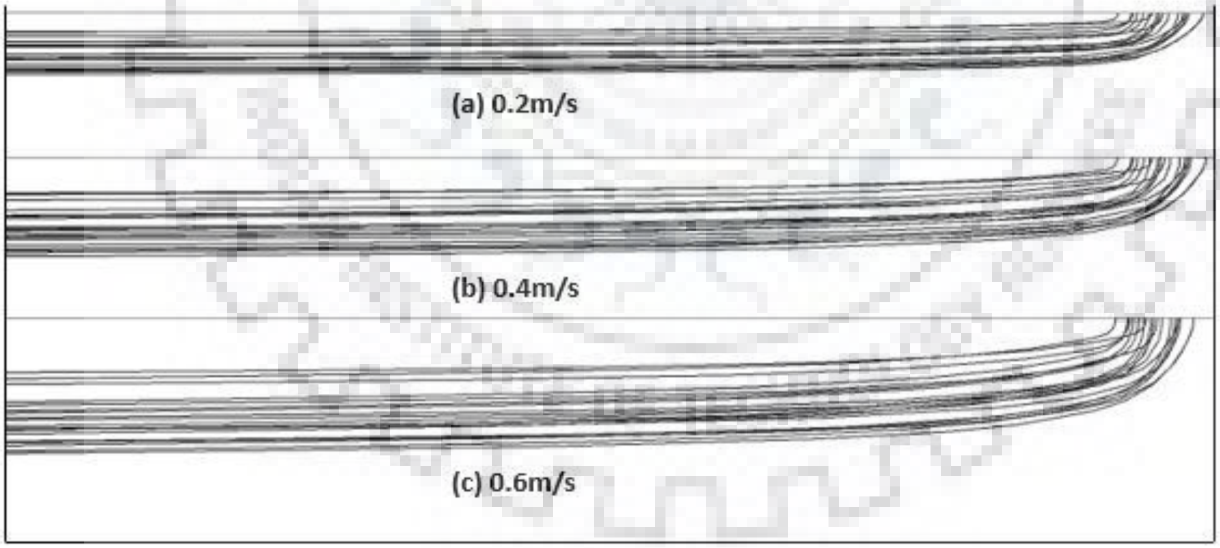


Figure 7.7 Flow behavior of sewage pollutant in canal

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To analyse the result quantitatively, the mass fraction of the sewage pollutant has been tracked at the outlet of the computational domain (near to Ganeshpur Bridge). The **Figure 7.8** shows the variation of mass fraction of sewage pollutant obtained at the outlet of canal after applying species transport model in the analysis of upper Ganga canal near Ganeshpur Bridge. This graph depicts that with the increase in velocity mass fraction of pollutant is also increasing at the outlet of the canal. It is due to less time available for diffusion of pollutant within the canal water with respect to velocity of the flow. As the length of canal outlet is constant and sewage velocity is increased, this modelled cause shows that with the increase in velocity, diffusion within the pollutant is poor which cause an abrupt increase in fraction of the pollutant at the Ganeshpur Bridge. Steepness in the flow of sewage with mentioned velocity in the **Figure 7.8** depicts an in-depth perspective of time with which the pollutant of respective sewage opening reaches the outlet. As it can be seen clearly from the graph that sewage opening which is more near to the outlet reaches outlet within less time when compared with the farthest sewage. Abrupt mixing of pollutant with opened sewages at an increased rate with increase in velocity. Equilibrium position of the sewage pollutant amount is achieved at the same time irrespective of the velocity, as it can be clearly seen from the **Figure 7.8**.

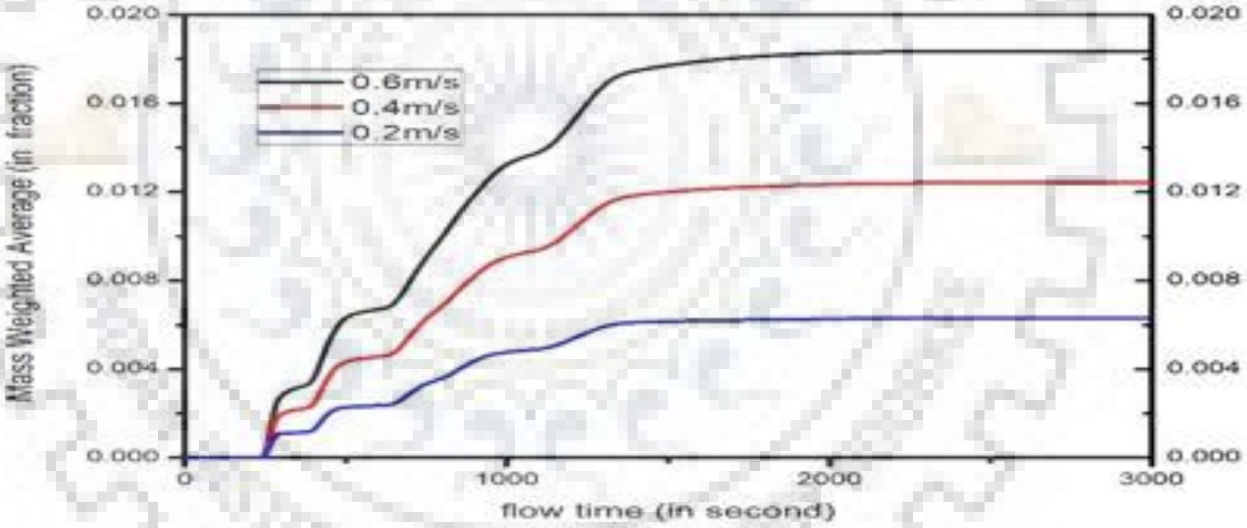


Figure 7.8 Variation of Mass weighted average of sewage pollutant with flow time at different velocity of sewage

Effect of sewage velocity on mass fraction of sewage pollutant is also detected along the width (60m) of canal at outlet. From **Figure 7.9,** it is observed that mass fraction of sewage is decreasing toward the depth and variation of sewage fraction lies between 0.025 and 0.065 in left side of canal, but in right side of canal mass fraction of sewage is constant (less than 0.01) at outlet because of only one opening of sewage . From **Figure 7.10,** it is also observed that mass fraction of sewage is decreasing toward the depth and variation of sewage fraction lies between 0.075 and

0.11 in left side of canal, but in right side of canal mass fraction of sewage is constant (lies between 0.01 and 0.02) at outlet because of only one opening of sewage. From **Figure 7.11,** it is observed that mass fraction of sewage pollutant is increasing with the velocity of both sides of the canal. It is observed that mass fraction of pollutant lies between 0.12 to 0.14 in left side of canal at outlet and in right side more than 0.02.

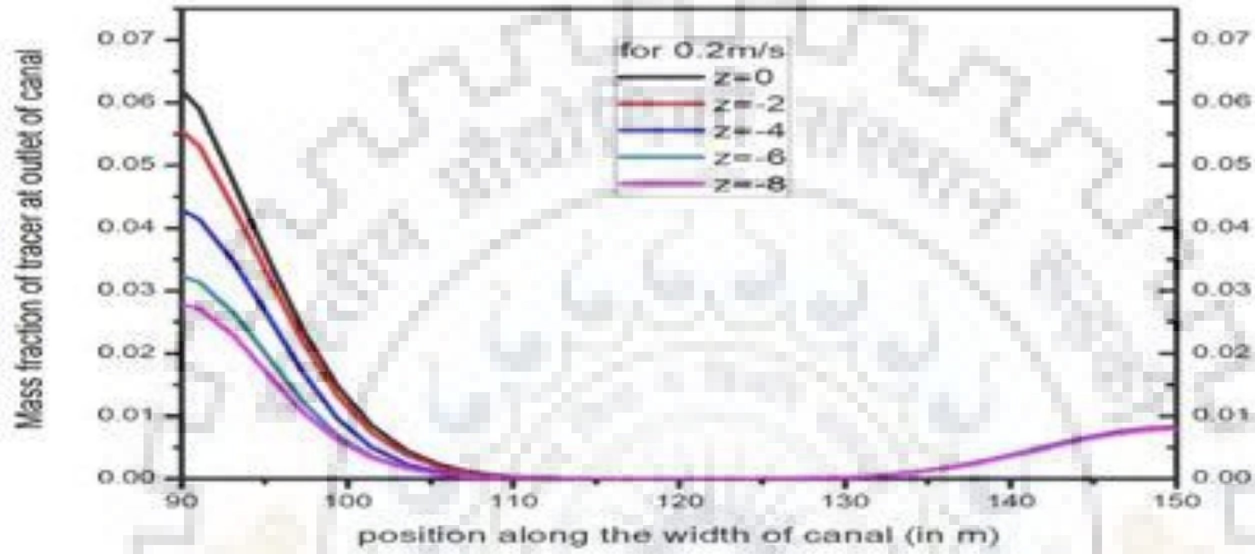


Figure 7.9 Variation of sewage pollutant mass fraction along the width at constant sewage velocity (0.2m/s)

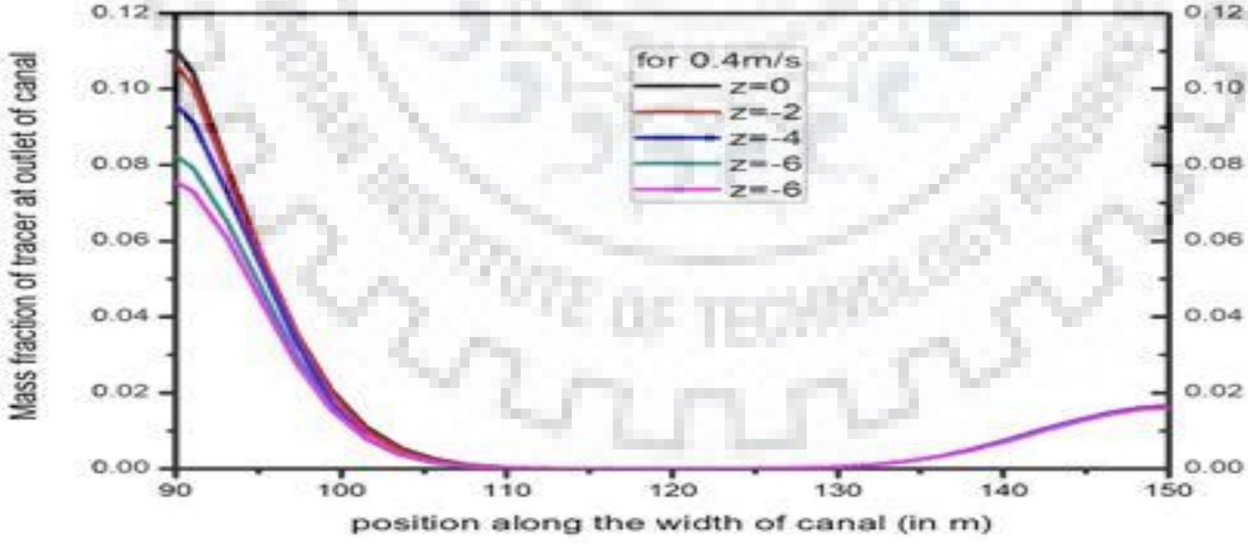


Figure 7.10 Variation of sewage pollutant mass fraction along the width at constant sewage velocity (0.4m/s)

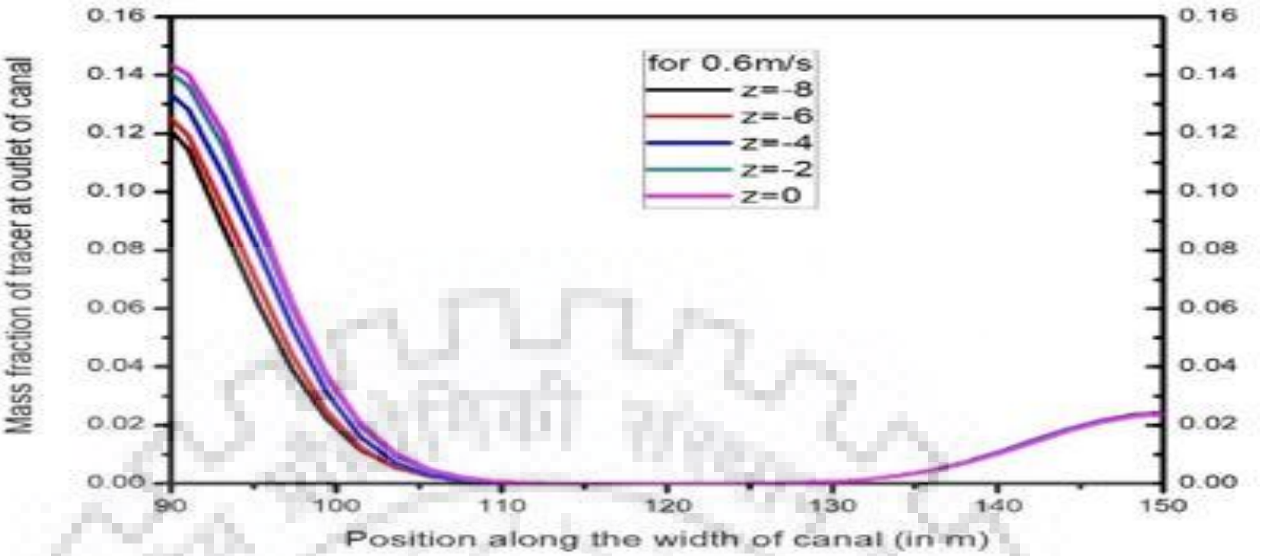


Figure 7.11 Variation of sewage pollutant mass fraction along the width at constant sewage velocity (0.6m/s)

The above figure depicts the variation of sewage concentration at different depths. All the five sewages are opened in the above three **Figures 7.9, 7.10 and 7.11** at different velocities of 0.2 m/s, 0.4 m/s and 0.6 m/s respectively. Four sewages are opened from the left side and one are opened from the right side of the canal. Sewage concentration checked at depth of every 2 meters from the free surface up to 8 meter depth, till its value becomes zero between the canal width of 110 meter and 130 meter. It can be said that water present within the width of 20 meter from the either side of the center of canal is pollutant free throughout the depth. Concentration of the pollutant is increasing with increase in velocity of the sewage flow inside the canal, because of less diffusion of sewage.

7.3.4 Velocity Profile of Fluid Flow

As the experimental data for the horizontal velocity profile is available, the validation of the experimental and predicted velocity profile could be judged, also the predicted velocity profile agrees the theoretical understanding. Therefore, conclusion is made indirectly that CFD simulation is capable of validating the velocity profile. As shown in **Figures 7.12 and 7.13** below that two phase velocity profile is generally asymmetric in nature about longitudinal axis at different velocities of sewage, which is due to irregular dispersion and diffusion of pollutant after injection of pollutant through sewage inlet in fluid flow direction. At higher velocities this asymmetrical nature is reduced but still the most of the sewage pollutant concentration is dispersed near to the wall of canal.

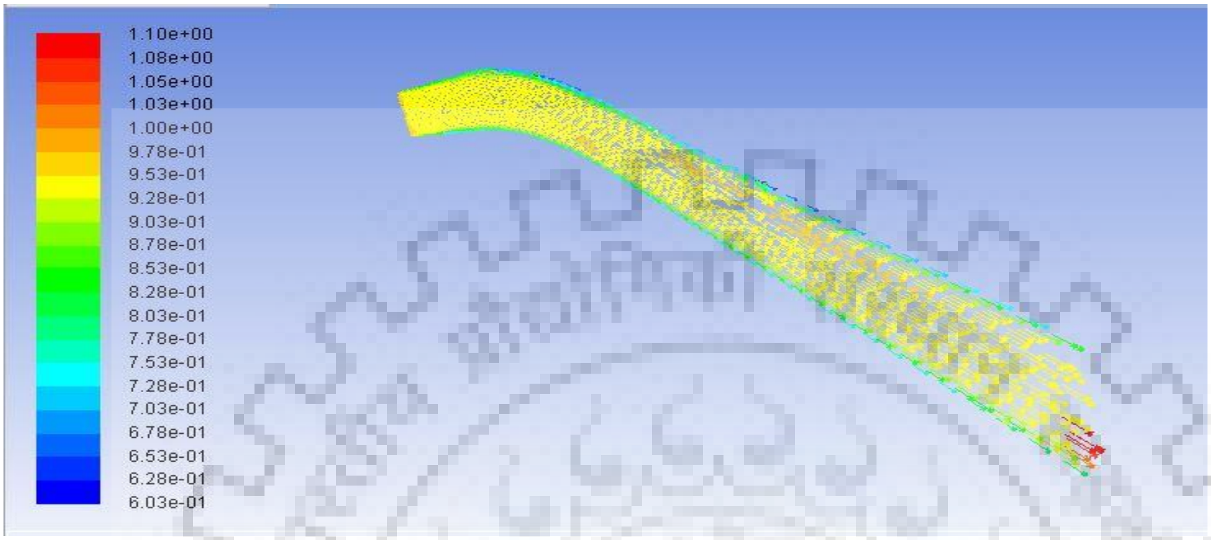


Figure 7.12 Velocity profile of fluid flow along horizontal plane at 0.2m/s sewage velocity

Asymmetric Velocity variation along the horizontal plane is shown in **Figures 7.12 and 7.13**. In case of sewage velocity = 0.2 m/s, the maximum velocity obtained at outlet (Ganeshpur bridge) is 1.10 m/s as can be seen from the graph and at sewage velocity = 0.4 m/s, the velocity near to Ganeshpur bridge is 1.11 m/s obtained, which matches with the established experimental data.

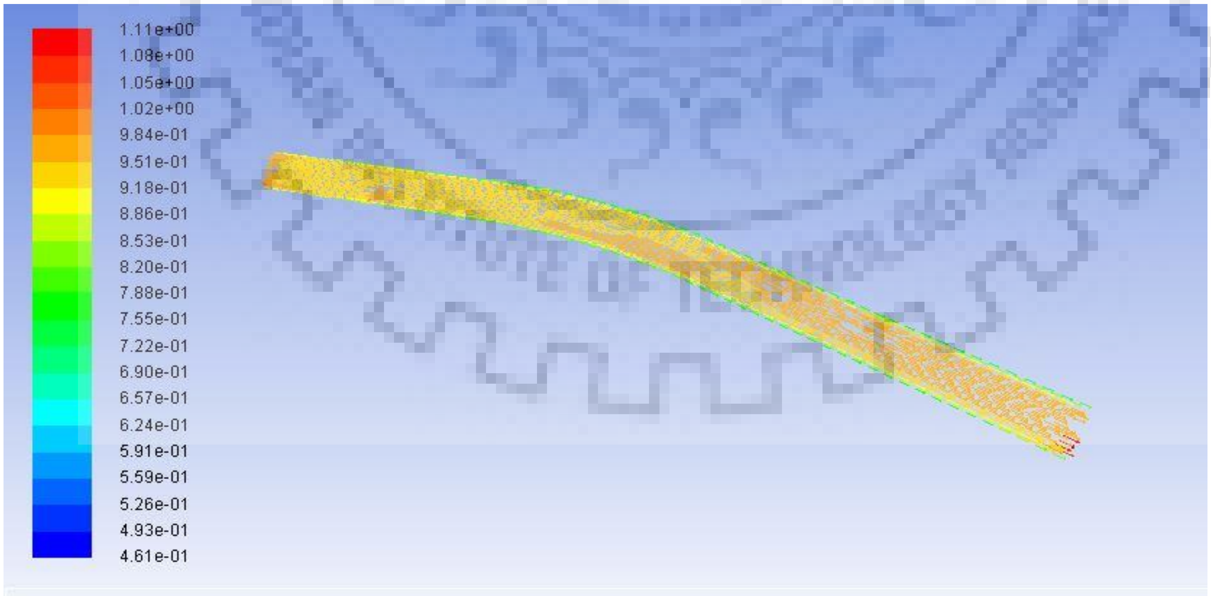
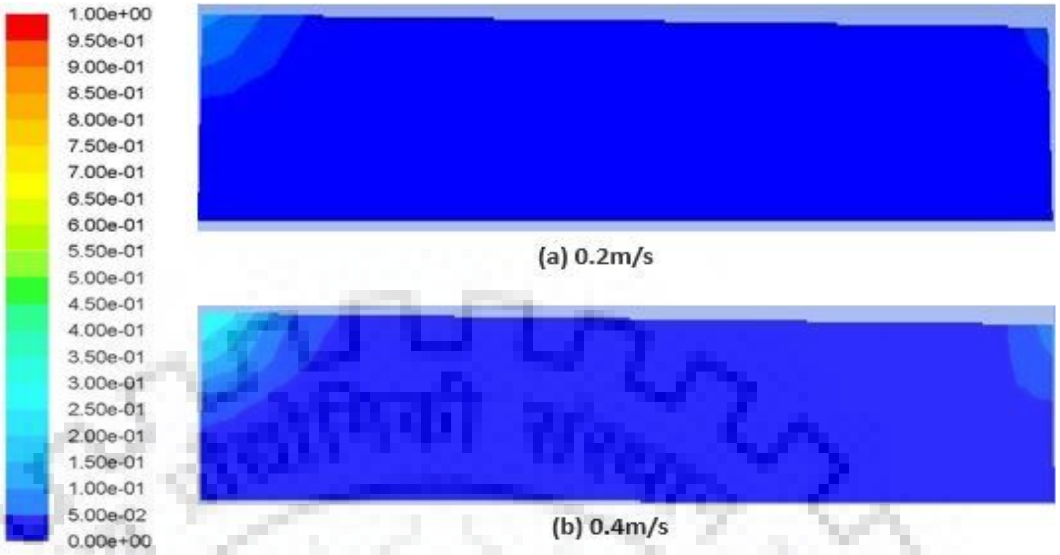


Figure 7.13 Velocity profile of fluid along horizontal plane at 0.4m/s sewage velocity



(a) 0.2m/s

(b) 0.4m/s

Figure 7.14 Effect of mixing of sewage pollutant in canal water with changing of velocity

7.3.5 Analysis Result of Mixture Model

Contour of volume fraction of phase 2 (swage pollutant) for 0.2m/s and 0.4m/s sewage velocity at outlet of canal has been discussed in the present section. The above contours **(Figure 7.14)** of mass fraction of sewage are obtained using mixing model. Here it can be seen that the concentration of pollutants increasing at the outlet of canal with increase in the sewage velocity. This is in contrast with the species transport model since no diffusion occurs in mixing model. Dispersion of pollutant is also less toward the depth and along the length of canal. Dispersion of sewage pollutant in fluid flow along the length of canal is shown in **Figure 7.15.**

Figure 7.15 Contour of mass fraction of sewage pollutant at each sewage inlet (0.4m/s) at the top surface of canal

In this contour of mass fraction it can be seen that the dispersion of right side sewage is not so much prominent. This result is similar for the first sewage on the left side too but at subsequent sewage points the cumulative effect of upstream sewage could be seen as the dispersion increases as we moved from first sewage to last sewage location. In case of mixing model the value of mass fraction of sewage pollutant matches with the mass fraction of sewage pollutant deduced from qualitative analysis of experimental data. Mass fraction variation of sewage pollutant is also examined towards the depth of canal at subsequent sewage inlet. Effect of sewage pollutant towards the depth of canal from the 2nd sewage to 5th sewage along the longitudinal direction near to left side wall of specified domain is shown in **Figure 7.16.** It can be seen that when all the sewages are open then cumulative effect of dispersion can be seen at subsequent sewages on the left side of canal and this effect exists along the length of the canal. Dispersion of sewage pollutant is less affected after 4m depth. The effect of dispersion in species transport model is observed more than mixture model toward the depth as shown in **Figure 7.4.**

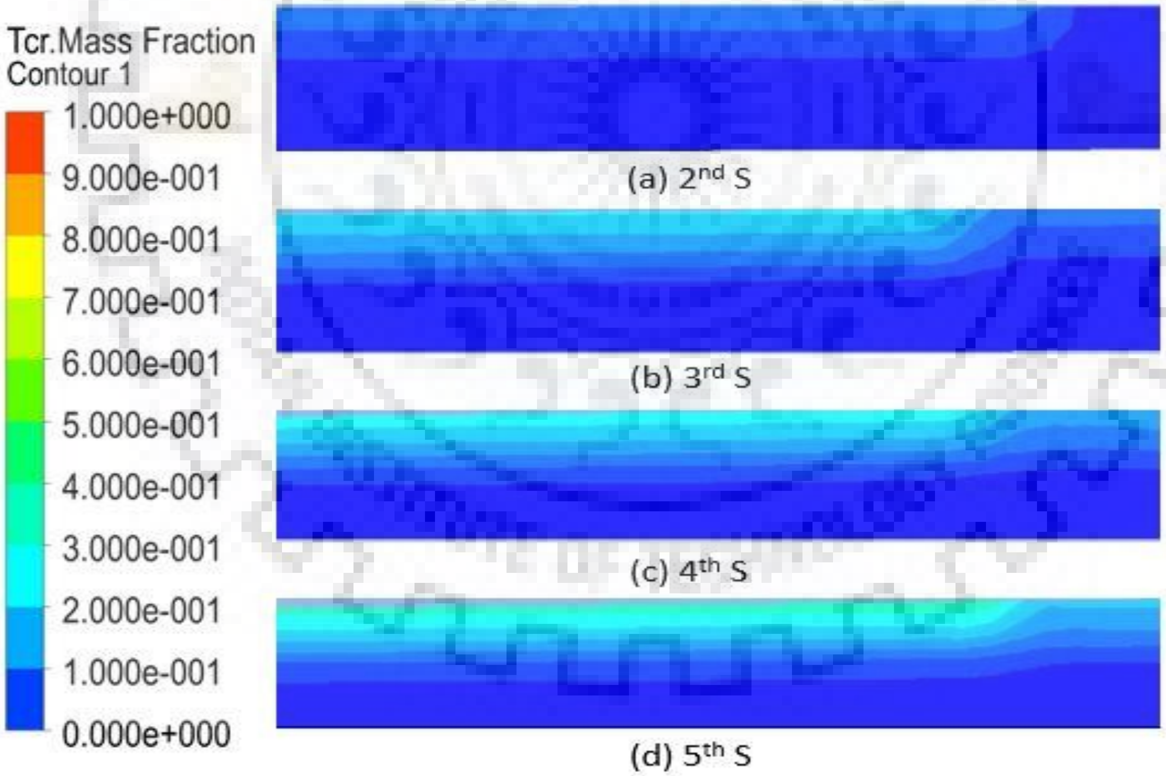


Figure 7.16 Contour of mass fraction of sewage pollutant at each sewage inlet (0.4m/s) near to left side wall of canal

To analyse the result quantitatively, the mass fraction of the sewage pollutant has been tracked at the outlet of the computational domain (near to Ganeshpur Bridge). The **Figure 7.17** shows the variation of mass fraction of sewage pollutant obtained at the outlet of canal after applying Mixture model in the analysis of upper Ganga canal near Ganeshpur Bridge.

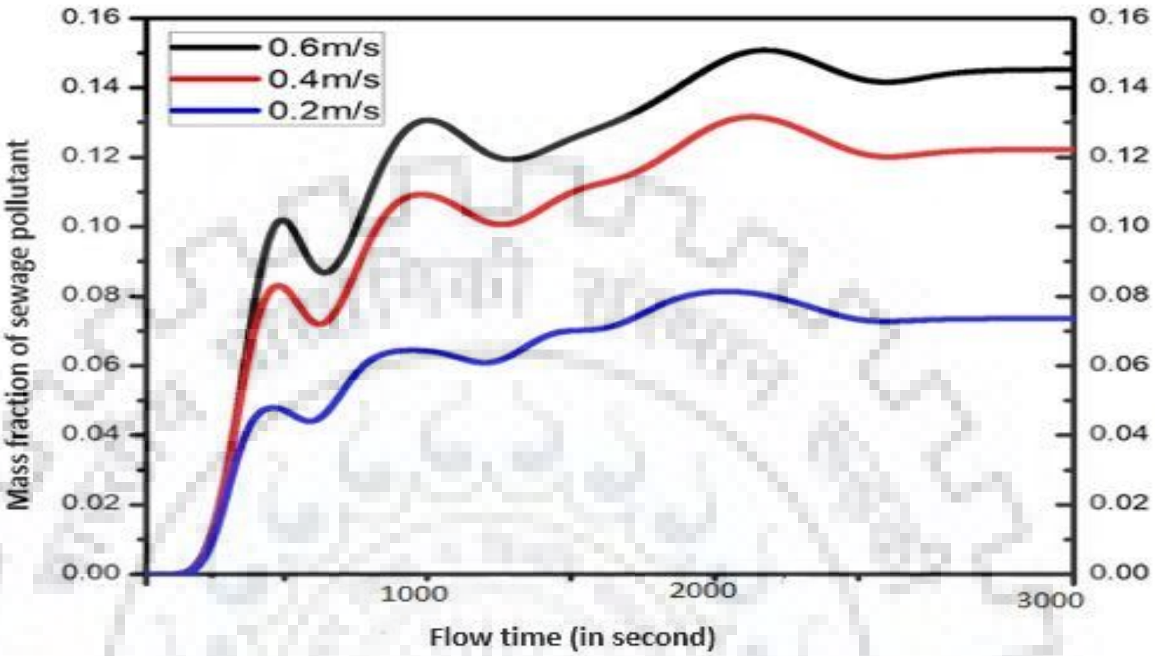


Figure 7.17 Variation of mass fraction of sewage pollutant with flow time

Figure 7.17 shows the mass fraction of the sewage pollutant in the canal water at the outlet of the computational domain. The mass fraction of pollutant has been tracked for three different cases (a) at 0.2 m/s, (b) at 0.4 m /s and (c) 0.6 m/s velocity of incoming pollutant through all the sewage inlets. It can be seen that first visible increase in mass fraction of pollutant is obtained after 450 seconds (approx.). This depict that time taken by pollutant coming from sewage 5 is 450 seconds. Further, quick rise in sewage concentration can be seen for all the three cases. After attaining a peak value, the mass fraction of pollutant decreases and again rises. The initial rise in the curve is because some portion of the pollutant does not mix with the water and directly moves out from the domain outlet. Later, it become stable as the pollutant homogenously mixes with water, which attains the average mass fraction of pollutant (of sewage 5 only) in canal water. Hence, mass fraction of pollutant decreases to stable condition. In progression, pollutant coming from sewage 4 again increases the mass fraction of pollutant. Similar change in mass fraction of pollutant have been observed for all the sewages. After sewage 5 pollutant reaches to domain outlet, the equilibrium of mass fraction can be seen in the figure. It can also be seen from the **Figure 7.17** that the pattern of change in mass fraction are same at all the three velocities and the occurrence of rises and falls in mass fraction are at the equal time duration. However, the value of mass fraction of pollutant increases with the increase in sewage inlet velocity.

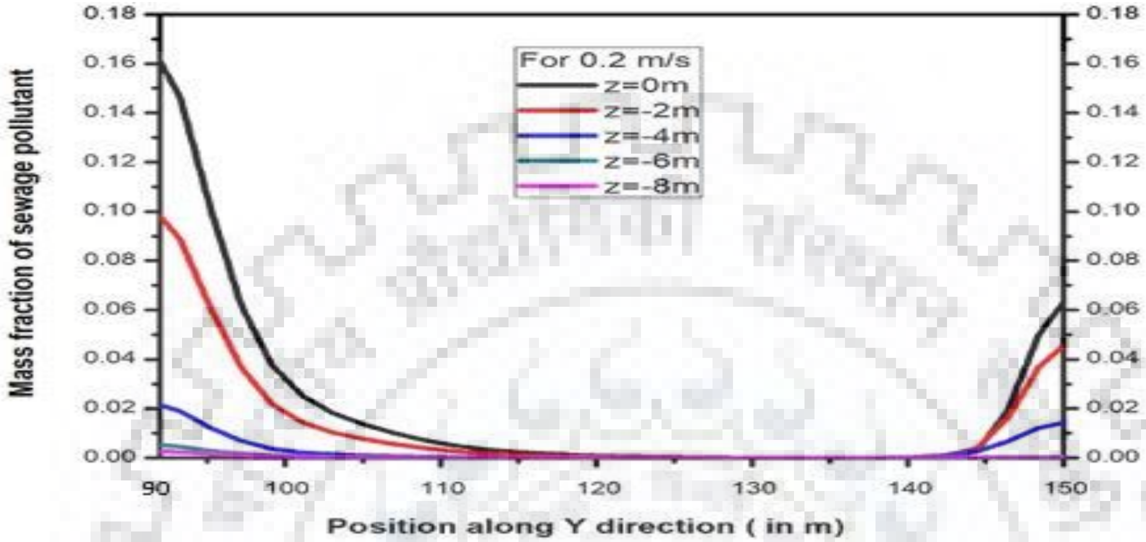


Figure 7.18 Variation of mass fraction of sewage pollutant along the width toward the depth at outlet

Figure 7.18 shows the mass fraction of the sewage pollutant in the canal water at the outlet of the computational domain using mixing model at 0.4 m/s sewage velocity. The mass fraction of pollutant can be seen decreasing from top free surface to bottom of the canal in the graph. The effect of pollutant is observed up to 10 m distance from left bank of the canal and up to 30 m from the right bank of the canal. Pollutant free zone is of 20 m same as in species transport model. In this model considerable variations in the mass fraction of sewage along the depth of the canal can be seen near the left bank where as in species transport model this variation was negligible. The variation in mass fraction along the depth ranges from 0.063 to 0.014 as we go along the depth for the right bank whereas, The variation in mass fraction along the depth ranges from 0.16 to 0.02 as we go along the depth for the left bank. This range of variation in mass fraction in this model is more than twice than that in species transport model. The lack of diffusion of pollutant is the main cause for such results in mixing model.

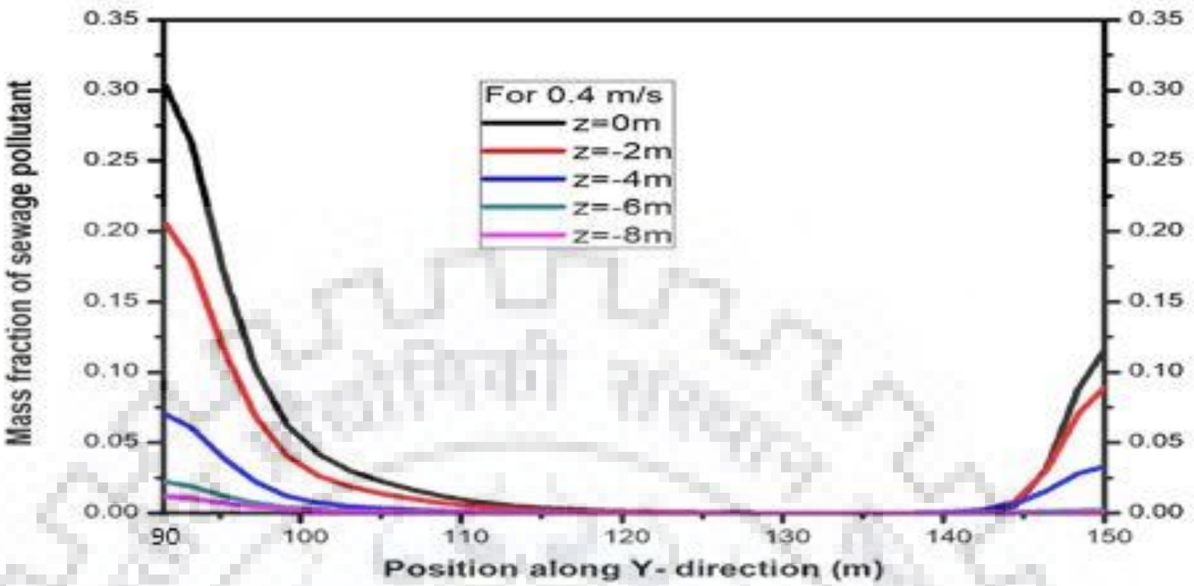


Figure 7.19 Variation of mass fraction of sewage pollutant along the width toward the depth at outlet

Figure 7.19 shows the mass fraction of the sewage pollutant in the canal water at the outlet of the computational domain using mixing model at 0.4 m/s sewage velocity. The trend is same in the graph as in previous graph of mass fraction variation for 0.2 m/s sewage velocity but the range is more. The variation in mass fraction along the depth ranges from 0.13 to 0.003 as we go along the depth for the right bank whereas, The variation in mass fraction along the depth ranges from 0.31 to 0.01 as we go along the depth for the left bank.

7.3.6. Dispersion of Solid Particles in the Canal

From the sewage inlet, solid particles also move into the canal. These solid particles are of different properties such as density, size, chemical properties, etc. Chemical properties decide the dissolution of these particles into the water, which further affects the water quality for drinking and irrigation use. However, in present study, the chemical property of the solid particle pollutant has not been considered and assumed to be inert that does not have any reaction with the canal water. The size and density of the solid particles have been varied to study the flow and settling to the bottom of the canal. The shape of the particles are assumed as spherical and five different diameters (D1 = 0.00015 m, D2 = 0.00008 m, D3 = 0.000023 m, D4 = 0.000008 m, and D5 = 0.0000023 m) and three different densities (1200 kg/m^3, 1500 kg/m^3, and 2000 kg/m^3) have been studied. The selection of these size and density has been made based on the flow the small sand particles with the sewage pollutant. During the study, it has been assumed that when solid particles settles down it get trapped to the canal base. The simulation has been performed with the insertion of 1000 solid particles of equal diameter and density, with the sewage pollutant from the sewage inlet.

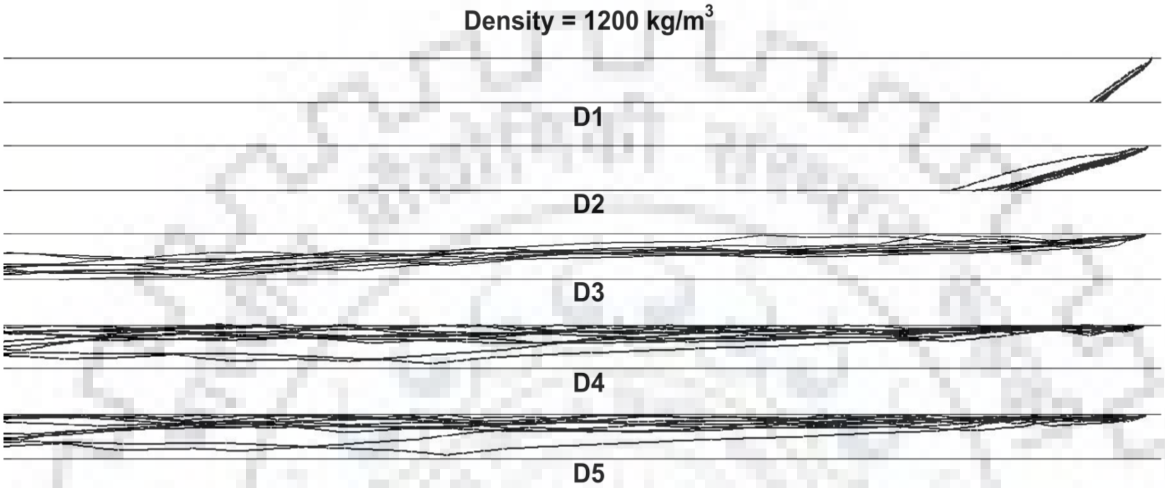


Figure 7.20 Track path of solid particles of density 1200 kg/m^3, along the canal water flow direction

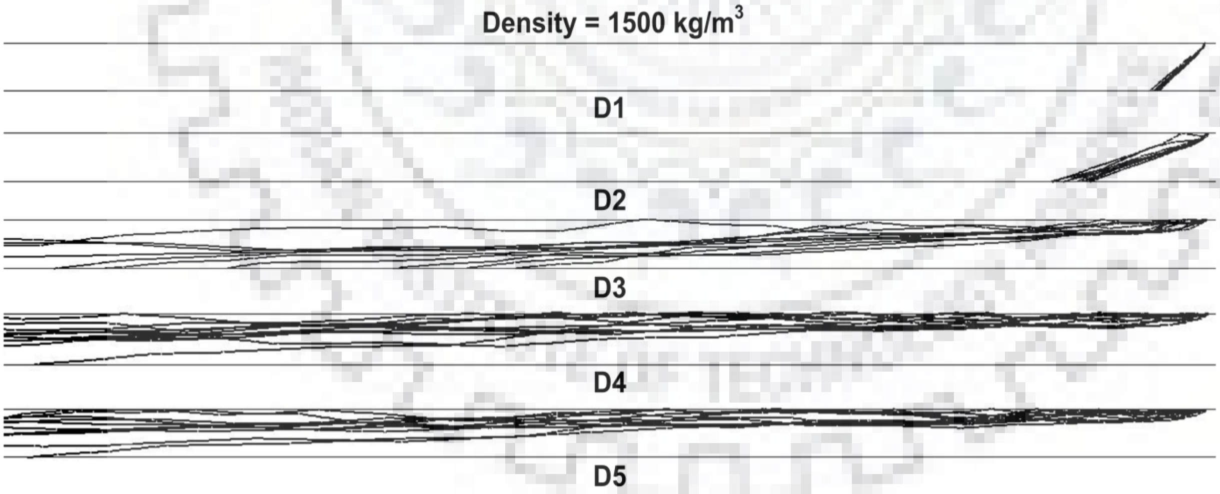


Figure 7.21 Track path of solid particles of density 1500 kg/m^3, along the canal water flow direction

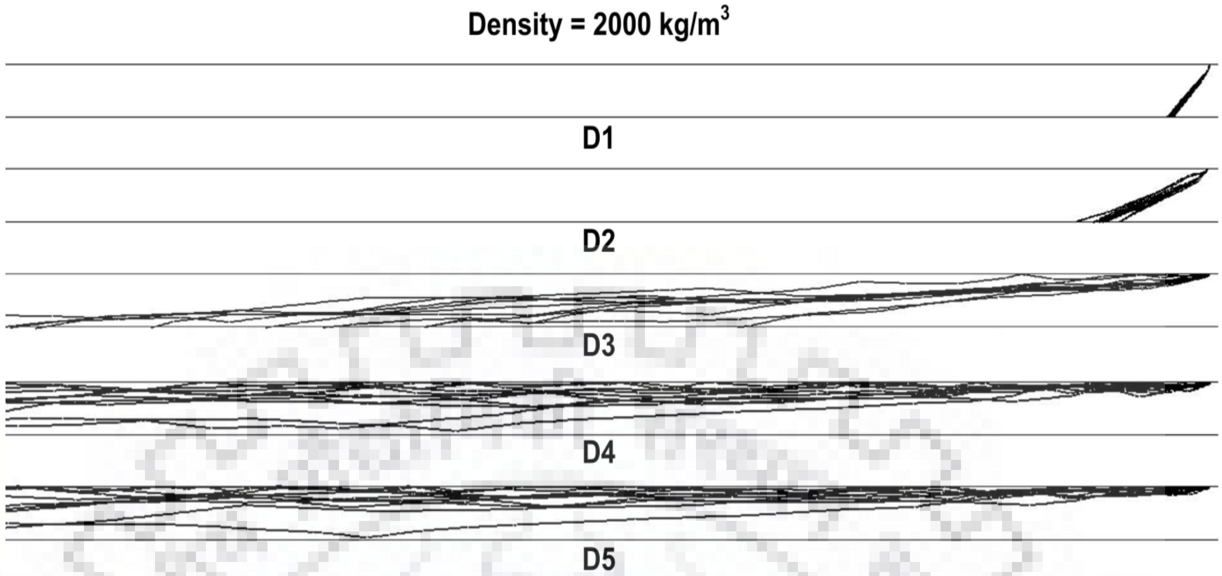


Figure 7.22 Track path of solid particles of density 2000 kg/m^3, along the canal water flow direction

Figures 7.20, 7.21 and 7.22 shows the path of the particles tracked after insertion from the sewage inlet for different particle diameter with density 1200 kg/m^3, 1500 kg/m^3, and 2000 kg/m^3 respectively, along the canal flow direction. It has been observed that with the decrease in diameter of the particles, the chance of flotation of particles increases or settlement of particles to the canal base decreases. It can be seen that solid particles of diameter D1 and D2 quickly get settle to the canal base, while particles of diameter D3, D4, and D5 floats with the canal water flow. This infers that flow of solid particles of diameter D1 and D2 with the sewage water will not affect the canal water much as it quickly settles down. From **Figures 7.20, 7.21 and 7.22**, it can also be seen that with the increase in particle density the affinity of the particles to settle down decreases. However, for the all particle densities taken during the study has similar behaviour related to flotation and settlement to the canal base i.e. particles of diameter D1 and D2 settles down and particles of diameter D3, D4, and D5 floats.

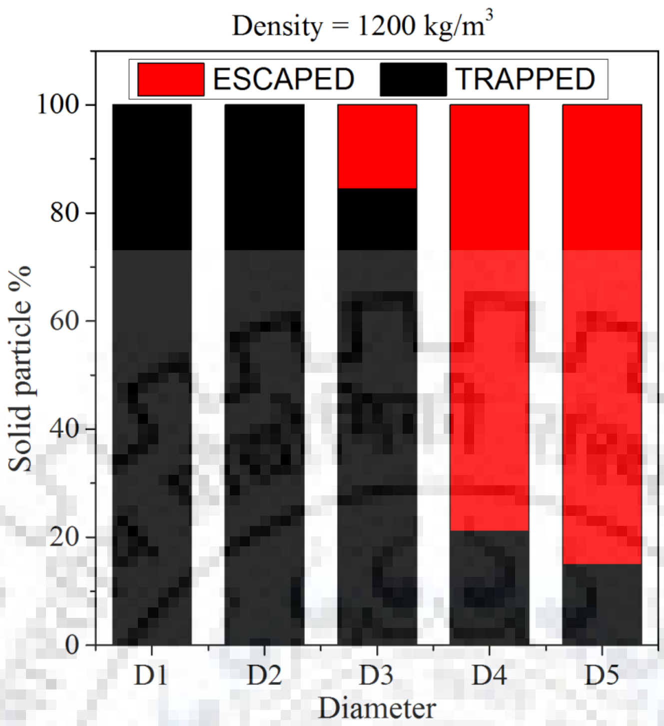


Figure 7.23 Percentage of solid particles get trapped to the base and escaped to the outlet for density 1200 kg/m^3

Figures 7.23, 7.24 and 7.25 shows the percentage of solid particles being trapped to the canal base and escaped to the canal outlet for different diameters and density 1200 kg/m^3, 1200 kg/m^3, and 2000 kg/m^3 respectively. It can be seen that all solid particles of diameter D1 and D2 get trapped to the canal base, which have also been seen in **Figures 7.20, 7.21 and 7.22**. For particles of diameter D3, the minimum particle get trapped to the canal base is 84% for particle density 1200 kg/m^3, and maximum of 98% for particle density 2000 kg/m^3. For particle diameter D4 and D5, the affinity of particle to settle down is comparatively less than. The maximum of 30% solid particles have been found to settle down the canal base for diameter D4 and D5. The result shows that solid particles of large size (diameter) and high density have high affinity to get settle down the canal base, while particles of small size and less density floats with the canal water and travel large distance to get settle down.

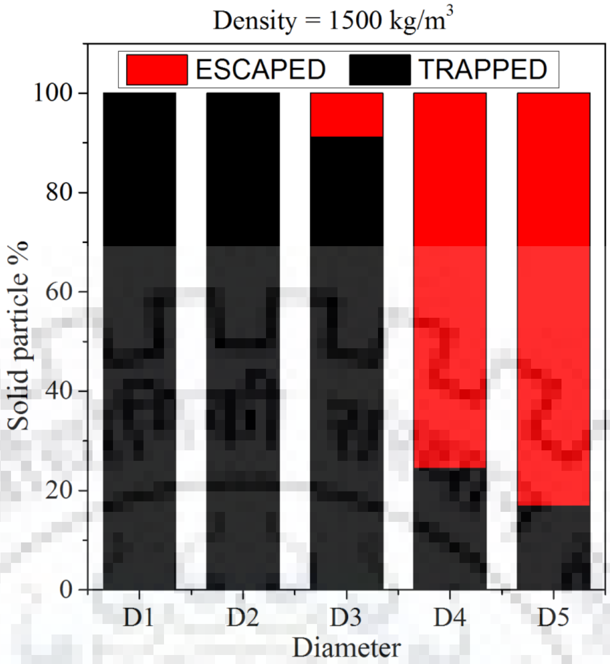


Figure 7.24 Percentage of solid particles get trapped to the base and escaped to the outlet for density 1500 kg/m^3

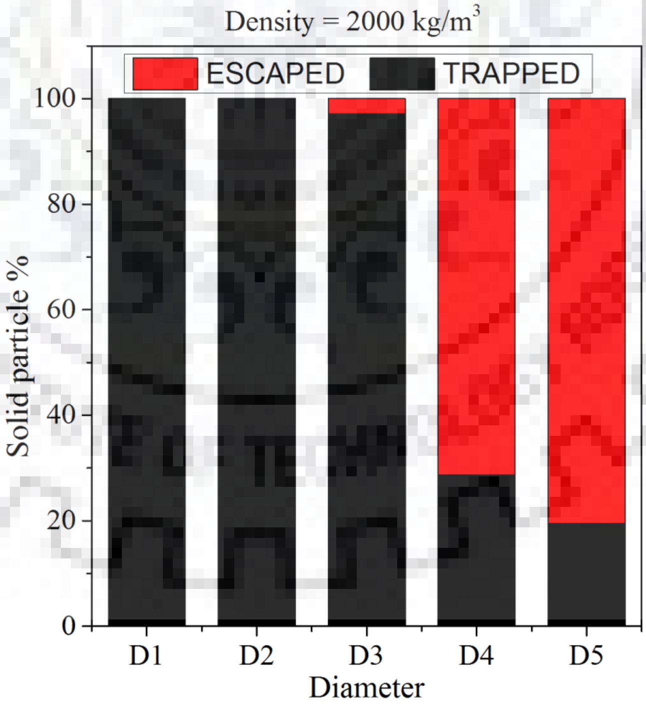


Figure 7.25 Percentage of solid particles get trapped to the base and escaped to the outlet for density 2000 kg/m^3

7.4 Conclusion

In this study, capabilities of numerical methods were explored to model complex two phase fluid flow in Upper Ganga canal. The commercial computational tool ANSYS Fluent 16.0 was found capable to successfully model the diffusion of pollutant in water flow. Following conclusions have been drawn from the present study.

1. It was observed that at higher velocities, the rate of change of mass fraction of pollutant and dispersion of pollutant at outlet increased. The concentration of pollutants in the centre of the canal is negligible and is maximum near the canal bank, which decreases along the depth. This is due to diffusion phenomena in case of species transport analysis.
2. The mass weighted average (fraction) of sewage pollutant increased from 0.006 to 0.018 in flow time of 50 minutes, when velocity of sewage was increased from 0.2 m/s to 0.4 m/s. The mass fraction of pollutant was found to be decreased along the length of the canal for a fixed velocity of sewage due to diffusion. Thus, the concentration of pollutant is negligible in the centre of canal but, it is higher near the canal bank.
3. Dispersion of pollutant was observed to be increasing from the side wall in the transverse direction of canal depending upon the number of sewer openings.
4. It was also observed that dispersion effect of pollutant in water flow increased from the side wall of domain along the width and reached maximum at 20 m at the outlet.
5. Effect of pollutant dispersion toward the depth was increasing along the longitudinal direction with subsequent opening of sewer.
6. Studying the insertion of solid particles with the sewage pollutant it has been observed that solid particles of large size (diameter of the order of 150 μm to 80 μm) and high density have high affinity to get settle down the canal base, while particles of small size (below 25 μm diameter) and less density float with the canal water and travel a large distance to get settle down.
7. The mass fraction obtained at outlet matches approximately with the quantitative analysis at the section just beyond sewers for the mixture model. In case of species transport model it is 90 percent less than that obtained in mixture model due to role played by diffusion in species transport model.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Summary

Water pollution is a sensitive issue for mankind and a cause of deaths and diseases worldwide. An increased industrialization, urbanization along with rapid increase in population has aggravated the problem in Indian regions. All the water uses require a definite threshold water quality regarding biological, physical and chemical characteristics of the suspended or dissolved constituents, which should ascertain no harmful effects to the user. The canal and river waters of many countries are in danger due to undesirable changes in the biological and physiochemical nature of water. Toxic trace and heavy metals are also critical as they damage crop, pollute water causing persistent poisoning to aquatic animals, livestock and human health. Thus, the study on water quality assessment is important to preserve and maintain the natural ecosystem.

In India, the canal system plays a vital role in optimal use of available water in rivers, dams, lakes, groundwater and other sources. Canals are meant for optimum utilization of river water by irrigating the remote areas, thus the water quality monitoring, and pollution of rivers waters are significantly studied in this research work. The quality of canal water for irrigation has to be good in order to prevent the crops and livestock diseases, and for rising and improving the quality of agriculture and crop production. Whereas, the use of poor quality or contaminated water for long time can make the soil less productive or even barren depending on the amount and type of constituents present in the canal water, and unsuitability of water at an acceptable quality can be detriment to crops. Majority of the Indian rivers are polluted due to discharge of industrial and domestic sewage into water which may propagate to the canals diverted from them. Therefore, it is necessary to evaluate canal water quality for environmental management.

Upper Ganga Canal (UGC) water plays an important role in the Northern India for irrigation, drinking, navigation and spiritual beliefs. Thus, the perennial flow of the main Ganga River is diverted into the UGC to have round the year agricultural production. The Ganga River is the most polluted river of India (NRCD, 2009). Hence, the water quality of UGC should be assessed before being used for agriculture and drinking purposes. Keeping this in background, the present study was carried out to assess the UGC water quality at Roorkee with following specific objectives:

1. To assess the UGC water quality for irrigation purpose.
2. To assess the UGC water quality for livestock drinking
3. To assess the UGC water quality for human drinking.
4. Numerical modelling of sewage pollutant dispersion in the UGC water.

8.1.1 Data collection and laboratory analysis

In this study, water samples were collected from 18 different sampling sites (coded as S1 to S18) in the study area (UGC, Roorkee) from a depth of 20-30 cm. Before the samples collection, all polyethylene plastic bottles were thoroughly cleaned by 8M HNO3, followed by repeated washing with de-ionized water. All the collected samples were preserved in deep refrigerator at 4°C before analyses in the laboratory. The samples collected at monthly interval for a period of one year (from November, 2014 to October, 2015), includes three main period (viz. winter, summer and monsoon) data to study the seasonal variations in water quality. In this study, the most important 15 physicochemical parameters (pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, $HCO3^-$, $CO3^{2-}$, Cl^-, $SO4^{2-}$, $NO3^-N$, DO, COD and B), and 11 trace metals (Al, As, Cd, Cr, Co, Cu, Fe, Hg, Pb, Mn, Se and Zn) were analyzed on seasonal time-scale.

8.1.2 Physicochemical parameters and toxic trace metals

Several instruments and standard methods were used for determination of the physicochemical parameters and trace metals in the UGC water. The physical parameters such as water temperature (Tw), pH, EC and TDS were tested *In-Situ* by Portable Single-multi-parameters water quality meters (Model OR900P). The chemical parameters were analyzed and determined in water quality laboratory by employing different instruments and the standard methods (Federation & APHA, 2005), TH as $CaCO_3$, Ca as $CaCO_3$, and Mg as $CaCO_3$ by Titration method using EDTA; TA, CO_3 and HCO_3 by Titration method using H_2SO_4; Cl by Titration method using $AgNO_3$ (Argentometric); K and Na were analyzed by Flame photometer; NO_3-N, and B were analyzed by UV-VIS Spectrophotometer (Model DN 5000 HACH); SO4 was analyzed by Turbidimeter (Model HACH 2100AN); and Boron was measured by the carmine method using UV-VIS Spectrophotometer model (DN 5000 HACH model). In this study, physicochemical parameters were compared to the guidelines and standards suggested by Bureau of Indian Standards (BIS-10500, 2012), Environmental Protection Agency (EPA, 2001), Indian Council Medical Research (ICMR, 1995) and World Health Organization (WHO, 2004).

Numerous Water Quality Indices namely Sodium Adsorption Ratio (SAR), Residual Sodium Content (RSC), Residual Sodium Bicarbonate (RSBC), Sodium Soluble Percentage (SSP), Magnesium Adsorption Ratio (MR), Permeability Index (PI) and Kelley`s Index Ratio (KR) were studied and evaluated for suitability of UGC water for irrigation. For agronomical aspects, major water quality parameters were grouped into salinity and sodicity classes that may affect soil, plants and humans directly and indirectly.

The total heavy metals i.e. Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Pb, and Zn, which are important parameters for irrigation and livestock drinking water were measured after digestion with a concentrated HCO_3 using GBC Atomic Adsorption Spectrophotometer model (GBC Avanta A.A.S.).

8.1.3 Water Quality Indices (WQI)

The method for calculating WQI was developed by Horton (1965). A zero value of WQI indicates absolute absence of pollutants, whereas WQI < 100 can be considered as usable, and WQI >100 can be considered as unsuitable for human use (Reza & Singh, 2010).

Further, the weighted Arithmetic Index method (Amadi et al. 2010, Khwakaram et al., 2015; Mukhtar et al., 2014) has been used to compute WQI using 11 trace heavy metals viz., Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Pb, and Zn. The WQI was calculated using the standards of drinking BIS-10500 (1991 & 2012). The weighted arithmetic of canal water quality was estimated according to Al-Mashagbah (2015), Amadi et al. (2010), and Goher et al. (2014). In this analysis, water quality components were multiplied by weighting factors, and then aggregated using the simple arithmetic mean. Inter-relationships between different water quality parameters, mainly heavy metals, were also analyzed by Pearson’s correlation matrix.

Moreover, the study also includes the Australian and New Zealand Guidelines for fresh and Marine Water Quality (ANZECC, 2000), Ayers and Westcott (1985, 1994) for livestock drinking water, Canadian Council of Ministers of the Environment (CCME, 2008), Food and Agriculture Organization of the United Nations (Rhoades, 1992) and by Bureau of Indian Standards (BIS-10500, 2012) and World Health Organization of the United Nations (WHO, 2004) for human drinking water.

8.1.4 Numerical modelling of pollutant dispersion

For numerical modelling of pollutant dispersion in UGC water, the geometrical data such as distance from old canal bridge to Ganeshpur bridge, depth and width of the canal, and sewage positions were obtained physically from the canal site. Moreover, the parameters such as water flow velocity and sewage discharge velocity have been measured manually and executed in the numerical model.

In this study, three dimensional model geometry has been developed from old canal bridge to Ganeshpur bridge, Roorkee. In the UGC, five sewages were identified along both the sides of canal which are considered for modeling the geometry. The model geometry was developed on the basis of geometrical data obtained between old canal bridge to Ganeshpur bridge of UGC, Roorkee. The computations were performed by using the commercial tool Ansys Fluent 15.0.

8.2 Water Quality of Upper Ganga Canal (UGC)

8.2.1 UGC water quality for irrigation

Physicochemical parameters

According to the FAO guidelines and standards given by Ayers and Westcott (1985), the values of T_w, pH, TA, TH, Ca^{2+}, Na^+, K^+ , Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-, CO_3^{2-} at all sites (from S1 to S18) of UGC, Roorkee during all the three seasons were within maximum allowable limits for irrigation purpose i.e. for agricultural crop utility. Only the concentration of Mg^{2+} was higher than the prescribed range for irrigation. During all seasons, Boron value was within the permissible limits at all sites, except at sites S4, S5 and S7 in summer season, and at site S5 in winter season.

Result showed that water quality indices namely SAR, SSP, EC and TDS were ‘excellent’; RSC and RSBC were ‘safe’, KR was ‘good’ for irrigation. However, MAR values at sites S4, S11, S13, S16, S17 and S8 (winter season), sites S1 and S7 (summer season), and almost all water samples (monsoon season) were higher than the permissible limit (MAR >50). PI values were ‘moderate (class II)’ except that it was ‘Low (class III)’ at sites S5 and S7 during winter, at almost all sites during summer, and at sites S2, S5 and S7 during monsoon season, which indicate that the canal water at these sites may be ‘Unsuitable’ for irrigation.

Toxic trace metals

The toxic metals (except Cobalt) in UGC water for all the sites, except at S4, S5 and S7, were within the permissible limits of FAO standards (Ayers and Westcott, 1985) during all three seasons. For these three sites (S4, S5 and S7), the Mn concentrations during winter season, the Zn concentrations during winter as well as summer seasons, and the Cobalt concentration during all the three seasons were beyond the allowable limits for irrigation. The concentration of Cobalt was just above the permissible limit at 9 sites (S10, S11, S12, S13, S14, S15, S16, S17 and S18) in winter.

Water Quality Index (WQI)

The WQI values of the UGC water sites ranged from 18.78 to 89.31 (mean of 45.56 and SD of 29.79) in winter season**;** from 25.99 to 84.94 (mean of 53.84 and SD of 18.99) in summer season; and from 15.58 to 57.76 (mean of 34.02 and SD value of 12.91) in monsoon season. Result reveals that UGC canal water is suitable for irrigation purpose.

8.2.2 UGC water quality for livestock drinking

Physicochemical parameters

According to the guidelines and standards of FAO (Ayers and Westcott, 1985) and BIS (IS 2296: 1992), all the physicochemical parameters considered in this study were within the permissible limits, therefore suitable for livestock drinking.

Toxic trace metals

Many of the toxic metals in UGC water for all the sites except at S4, S5 and S7, were within the permissible limits of ANZECC (2000), CCME (2008), and DWAF (1996) and FAO (Ayers and Westcott, 1985 and 1994) during all the three seasons. Therefore, UGC water can be used for livestock drinking purpose.

Water Quality Index (WQI)

The WQI values of the UGC water sites were ranged from 22.79 to 190.46 (mean of 66.30 and SD of 55.37) in winter season, from 36.12 to 170.52 (mean of 72.95 and SD of 45.77) in summer season, and from 15.36 to 172.99 (mean of 62.17 and SD value of 49.39) in monsoon season. However, the WQI values were above 100 for sites S4, S5 and S7 during all the seasons, whereas for other sites it is within permissible limit.

8.2.3 UGC water quality for human drinking

In this analysis, results were compared to the guidelines by Bureau Indian Standards (IS 10500: 2012), Indian Council Medical Research (ICMR, 2012), World Health Organization (WHO, 2004) and Environmental Protection Agency (EPA, 2001) to assess suitability of UGC water for human drinking.

Physicochemical parameters

According to the guidelines and standards of BIS (IS 10500: 2012), ICMR (2012), WHO (2004) and EPA (2001), result showed that the physicochemical parameters viz., Ca, K, B, DO and COD were beyond the permissible limits, therefore UGC water is not suitable for human drinking.

Toxic trace metals

Most of the trace metals in UGC water have higher concentration compared to the permissible limits of the standards limits for human drinking purpose. The higher concentration of these metals contributes toxicity in the UGC water, and hence it is not suitable for human drinking.

Water Quality Index (WQI)

The WQI values of the UGC water sites ranged from 104.64 to 1485.64 (mean of 443.48 and SD of 459.28) in winter season; from 127.65 to 1518.1 (mean of 458.51 and SD of 463.52) in summer season; and from 104.24 to 1484.66 (mean of 434.71 and SD value of 455.38) in monsoon season. Therefore, UGC water is not suitable for human drinking.

8.2.4 Sewage pollutant dispersion in UGC water

A numerical model of UGC from old canal bridge to Ganeshpur bridge, Roorkee has been developed to simulate water flow in the canal with the inflow of pollutants from sewages at five different locations. Influence of opening of various sewages as well as sewage velocities on the change in concentration of canal water was investigated. Three different sewage velocities i.e. 0.2 m/s, 0.4 m/s and 0.6 m/s were considered in the investigation. The study was augmented by analyzing the insertion of solid particle pollutants from sewage inflow. Three different densities and five different sizes of the solid particles were used during the analysis. Result shows that the inlet of sewage pollutant to the canal water leads to maximum change in water concentration near the canal banks, and have minimal effect at the centre. Tracking the insertion of solid particles shows that the large size particles (of diameter 80 and 150 μm) settle down quickly. The settlement of small size particles (from 2 to 25μm diameter) to bottom was visualized using the particle tracks.

8.3 Conclusions

1. The Upper Ganga Canal (UGC), Roorkee water is suitable for irrigation except that the parameters such as B, Mg^{2+}, Co, Mn, Zn, MAR and PI should be checked at the sites during

monsoon, summer and winter seasons before the start of irrigation. Moreover, the application of water for irrigation from S4, S5 and S7 sites should be carried out with utmost care.

2. For livestock drinking, the physicochemical parameters and toxic trace metals in the UGC water are within the permissible limits which is also inferred from the WQI values.

3. For human drinking, the physicochemical parameters (namely Ca, K, B, DO and COD) and most of the trace metals were beyond the standard permissible limits. Also, the WQI values inferred that the UGC canal water is polluted and thus, 'Unsuitable' for human drinking use.

4. A three-dimensional numerical model of the UGC at Roorkee showed that the rate of sewage pollutant dispersion and mass fraction increases with high sewage inlet velocity. The mass weighted average (fraction) of sewage pollutant increased from 0.006 to 0.018 in flow time of 50 minutes, when velocity of sewage was increased from 0.2 m/s to 0.4 m/s. The concentration of pollutant is negligible in the centre of canal; however, it is higher near the canal bank and decreases with depth.

5. The study of solid particle insertion along with the sewage pollutant revealed that the solid particles of large size (diameter of the order of 150 μm to 80 μm) and high density have high affinity to get settle down at the canal base, whereas the particles of small size (below 25 μm diameter) and lesser density floats with the canal water and travel large distance to settle down.

8.4 Major Research Contributions

1. Various physicochemical parameters and toxic trace metals were compared with multiple authentic standards of water quality for irrigation, livestock drinking and human drinking purposes.

2. Seasonal Water Quality Indices (WQI) were explored to assess the suitability of a canal water for irrigation, livestock drinking and human drinking purposes considering physicochemical parameters and toxic trace metals.

3. Numerical modelling framework for pollutant dispersion in UGC water shall be useful to check the rate and mass transfer of sewages in canal.

4. This study will provide valuable insights to study the seasonal pollution status of canal water.

8.5 Scope for Future Research

- Although the water quality of UGC was assessed for three seasons (winter, summer and monsoon), the effect of climatic change on UGC water quality can be a scope for future research.
- Future work can be initiated including some local monitoring, management and assessment to cope up with the water pollutants in the UGC.
- In this study water quality sampling was carried out at 18 sites throughout the year (November-2014 to October-2015). The concentration of water pollutant at each year may be different with varying quantity and quality of sewages, which can be identified and analyzed considering anthropogenic changes near by the canal area.

REFERENCES

Abbas, T. E., Elzubeir, E. A., & Arabbi, O. H. (2008). Drinking water quality and its effects on broiler chicks performance during winter season. *International Journal of Poultry Science*, *7*(5), 433-436.

Abd-El-Kader, M. A., Abd-Elall, A. M. M., Marzouk, M. A., & Atia, A. S. (2009). Chemical evaluation of poultry drinking water at Sharkia Governorate. *Journal of Suez Canal Veterinary Medicine, (2)*, 82-103.

Adamsson, Å., Stovin, V., & Bergdahl, L. (2003). Bed shear stress boundary condition for storage tank sedimentation. *Journal of Environmental Engineering*, *129*(7), 651-658.

Adewuyi, G. K., Badejo, O. T., Idowu, F. F., Ogunjobi, G. A., & Gbopa, A. (2017). Analysis of Physico-Chemical Parameters: An Empirical Study of Yewa River Ogun and Part of Badagry Creek Lagos, Southwest Nigeria. *Int J Hydro*, *2*(1), 00036.

Aftab, T., Shafiq, T., Khan, B., & Chaudhry, M. N. (2011). Physicochemical properties, contamination and suitability of canal water for irrigation, Lahore branch Pakistan. *Pakistan Journal of Analytical & Environmental Chemistry*, *12*(1 & 2), 7.

Akkoyunlu, A., & Akiner, M. E. (2012). Pollution evaluation in streams using water quality indices: A case study from Turkey's Sapanca Lake Basin. *Ecological Indicators*, *18*, 501-511.

Al Obaidy, A. H. M. J., Al Mashhady, A. A., Awad, E. S., & Kadhem, A. J. (2014). Heavy metals pollution in surface water of Mahrut River, Diyala, Iraq. *International Journal of Advanced Research*, *2*(10), 1039-1044.

Alabama A & M and Auburn Universities (1995). Drinking water for Livestock and Poultry, Agricultural and Natural Resources Water Quality: Managing Drinking Water, ANR-790-2.6, pp2.6.1-2.6-5.

Alam, M. J., Islam, M. R., Muyen, Z., Mamun, M., & Islam, S. (2007). Water quality parameters along rivers. *International Journal of Environmental Science & Technology*, *4*(1), 159-167.’

Al-Badaii, F., Shuhaimi-Othman, M., & Gasim, M. B. (2013). Water quality assessment of the Semenyih River, Selangor, Malaysia. Journal of Chemistry, 2013.

Alemu, T., Mulugeta, E., & Tadese, M. (2017). Determination of physicochemical parameters of “Hora” natural mineral water and soil in Senkele Kebele, Oromia Region, Ethiopia. *Cogent Chemistry*, *3*(1), 1354800.

Al-Mashagbah, A. F. (2015). Assessment of surface water quality of king abdullah canal, using physico-chemical characteristics and water quality index, Jordan. *Journal of Water Resource and Protection, 7*(04), 339.

Amadi, A. N., Olasehinde, P. I., Okosun, E. A., & Yisa, J. (2010). Assessment of the water quality index of Otamiri and Oramiriukwa Rivers. *Physics International, 1*(2), 116-123.

Amarasinghe, U. A., Smakhtin, V., Bharati, L., & Malik, R. P. (2013). Reallocating water from canal irrigation for environmental flows: benefits forgone in the Upper Ganga Basin in India. *Environment, Development and Sustainability*, *15*(2), 385-405.

ANZECC (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environmental and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand:

Canberra. *Agriculture and Resource Management Council of Australia and New Zealand, Canberra*.

Asiwaju-Bello, Y. A., Olabode, F. O., Duvbiama, O. A., Iyamu, J. O., Adeyemo, A. A., & Onigbinde, M. T. (2013). Hydrochemical evaluation of groundwater in Akure Area, south-western Nigeria, for irrigation purpose. *European International Journal of Science and Technology, 2*(8), 235-249.

Atta-Darkwa, T., Kabo-bah, A. T., Akolgo, G. A., Kotei, R., & Amo-Boateng, M. (2016). Assessment of groundwater quality for irrigation in the Oda river basin, Ejisu-besease, Ghana, *International Journal of Current Research, 8*(5), 30994-31001.

Augoustis, A., Hatziioannou, M., Papadopoulos, S., Kateris, D., Neofytou, C., & Vafidis, D. (2012). Assessing quality of an irrigation canal ecosystem, through water and sediment environmental parameters. A case study in Thessaly region, Greece. *WSEAS Transactions on Environment and Development, 8*(1), 23-32.

Ayers, R. S., & Westcot, D. W. (1985). Water quality for agriculture. FAO Irrigation and drainage paper 29 Rev. 1. *Food and Agricultural Organization, Rome, 1,* 74.

Ayers, R. S., & Westcot, D. W. (1994). Water quality for agriculture. *FAO Irrigation and Drainage Paper, 29,* 156.

Banerjee, T., & Srivastava, R. K. (2009). Application of water quality index for assessment of surface water quality surrounding integrated industrial estate-Pantnagar. *Water Science and Technology, 60*(8), 2041-2053.

Barakat, A., El Baghdadi, M., Meddah, R., Rais, J., Nadem, S., & Afdali, M. (2013). Evaluation of water quality in open channels flowing through Beni-Mellal City (Morocco)/Ocena jakości wody w otwartych kanałach płynących przez miasto Beni-Mellal (Maroko). *Journal of Water and Land Development, 19*(1), 3-11.

Basha, C. A., Ghosh, P. K., & Gajalakshmi, G. (2008). Total Dissolved solids removal by electrochemical ion exchange (EIX) process. *Electrochimica Acta, 54*(2), 474-483.

Bassuony, M. A., Ali, M. E., Abdel Hameed, A. H., & Jahin, H. S. (2014). Evaluation of irrigation water quality in different regions of North East Delta-Egypt. *Journal of Engineering and Applied Sciences, 5,* 10-16.

Bauder, T. A., Waskom, R. M., & Davis, J. G. (2007). Irrigation water quality criteria. Colorado State University. *US Department of Agriculture.*

Beede, D. K. (2005, April). Assessment of water quality and nutrition for dairy cattle. In *Proc. Mid-south Ruminant Nutrition Conf* (pp. 1-19).

Bharati, L., Lacombe, G., Gurung, P., Jayakody, P., Hoanh, C. T., & Smakhtin, V. (2011). *The impacts of water infrastructure and climate change on the hydrology of the Upper Ganges River Basin* (Vol. 142). IWMI.

Bhaskar, C. V., Kumar, K., & Nagendrappa, G. (2010). Assessment of heavy metals in water samples of certain locations situated around Tumkur, Karnataka, India. *Journal of Chemistry, 7*(2), 349-352.

Bhattarai, G., Srivastava, P., L. Marzen, D. Hite, & Hatch, L. (2008). Assessment of economic and water quality impacts of land use change using a simple bio-economic model. Journal of Environmental Management. *Environmental Management, 42*(1): 122-131.

BIS (1991). Bureau of Indian Standards: Drinking water specifications. 1st Revision IS 10500: 1991, New Delhi, India.

BIS (2009). Bureau of Indian Standards: Guidelines for the quality of Irrigation water. IS 11624: 2009, New Delhi, India.

BIS (2012). Bureau of Indian Standards: Drinking water specifications. IS 10500: 2012, New Delhi, India.

Boyd, C. E. (2000). Water Quality: An introduction. *Kluwer academic publishers, Norwell, Massachusetts*, 2061.

Breitburg, D. L. (1994). Behavioral response of fish larvae to low dissolved oxygen concentrations in a stratified water column. *Marine Biology*, *120*(4), 615-625.

Brown, R. M., McClelland, N. I., Deininger, R. A., & Tozer, R. G. (1970). A water quality index: Do we dare? *Water & Sewage Works*, *117*, 339–343.

Brraich, O. S., & Jangu, S. (2015). Evaluation of water quality pollution indices for heavy metal contamination monitoring in the water of Harike Wetland (Ramsar Site), India. *International Journal of Scientific and Research Publications*, *5*(2), 1-6.

Buccolieri, R., Sartoretto, F., Giacometti, A., Di Sabatino, S., Leo, L., Pulvirenti, B., ... & Wigö, H. (2010). Flow and pollutant dispersion within the Canal Grande channel in Venice (Italy) via CFD techniques. In *13th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, HARMO 2010, 1-4 June 2010, Paris, France* (pp. 760-764).

Buschmann, J., Berg, M., Stengel, C., Winkel, L., Sampson, M. L., Trang, P. T. K., & Viet, P. H. (2008). Contamination of drinking water resources in the Mekong delta floodplains: Arsenic and other trace metals pose serious health risks to population. *Environment International*, *34*(6), 756-764.

Butcher, C. A. (1988). Water Quality Criteria for Aluminum. *Water Quality Unit Resource Quality Section Water Management Branch, Ministry of Environment and Parks Province of British Colombia, pp76-77*.

Butler, G.A., & Srivastava, P. (2007). An Alabama BMP database for evaluating water quality impacts of alternative management practices. *Applied Engineering in Agriculture 23*(6): 727-736.

Caraco, N. F., Cole, J. J., & Likens, G. E. (1989). Evidence for sulphate-controlled phosphorus release from sediments of aquatic systems. *Nature*, *341*(6240), 316.

CCME (2005). Guidelines for Compost Quality, Canada. *Canadian Council of Ministers of the Environment.*

CCME (2008). Canadian Water Quality Guidelines (CWQG). *Canadian Council of Ministers of the Environment.*

Chapelle, F. H., & Lovley, D. R. (1992). Competitive exclusion of sulfate reduction by Fe (lll)-reducing bacteria: a mechanism for producing discrete zones of high-iron ground water. *Groundwater*, *30*(1), 29-36.

Chaturvedi, J., & Pandey, N. K. (2006). Physico-chemical analysis of river Ganga at Vindhyachal Ghat. *Current World Environment*, *1*(2), 177-179.

Chauhan, A., & Singh, S. (2010). Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. *Report and Opinion*, *2*(9), 53-61.

Chen, L. P., Cheng, J. T., & Deng, G. F. (2013). Anisotropic diffusion of volatile pollutants at air-water interface. *Water Science and Engineering*, *6*(2), 153-163.

Choudhary, P., Dhakad, N. K., & Jain, R. (2014). Studies on the Physico-Chemical Parameters of Bilawali Tank, Indore (MP) India. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSRJESTFT), 8*(1), 37-40.

Chowdary, V.M., Rao, N.H., & Sarma, P.B.S. (2004). A coupled soil water and nitrogen balance model for flooded rice fields in India. *Agriculture, Ecosystems & Environment 103* (3), 425-441.

Chowdary, V.M., Rao, N.H., & Sarma, P.B.S. (2005). Decision support framework for assessment of non-point-source pollution of groundwater in large irrigation projects. *Agricultural Water Management, 75* (3), 194-225.

Das, T., Chakraborti, S., Mukherjee, J., & Sen, G. K. (2018). Mathematical modelling for phytoplankton distribution in Sundarbans Estuarine System, India. *Ecological Modelling*, 368, 111-120.

Dash, A., Das, H. K., Mishra, B., & Bhuyan, N. K. (2015). Evaluation of water quality of local streams and Baitarani River in Joda area of Odisha, India. *Int J Curr Res*, *7*(3), 13559-13568.

Davis, A. P., Shokouhian, M., Sharma, H., Minami, C., & Winogradoff, D. (2003). Water quality improvement through bioretention: Lead, copper, and zinc removal. *Water Environment Research*, *75*(1), 73-82.

Dhembare, A. J. (2012). Assessment of water quality indices for irrigation of Dynaneshwar Dam Water, Ahmednagar, Maharashtra, India. *Archives of Applied Science Research*, *4*(1), 348-352.

Di Sabatino, S., Buccolieri, R., Pulvirenti, B., & Britter, R. E. (2008). Flow and pollutant dispersion in street canyons using FLUENT and ADMS-Urban. *Environmental Modeling & Assessment*, *13*(3), 369-381.

Diamond, J. M., Winchester, E. L., Mackler, D. G., Rasnake, W. J., Fanelli, J. K., & Gruber, D. (1992). Toxicity of cobalt to freshwater indicator species as a function of water hardness. *Aquatic Toxicology*, *22*(3), 163-179.

Doneen, L. D. (1964). Notes on water quality in agriculture. *Department of Water Science and Engineering, University of California, Davis.*

Drolc, A., & Končan, J. Z. (1996). Water quality modelling of the river Sava, Slovenia. *Water Research*, 30(11), 2587-2592.

DWAF (Department of Water Affairs and Forestry of the Republic of South Africa). (1996). South African water quality guidelines. *Agricultural use: Livestock watering.* 5. pp. 31-136.

Eaton, F. M. (1950). Significance of carbonates in irrigation waters. *Soil Science*, *69*(2), 123-134.

El Mahdy, C., Boaru, A., Popescu, S., & Borda, C. (2016). Water Quality, Essential Condition Sustaining the Health, Production and Reproduction in Cattle. A Review. *Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. Animal Science & Biotechnologies*, *73*(2), 113-125.

Elhaddad, E. (2014). Effects of pollution on hydro-chemical and water quality assessment of the Ismailia Canal water, Egypt. *International Journal of Pure & Applied Bioscience*, *2*(5), 124-131.

Ellis, D., Bouchard, C., & Lantagne, G. (2000). Removal of iron and manganese from groundwater by oxidation and microfiltration. *Desalination*, *130*(3), 255-264.

Ensink, J. H., Scott, C. A., Brooker, S., & Cairncross, S. (2010). Sewage disposal in the Musi-River, India: water quality remediation through irrigation infrastructure. *Irrigation and Drainage Systems*, *24*(1-2), 65-77.

EPA (2001). Parameters of water quality: Interpretation and standards. *Environmental Protection Agency, Ireland.*

Etemad-Shahidi, A., & Taghipour, M. (2012). Predicting longitudinal dispersion coefficient in natural streams using M5′ model tree. *Journal of hydraulic engineering*, *138*(6), 542-554.

FAO (1985), Food and Agriculture Organization of the United Nations, Wastewater Treatment and Use in Agriculture – Rome - FAO Irrigation and Drainage Paper 29, 1985.

Federation, W. E., & APHA (2005). Standard methods for the examination of water and wastewater. *American Public Health Association (APHA): Washington, DC, USA.*

Frimpong, J. O., Amoako, E. E., & Nkoom, M. (2015). Assessment Of The Physicochemical And Microbial Quality Of Water In Ke-Nya Stream At Babato-Kuma Community In The Kintampo North Municipal Assembly Of Brong Ahafo Region Of Ghana. *International Journal of Scientific & Technology Research*, *4*(6), 405-411.

Gadekar, M. R., Gonte, R. N., Paithankar, V. K., Sangale, Y. B., & Yeola, N. P. (2012). Review on River Water Quality Designation. *International Journal of Emerging Technology and Advanced Engineering*, *2*(9), 493-495.

Gambrell, R. P. (1994). Trace and toxic metals in wetlands—a review. *Journal of Environmental Quality*, *23*(5), 883-891.

García-Ávila, F., Ramos-Fernández, L., Pauta, D., & Quezada, D. (2018). Evaluation of water quality and stability in the drinking water distribution network in the Azogues city, Ecuador. *Data in brief*, *18*, 111-123.

Gautam, S.P. (2008). Guide Manual: Water and Wastewater Analysis. *Hydrology Project-II, Ministry of Water Resources (MoWR).*

Goel, P. K. (2006). Water Pollution: Cause, Effects and Control. *Revised Second Edition, New Age International (P) Ltd.*

Goher, M. E., Hassan, A. M., Abdel-Moniem, I. A., Fahmy, A. H., & El-sayed, S. M. (2014). Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. *The Egyptian Journal of Aquatic Research, 40*(3), 225-233.

Gopal, V. & Joseph V. (2015). Irrigational quality of Vamanapuram River, Kerala, India. *International Journal of Scientific & Engineering Research, 6*(10), 803-811.

Gupta, N., Yadav, K. K., Kumar, V., & Singh, D. (2013). Assessment of physicochemical properties of Yamuna River in Agra City. *International Journal of ChemTech Research, 5*(1), 528-531.

Gupta, S. K., & Gupta, I. C. (1987). Management of saline soils and waters. *ISBN: 0120402065, Oxford & IBH Publishing Co. Pvt. Ltd.*

Hanson, A. T., Dwyer, B., Samani, Z. A., & York, D. (1993). Remediation of chromium-containing soils by heap leaching: Column study. *Journal of Environmental Engineering, 119*(5), 825-841.

Hashemabadi, D., Zaredost, F., & Solimandarabi, M. J. (2015). The Effect of Magnetic Water and Irrigation Intervals on the Amount of the Nutrient Elements in Soil and Aerial Parts of Periwinkle (Catharanthus roseus L.). *Journal of Ornamental & Horticultural Plants*, *5*(3).

Hooda, P. S., Edwards, A. C., Anderson, H. A., & Miller, A. (2000). A review of water quality concerns in livestock farming areas. *Science of the Total Environment*, *250*(1-3), 143-167.

Horn, A.L., Rueda, F.J., Hörmann, G., & Fohrer, N. (2004): Implementing river water quality modelling issues in mesoscale watershed models for water policy demands - an overview on current concepts, deficits, and future tasks. *Physics and Chemistry of the Earth, Parts A/B/C*, *29*(11-12), 725-738.

Horton, R. K. (1965). An index number system for rating water quality. *Journal of Water Pollution Control Federation*, *37*(3), 300-306.

Hossain, A., & Naser, J. (2009). Analytical and CFD investigation of turbulent diffusion model for particle dispersion and deposition in horizontal pipe flow. *J. Mech. Eng*, *40*(1), 39-53.

Huang, J. (2013). Testing and Analyzing Surface Water Quality of Yue-Guan Canal in Yueqing, China. *Doctoral dissertation, SUNY College of Environmental Science and Forestry*.

Husien, A., Seboka, S., & Shifarra, W. (2017). Assessment of irrigation water quality of lowlands in the Bale Zone, South Eastern Oromia, Ethiopia. *International Journal of Water Resources and Environmental Engineering*, *9*(12), 264-269.

Ibrahim, M. B., & Saseetharan, M. K. (2007). Physico-chemical characteristics and correlation, and regression study on ground water of Coimbatore north zone. *Journal of environmental science & engineering*, *49*(3), 215-224.

ICMR (1975). Manual of Standards of Quality for Drinking Water Supplies. *Indian Council of Medical Research*, Spl. Rep. No. 44: 27.

Islam, M. S., & Shamsad, S. Z. K. M. (2009). Assessment of irrigation water quality of Bogra district in Bangladesh. *Bangladesh Journal of Agricultural Research, 34*(4), 507-608.

Islam, M. S., Han, S., Ahmed, M. K., & Masunaga, S. (2014). Assessment of trace metal contamination in water and sediment of some rivers in Bangladesh. *Journal of Water and Environment Technology*, *12*(2), 109-121.

Jain, C. K., & Ali, I. (2000). Arsenic: occurrence, toxicity and speciation techniques. *Water Research, 34*(17), 4304-4312.

Jain, S. K., Agarwal, P. K., & Singh, V. P. (2007). Hydrology and water resources of India (Vol. 57). *Springer Science & Business Media*.

Jayalakshmi, V., Lakshmi, N., & Singara Charya, M. A. (2011). Assessment of physico-chemical parameters of water and waste waters in and around Vijayawada. *International Journal of Research in Pharmaceutical and Biomedical Sciences, 2*(3), 1040-1046.

Jensen, P.K., Van Der Hoek, W., Matsuno, Y., & Cairncross, S. (2001). Limitations of irrigation water quality guidelines from a multiple use perspective. *Irrigation and Drainage Systems*, *15*(2), 117 - 128

Jha, P. K., & Dash, S. K. (2002). Effect of outlet positions and various turbulence models on mixing in a single and multi strand tundish. *International Journal of Numerical Methods for Heat & Fluid Flow*, *12*(5), 560-584.

Jha, R., & Singh, V.P. (2008). Evaluation of River water Quality by Entropy. KSCE *Journal of Civil Engineering, 12*(1):61-69.

Ji, Z. G. (2017). Hydrodynamics and water quality: modeling rivers, lakes, and estuaries. *John Wiley & Sons*.

Joshi, D. M., Kumar, A., & Agrawal, N. (2009). *Assessment of the irrigation water quality of river Ganga in Haridwar District. Rasayan Journal Chemistry*, *2*(2), 285-292.

Joshi, M., & Srivastava, R. K. (2006). Study of drinking water quality in tarai region of Uttaranchal. *Pollution Research*, *25*(1), 179.

Jothivenkatachalam, K., Nithya, A., & Chandra Mohan, S. (2010). Correlation analysis of drinking water quality in and around Perur block of Coimbatore District, Tamil Nadu, India. *Rasayan Journal Chemistry*, *3*(4), 649-654.

Jouanneau, S., Recoules, L., Durand, M. J., Boukabache, A., Picot, V., Primault, Y., ... & Thouand, G. (2014). Methods for assessing biochemical oxygen demand (BOD): A review. *Water research*, *49*, 62-82.

Kachiashvili, K., Gordeziani, D., Lazarov, R., & Melikdzhanian, D. (2007). Modeling and simulation of pollutants transport in rivers. *Applied mathematical modelling*, *31*(7), 1371-1396.

Kankal, N. C., Indurkar, M. M., Gudadhe, S. K., & Wate, S. R. (2012). Water quality index of surface water bodies of Gujarat, India. *Asian J. Exp. Sci*, *26*(1), 39-48.

Kar, D., Sur, P., Mandai, S. K., Saha, T., & Kole, R. K. (2008). Assessment of heavy metal pollution in surface water. *International Journal of Environmental Science & Technology*, *5*(1), 119-124.

Kaur, J., & Kaur, S. (2014). Seasonal Variations in Water Quality Index of Sirhind Canal Passing Through Moga, Punjab, India. *International Journal of Research in Engineering and Technology*, *3*(5), 558-563.

Kaur, S., & Kaur, J. (2015). Assessment of Seasonal variations in oxygen demanding parameters (DO, BOD, COD) along Sirhind Canal passing through Moga, Punjab India. *International Journal of Innovative Science, Engineering & Technology*, *2*(5), 697-700.

Kazmi, A. A., & Hansen, I. S. (1997). Numerical models in water quality management: a case study for the Yamuna river (India). *Water Science and Technology*, *36*(5), 193-200.

Kelly, W.P. (1951). Alkali soils, their formation, properties and reclamation, 3rd edition. *Reinhold Publ., New York, USA.* P. 92.

Keupers, I., & Willems, P. (2017). Development and testing of a fast conceptual river water quality model. *Water Research*, *113*, 62-71.

Khwakaram, A. I., Majid, S. N., & Hama, N. Y. (2012). Determination of water quality index (WQI) for Qalyasan stream in Sulaimani city/Kurdistan region of Iraq. *International journal of plant, animal and environmental sciences*, *2*(4), 148-157.

Khwakaram, A. I., Majid, S. N., Ahmed, Z. H., & Hama, N. Y. (2015). Application of water quality index (WQI) as a possible indicator for agriculture purpose and assessing the ability of self-purification process by Qalyasan stream in Sulaimani City/Iraqi Kurdistan Region (Ikr). *International Journal of Plant, Animal and Environmental Sciences*, *5*(1), 162-173.

Korgaonkar, D. S., Bharamal, D. L., & Koli, Y. J. (2014). Determination of Water Quality Index Devgad Taluka, District Sidhudurg, Maharashtra. *Biolife*, *2*(4), 1268-1273.

Kramer, D. L. (1987). Dissolved oxygen and fish behavior. *Environmental Biology of Fishes*, *18*(2), 81-92.

Kumar, A., & Dua, A. (2009). Water quality index for assessment of water quality of river Ravi at Madhopur (India). *Global journal of environmental sciences*, *8*(1), 49.

Kumar, A., Datta, M., Nema, A. K., & Singh, R. K. (2016). An improved rating system for assessing surface water contamination potential from MSW landfills. *Environmental Modeling & Assessment*, *21*(4), 489-505.

Kumar, P., Kaushal, R. K., & Nigam, A. K. (2015). Assessment and management of Ganga River water quality using multivariate statistical techniques in India. *Asian Journal of Water, Environment and Pollution*, *12*(4), 61-69.

Kumar, V., & Chopra, A. K. (2012). Hydrological characteristics of abandoned Old Ganga Canal at Haridwar (Uttarakhand) India. *Journal of Chemical and Pharmaceutical Research*, *4*(11), 4774-4782.

Kundu, S. (2012). Assessment of surface water quality for drinking and irrigation purposes: a case study of Ghaggar River system surface waters. *Bulletin of Environment, Pharmacology & Life Sciences*, *1*(2), 1-1.

Launder, B. E., & Spalding, D. B. (1983). The numerical computation of turbulent flows. In *Numerical Prediction of Flow, Heat Transfer, Turbulence and Combustion* (pp. 96-116).

LeJeune, J. T., Besser, T. E., Merrill, N. L., Rice, D. H., & Hancock, D. D. (2001). Livestock drinking water microbiology and the factors influencing the quality of drinking water offered to cattle. *Journal of Dairy Science*, *84*(8), 1856-1862.

Lokgariwar, C., Chopra, R., Smakhtin, V., Bharati, L., & O'Keeffe, J. (2014). Including cultural water requirements in environmental flow assessment: an example from the upper Ganga River, India. *Water International*, *39*(1), 81-96.

Looper, M. L. (2012). Quantity and Quality of water for Dairy Cattle. *Agriculture and Natural Resources FSA 4021*.

Lukubye, B., & Andama, M. (2017). Physico-Chemical Quality of Selected Drinking Water Sources in Mbarara Municipality, Uganda. *Journal of Water Resource and Protection*, *9*(07), 707.

Maglangit, F., Galapate, R., & Bensig, E. (2014). Physico-chemical Assessment of the Water Quality of Buhisan River, Cebu, Philippines. *International Journal of Research in Environmental Science and Technology*, *4*, 83-87.

Mahesh Kumar, M. K., Mahesh, M. K., & Sushmitha, B. R. (2014). Water quality index and assessment of physico-chemical parameters of chikkakere, periyapatna, Mysore District, Karnataka State, India. *IJIRST*, *3*, 15343-15347.

Majumdar, D. K. (2001). Irrigation water management: principles and practice. *PHI Learning Pvt. Ltd.*, 360-409.

Manohar, S., Mang'oka, J. M., Ndunda, E., & Gathuru, G. (2017). Assessment of Yatta Canal Water Quality for Irrigation, Machakos County, Kenya. *J Environ Anal Toxicol*, *7*(423), 2161-0525.

Martínez-Solano, F.J., Iglesias Rey, P.L., Gualtieri, C., & López-Jiménez, P.A. (2010) Modelling flow and concentration field in rectangular water tanks. *Model. Environ. Sake Proc. 5th Bienn. Conf. Int. Environ. Model. Softw. Soc. iEMSs 2010, Ottawa, Canada* (pp. 389–398).

Marusic, G. A. L. I. N. A. (2013). A study on the mathematical modeling of water quality in" river-type" aquatic systems. *WSEAS transactions on fluid mechanics*, *2*(8), 80-89.

Marusic, G., Ciufudean, C., & Bostan, V. (2016). The use of Computational Fluid Dynamics analysis (CFD) in studying river-type systems. *International Journal of Energy and Environment*, *10*, 234-237.

Mathebula, B. (2016). Assessment of the surface water quality of the main rivers feeding at Katse Dam Lesotho. *Doctoral dissertation, University of Pretoria.*

Matta, G. (2014). Water quality assessment of Ganga Canal system. *Journal of Advanced Scientific Research*, *5*(4), 19-24.

Matta, G. (2015). Effect of water quality on phytoplankton ecology of Upper Ganga Canal. *International Journal of Scientific & Engineering Research*, *6*(2), 762-768.

Matta, G., Pandey, R. R., & Saini, K. K. (2015). Assessment of pollution on water quality and phytoplankton diversity in canal system of River Ganga. *World Journal of Pharmaceutical Research*, *4*(11), 889-908.

Matta, G., Srivastava, S., Pandey, R. R., & Saini, K. K. (2017). Assessment of physicochemical characteristics of Ganga Canal water quality in Uttarakhand. *Environment, Development and Sustainability*, *19*(2), 419-431.

Meddah, S., Saidane, A., Hadjel, M., & Hireche, O. (2015). Pollutant dispersion modeling in natural streams using the transmission line matrix method. *Water*, *7*(9), 4932-4950.

Michael, A. M. (1978). Irrigation Theory and Practice. *Vikas Publishing House. Pvt. Ltd. New Delhi, India.*

Michael, A. M. (2007). Irrigation: theory and practice. *Second Edition. Vikas Publishing House Pvt. Ltd.*

Mishra, N., Khare, D., Shukla, R., & Singh, L. (2013). A study of temperature Variation in Upper Ganga Canal Command India. *Advances in Water Resource and Protection (AWRP)*, *1*(3), 1-7.

Modenesi, K., Furlan, L. T., Tomaz, E., Guirardello, R., & Núnez, J. R. (2004). A CFD model for pollutant dispersion in rivers. *Brazilian Journal of Chemical Engineering*, *21*(4), 557-568.

Mohamed, A. I. (2013). Irrigation water quality evaluation in el-salam canal project. *International Journal of Engineering*, *3*(1), 2305-8269.

Mohanty, C. R., & Nayak, S. K. (2017). Assessment of seasonal variations in water quality of Brahmani river using PCA. A*dvances in environmental research*, *6*(1), 53-65.

Mohsin, M., Safdar, S., Asghar, F., & Jamal, F. (2013). Assessment of drinking water quality and its impact on residents health in Bahawalpur city. *International Journal of Humanities and Social Science*, *3*(15), 114-128.

Mukhtar, F., Bhat, M. A., Bashir, R., & Chisti, H. (2014). Assessment of surface water quality by evaluating the physico-chemical parameters and by checking the water quality index of Nigeen Basin and Brari Nambal Lagoon of Dal Lake, Kashmir. *Journal of Materials and Environmental Science*, *5*(4), 1178-1187.

Munawar, M. (2013). Editorial. Aquatic Ecosystem Health & Management, *16*(4), 357-359, DOI: 10.1080/14634988.2013.857261.

Murthi, V. S., Urian, R. C., & Mukerjee, S. (2004). Oxygen reduction kinetics in low and medium temperature acid environment: correlation of water activation and surface properties in supported Pt and Pt alloy electrocatalysts. *The Journal of Physical Chemistry B*, *108*(30), 11011-11023.

Nahid, S., Haque, M. A., & Syed, F. E. (2009). Evaluation of surface irrigation water quality in Muktagacha Upazila of Bangladesh. *Songklanakarin Journal of Science and Technology*, *31*(2), 229-235.

Nazif, W., Perveen, S., & Shah, S. A. (2006). Evaluation of irrigation water for heavy metals of akbarpura area. *Journal of Agricultural and Biological science, 1*(1), 51-54.

NRCD (2009). Status Paper on River Ganga: State of Environment and Water Quality. *National River Conservation Directorate, Ministry of Environment and Forests, Government of India.*

NRCD, (2010). Guidelines for Preparation of Project Reports under National Conservation Plan and National Ganga River Basin Authority, Ministry of Environment & Forests National River Conservation Directorate (NRCD) New Delhi, December 2010, pp. 1-176.

Oboh, I. P., & Agbala, C. S. (2017). Water quality assessment of the Siluko River, southern Nigeria. *African Journal of Aquatic Science*, *42*(3), 279-286.

Ojutiku, R. O., Ibrahim, A., & Raymond, A. (2014). Assessment of water quality parameters and trace metal contents of drinking water sources in Minna Metropolis, Niger State. *International Journal of Current Microbiology and Applied Science*, *3*(5), 1029-1037.

Oketola, A. A., Adekolurejo, S. M., & Osibanjo, O. (2013). Water quality assessment of River Ogun using multivariate statistical techniques. *Journal of Environmental Protection*, *4*(05), 466.

Olkowski, A. A. (2009). *Livestock water quality: A field guide for cattle, horses, poultry and swine*. Agriculture and Agri-Food Canada.

Olowu, R. A., Ayejuyo, O. O., Adewuyi, G. O., Adejoro, I. A., Akinbola, T. A., Osundiya, M. O., & Onwordi, C. T. (2010). Assessment of pollution trend of Oke Afa Canal Lagos, Nigeria. *Journal of Chemistry*, *7*(2), 605-611.

Ombaka, O., & Gichumbi, J. M. (2012). Water quality assessment of Ruguti River in Meru South, Kenya. *International Journal of Water Resources and Environmental Engineering*, *4*(12), 404-414.

Omotoso, O. A., & Ojo, O. J. (2012). Assessment of quality of river Niger floodplain water at Jebba, central Nigeria: implications for irrigation. *Water Utility Journal*, *4*, 13-14.

Orlob, G. T. (1983). Mathematical modeling of water quality: Streams, lakes and reservoirs (Vol. 12). *A Wiley- Interscience Publication, International Institute for Applied Systems Analysis, John Wiley & Sons*.

Ozkul, S., Harmancioglu, N.B., & Singh, V.P. (2000). Entropy-Based Assessment of Water Quality Monitoring Networks in Space/Time Dimensions. *Journal of Hydrologic Engineering, ASCE*, *5*(1), 90-100.

Pacheco, F. A. L., & Fernandes, L. S. (2016). Environmental land use conflicts in catchments: a major cause of amplified nitrate in river water. *Science of the Total Environment*, *548*, 173-188.

Paliwal, R., Sharma, P., & Kansal, A. (2007). Water quality modelling of the river Yamuna (India) using QUAL2E-UNCAS. *Journal of Environmental Management*, 83(2), 131-144.

Pandey, G., & Madhuri, S. (2014). Heavy metals causing toxicity in animals and fishes. *Research Journal of Animal, Veterinary and Fishery Sciences*, *2*(2), 17-23.

Pandey, R., Raghuvanshi, D., & Shukla, D. N. (2014). Assessment of Physico–Chemical Parameters of River Ganga at Allahabad with Respect to WQI. *International Journal of Innovative Research in Science, Engineering and Technology, 3*(9).

Perfus-Barbeoch, L., Leonhardt, N., Vavasseur, A., & Forestier, C. (2002). Heavy metal toxicity: cadmium permeates through calcium channels and disturbs the plant water status. *The Plant Journal*, *32*(4), 539-548.

Piller, O., & Tavard, L. (2014). Modeling the transport of physicochemical parameters for water network security. *Procedia Engineering, 70,* 1344-1352.

Provin, T. L., & Pitt, J. L. (2002). Description of Water Analysis Parameters, *Texas A & M Agrilife Extension*, SCS 2002-10.

Rai, B. (2013). Pollution and conservation of Ganga river in modern India. *International Journal of Scientific and Research Publications*, *3*(4), 1-4.

Rama, B., Manoj, K., & Kumar, P. P. (2013). Index analysis, graphical and multivariate statistical approaches for hydrochemical characterisation of Dam Oder River and its canal system, Durgapur, West Bengal, India. *International Research Journal of Environmental Sciences*, *2*(2), 53-62.

Raychaudhuri, M., Raychaudhuri, S., Jena, S. K., Kumar, A., & Srivastava, R. C. (2014). WQI to monitor water quality for irrigation and potable use. *Directorate of Water Management (Indian Council of Agricultural Research) Research Bulletin No. 71.*

Reza, R., & Singh, G. (2010). Heavy metal contamination and its indexing approach for river water. *International Journal of Environmental Science & Technology, 7*(4), 785-792.

Rezania, S., Ponraj, M., Talaiekhozani, A., Mohamad, S. E., Din, M. F. M., Taib, S. M., ... & Sairan, F. M. (2015). Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater. *Journal of Environmental Management*, *163*, 125-133.

Rhoades, J. D. (1992). The use of saline waters for crop production. *FAO*, (No. 628.167 F3).

Richards, L.A. (1954). Diagnosis and improvement of saline and alkali Soils, U.S. Department of Agriculture Handbook, 60, 160.

Roccaro, P., Barone, C., Mancini, G., & Vagliasindi, F. G. A. (2007). Removal of manganese from water supplies intended for human consumption: a case study. *Desalination*, *210*(1-3), 205-214.

Rötting, T. S., Cama, J., Ayora, C., Cortina, J. L., & De Pablo, J. (2006). Use of caustic magnesia to remove cadmium, nickel, and cobalt from water in passive treatment systems: column experiments. *Environmental Science & Technology*, *40*(20), 6438-6443.

Roy, A. K., Sharma, A., & Talukder, G. (1988). Some aspects of aluminum toxicity in plants. *The Botanical Review*, *54*(2), 145-178.

Runkel, R. L. (1995). Simulation models for conservative and nonconservative solute transport in streams. In: *Effects of scale on interpretation and management of sediment and water quality. Proc. symposium, Boulder, 1995. IAHS Publication No. 226*, 153-159.

Samani, Z., Hu, S., Hanson, A. T., & Heil, D. M. (1998). Remediation of lead contaminated soil by column extraction with EDTA: II. Modeling. *Water, Air, and Soil Pollution, 102*(3-4), 221-238.

Samani, Z., Krishnan, S., & Jacquez, R. (1995). Removal of Heavy Metals from Contaminated Water Using an Organic Filter. In *Water Resources Engineering, ASCE*, 1738-1743.

Samanta, P., Mukherjee, A. K., Pal, S., Senapati, T., Mondal, S., & Ghosh, A. R. (2013). Major ion chemistry and water quality assessment of waterbodies at Golapbag area under Barddhaman Municipality of Burdwan District, West Bengal, India. *International Journal of Environmental Sciences, 3*(6), 1938.

Samantray, P., Mishra, B. K., Panda, C. R., & Rout, S. P. (2009). Assessment of water quality index in mahanadi and atharabanki rivers and Taldanda Canal in Paradip Area, India. *Journal of Human Ecology, 26*(3), 153-161.

Sapkota, P., Bharati, L., Gurung, P., Kaushal, N., & Smakhtin, V. (2013). Environmentally sustainable management of water demands under changing climate conditions in the Upper Ganges Basin, India. *Hydrological Processes*, *27*(15), 2197-2208.

Sardar, K., Ali, S., Hameed, S., Afzal, S., Fatima, S., Shakoor, M. B., ... & Tauqeer, H. M. (2013). Heavy metals contamination and what are the impacts on living organisms. *Greener Journal of Environmental management and public safety*, *2*(4), 172-179.

Sarkar, A., & Pandey, P. (2015). River water quality modelling using artificial neural network technique. *Aquatic Procedia*, 4, 1070-1077.

Savci, S., & Bellitürk, K. (2013). Assesment of irrigation water quality of some provinces of Turkey. *International Journal of Modern Engineering Research, 3*(1), 19-22.

Schmalz, B., Bieger, K., Grudzinski, A., Fohrer, N., & Hörmann, G. (2008). Water quality monitoring in a lowland river catchment- joint analysis of the stream, its tributaries and connected eutrophic lakes. *Geophysical Abstracts. EGU 2008* 13-18. April, Vienna.

Semwal, N., & Alkolkar, P. (2011). Suitability of irrigation water quality of canals in NCR Delhi. *International Journal of Basic and Applied Chemical Sciences*, *1*(1), 60-69.

Shainberg, I. & Oster, J.D (1978). Quality of Irrigation Water. *International Irrigation Information Center, IIC, Publication No.2.*

Shakya, A. K., & Ghosh, P. K. (2018a). Simultaneous removal of arsenic, iron and nitrate in an attached growth bioreactor to meet drinking water standards: Importance of sulphate and Empty Bed Contact Time. *Journal of Cleaner Production, 186*, 1011-1020.

Shakya, A. K., & Ghosh, P. K. (2018b). Simultaneous removal of arsenic and nitrate in absence of iron in an attached growth bioreactor to meet drinking water standards: Importance of sulphate and Empty Bed Contact Time. *Journal of Cleaner Production*, *186*, 304-312.

Sharma, D., Kansal, A., & Pelletier, G. (2017). Water quality modeling for urban reach of Yamuna river, India (1999–2009), using QUAL2Kw. *Applied Water Science,* 7(3), 1535-1559.

Sharma, N. & Singh, R. (2011). History of irrigation in Uttar Pradesh. *Indian National Committee on Irrigation & Drainage (INCID), New Delhi.*

Sharma, R. K., Yadav, M., & Gupta, R. (2017). Water Quality and Sustainability in India: Challenges and Opportunities. In *Chemistry and Water* (pp. 183-205).

Sharma, R., Rishi, M. S., Lata, R., & Herojeet, R. (2014). Evaluation of Surface Water Quality for irrigation purposes in Limestone Mining areas of District Solan, Himachal Pradesh, India. *International Journal of Innovative Science, Engineering & Technology, 1*(8).

Shinde, V.T., Tiwari, K.N., Nandgude, S.B., &Singh. M. (2017). Water Quality Assessment and Application of SWAT Model for Hydrologic Simulations in a Mined Watershed. *Climate Change and Environmental Sustainability*, *5* (2), 111-121.

Shortt, R., Matsuno, Y., Boelee, E., Madramootoo, C., Faubert, G., & Van Der Hoek, W. (2003). Evaluation of Thermotolerant Coliforms and Salinity in the Four Available Water Sources of an Irrigated Region of Southern Sri Lanka. *Irrigation and Drainage*, *52*(2), 133 – 146.

Singh, A. K. (2017). Water in India: Dimensions of Crisis- An Overview of the Water Related Problems in India. *Kepa-India Group & Centre for the Study of Developing Societies, New Delhi*.

Singh, I. B. (2007). The Ganga River. *Large rivers: geomorphology and management*, 347-71.

Singh, I., & Sirohi, A. S. (1977). Optimization of Water Resource of Upper Ganga Canal in Western Uttar Pradesh. *Indian Journal of Agricultural Economics*, *32*(1), 92.

Sinha, D. K., Rastogi, G. K., Kumar, R., & Kumar, N. (2009). Correlation study among water quality parameters an approach to water quality management. *Journal of environmental science & engineering*, *51*(2), 111-114.

Sivakumar, V., Asaithambi, M., Jayakumar, N., & Sivakumar, P. (2010). Assessment of the contamination from the tanneries & dyeing industries on to Kalingarayan Canal of Tamil Nadu. *International Journal of ChemTech Research*, *2*(2), 774-779.

Song, J., Yang, X., Zhang, J., Long, Y., Zhang, Y., & Zhang, T. (2015). Assessing the variability of heavy metal concentrations in liquid-solid two-phase and related environmental risks in the Weihe river of shaanxi province, China. *International journal of environmental research and public health*, *12*(7), 8243-8262.’

Sreeja, V., & Pillai, A. R. (2012). Assessment of characteristics of River Kodayar with reference to Physicochemical parameters. *IOSR Journal of Applied Chemistry*, *2*(5-8), 05-08.

Srivastava, A., Kumar, R., Gupta, V., Agarwal, G., Srivastava, S., & Singh, I. (2011). Water quality assessment of Ramganga river at Moradabad by physico-chemical parameters analysis. *VSRD-TNTJ*, *2*(3), 119-127.

Štambuk-Giljanović, N. (1999). Water quality evaluation by index in Dalmatia. *Water Research*, *33*(16), 3423-3440.

Sun, W., Xia, C., Xu, M., Guo, J., & Sun, G. (2016). Application of modified water quality indices as indicators to assess the spatial and temporal trends of water quality in the Dongjiang River. *Ecological Indicators*, *66*, 306-312.

Sun, X., Higgins, J., & Turchyn, A. V. (2016). Diffusive cation fluxes in deep-sea sediments and insight into the global geochemical cycles of calcium, magnesium, sodium and potassium. *Marine Geology*, *373*, 64-77.

Sundaray, S. K., Nayak, B. B., & Bhatta, D. (2009). Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India–a case study. *Environmental Monitoring and Assessment*, *155*(1-4), 227-243.

Suns, K., & Hitchin, G. (1990). Interrelationships between mercury levels in yearling yellow perch, fish condition and water quality. *Water, Air, and Soil Pollution*, *50*(3-4), 255-265.

Suthar, S., Nema, A. K., Chabukdhara, M., & Gupta, S.K. (2009). Assessment of metals in water and sediments of Hindon River, India: Impact of industrial and urban discharges. *Journal of Hazardous Materials*, *171*(1–3), 1088-1095.

Tajmunnaher, & Chowdhury, M. A. I. (2017). Correlation study for assessment of water quality and its parameters of Kushiyara River, Sylhet, Bangladesh. *International Journal of New Technology and Research (IJNTR), 3*(12), 1-6.

Taylor, D., Maddock, B. G., & Mance, G. (1985). The acute toxicity of nine 'grey list'metals (arsenic, boron, chromium, copper, lead, nickel, tin, vanadium and zinc) to two marine fish species: dab (Limanda limanda) and grey mullet (Chelon labrosus). *Aquatic Toxicology*, *7*(3), 135-144.

Tiwari, T. N., & Mishra, M. (1985). A preliminary assignment of water quality index of major Indian rivers. *Indian Journal of Environmental Protection, 5*(4), 276-279.

Todd, D.K. (1980). Groundwater Hydrology, 2nd edition, *Wiley, New York*, 31-130.

Tomar, M. (1999). Quality assessment of water and wastewater. *CRC press.*

Tüzen, M. (2003). Determination of heavy metals in fish samples of the middle Black Sea (Turkey) by graphite furnace atomic absorption spectrometry. *Food Chemistry, 80*(1), 119-123.

UCCC (1974). Guidelines for interpretations of water quality for irrigation, Technical Bulletin. *University of California Committee of Consultants, California, USA,* 20-28.

USDA, United State of Environmental Protection Agency. (1954). Diagnosis and improvement of saline and alkali soils. *Handbook No. 60, Washington, DC*.

Venkatesharaju, K., Ravikumar, P., Somashekar, R. K., & Prakash, K. L. (2010). Physico-chemical and bacteriological investigation on the river Cauvery of Kollegal stretch in Karnataka. *Kathmandu University Journal of Science, Engineering and Technology*, *6*(1), 50-59.

Verma, O. P., Khanan, B., & Shukla, S. (2012). Determination of physico-chemical characteristics of four canals of Allahabad region and its suitability for irrigation. *Advances in Applied Science Research, 3*(3), 1531-1537.

Wang, D., Singh, V. P., Zhu, Y. S., & Wu, J. C. (2009). Stochastic observation error and uncertainty in water quality evaluation. *Advances in Water Resources, 32*(10), 1526-1534.

Wattoo, M. H. S., Wattoo, F. H., Kazi, T. G., Tirmizi, S. A., Bhanger, M. I., Mahar, R. B., & Iqbal, J. (2004). Quality Characterization of Phulali Canal water for irrigation purposes. *The Nucleus, 41*(1-4), 69-75.

Weber-Scannell, P. K., & Duffy, L. K. (2007). Effects of total dissolved solids on aquatic organism: a review of literature and recommendation for salmonid species. In *American Journal of Environmental Sciences*.

WHO (2004). Guidelines for drinking-water quality: recommendations, Vol. 1. *World Health Organization.*

Wilcox, L. V. (1955). Classification and use of irrigation waters. *United States Department of Agriculture,* 969: 19.

Yahaya, A., Adegbe, A. A., & Emurotu, J. E. (2012). Assessment of heavy metal content in the surface water of Oke-Afacanal Isolo. Lagos, Nigeria. *Archives of Applied Science Research*, *4*(6), 2322-2326.

Yu, F.X., Adrian, D.D., & Singh, V.P. (1991). Modeling River Water Quality by the Superposition Method. *Journal of Environmental Systems, 20* (4): 359-374.

Zahedi, S. (2017). Modification of expected conflicts between drinking water quality index and irrigation water quality index in water quality ranking of shared extraction wells using multi criteria decision making techniques. *Ecological Indicators*, *83*, 368-379.

ANNEXURE A

A1. Field measurements during sample collection

Determination of Water temperature (T_w), Dissolved Oxygen (DO), pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS).

The water temperature in the sampling sites of the UGC around Roorkee was measured *in-Situ* during sampling by electronic method using the portable Single-Multi-parameters water quality meters (Model OR900P) having pH electrode, EC, TDS and dissolved oxygen probe. The water Sample was taken from 20-30cm deep in the canal by a DO sampler. The instrument can measure DO and water temperature automatically. The pH electrode was immersed into the sample in beaker with 100 ml capacity. The pH value was measured at 25 ^{0}C.

The Model OR900P was calibrated by immersing the pH electrode in three buffer solutions 4.01, 7.00 and 10.00 prepared from Potassium Chloride solution (KCl) for setting the conductivity meter electrode. Firstly, some amount of Potassium Chloride was taken. The KCl was dissolved in distilled water and the potassium chloride solution was prepared. The conductivity of KCl was checked using the conductivity meter of the equipment. When there was some error in the conductivity of KCl, then the settings of the conductivity meter was adjusted accordingly. The well mixed sample was taken in a beaker of 100 ml capacity. Finally, conductivity of the sample was measured by direct reading after the washing of pH electrode by distilled water. The same procedure was repeated for all the 18 water samples *in-situ* and the electrical conductivity of all the samples was recorded. All the samples were taken in the beaker (100 ml) one by one. The Total Dissolved Solids (TDS) was also measured by selecting the corresponding key. Finally, the TDS value in mg/L displayed on the screen was recorded.

A2. The Laboratory Analysis

Determination of Total Alkalinity (TA), Bicarbonate (HCO_3) and Carbonate (CO_3)

Alkalinity is measured volumetrically by titrating the sample with 0.02 NH_2SO_4 and is reported in the equivalent $CaCO_3$ (acid-base titration method). The indicators most commonly employed are phenolphthalein (color change around pH 8.5) and methyl orange (color change around pH 4.5), resulting in the additional terms phenolphthalein alkalinity and methyl orange alkalinity; the latter is synonymous with total alkalinity.

Method: Titrimetric Method

Apparatus Required

1. Burette – 50 ml capacity
2. Pipette
3. Erlenmeyer flask/conical flask (100ml capacity)
4. Beakers
5. Spatula
6. pH meter

Reagents:

1. Distilled water
2. N/50 H_2SO_4
3. Bromocresol green Indicator to determine the total alkalinity
4. Phenolphthalein indicator to find the bicarbonate and carbonate alkalinity

Calibration:

The (Ethylenediaminetetraaceticacid) EDTA solution needs be standardized against the standard calcium solution such that the strength of EDTA will be 1mL= 1mg as $CaCO_3$. Proper water sample collection, preservation and storage are mandatory activities.

Procedure:

a) **Total Alkalinity (TA)**

1. Take 100ml sample in 250 ml Erlenmeyer conical flask.
2. Add 0.2ml Bromocresol green or mixed indicator (5 drops).
3. Titrate with $\frac{N}{50}$ H_2SO_4 to yellow end point.
4. Record ml of acid used (T ml), T = Titrant.
5. Total alkalinity = T × 10 mg/L $CaCO_3$.
6. Follow the steps 1 to 5 with 25 ml of standard solution ($\frac{N}{50}$) of sodium carbonate for all the 18 water samples.

b) **Phenolphthalein Alkalinity (Found in Samples of pH > 8.5)**

1. Take 100 ml sample and add 0.2 ml Phenolphthalein indicator (5 drops), (pink, if Phenolphthalein alkalinity is present)
2. Titrate with $\frac{N}{50}$ H_2SO_4 to colorless end point
3. Record acid used (T ml)
4. Follow steps 1 to 4 with 25 ml of standard solution ($\frac{N}{50}$) of sodium carbonate for all the 18 water samples
5. Phenolphthalein alkalinity = P ×10 mg/L $CaCO_3$.

Since in all the sampling sites of the UGC, the value of pH was varied between pH 4.5 to pH 8.5 and the P was zero, then the result of the titration of all 100 ml samples were only HCO_3 Alkalinity (mg/L as CaCO3). And, the observed CO_3 value in all the samples of the UGC was recorded to be zero value.

Calculation:

Calculate alkalinity in the water sample as follows:

$$\text{Total Alkalinity} = \left(\frac{1}{50}\right) \times \left(\frac{T}{100}\right) \times 50 \times 1000 \text{mg/L CaCO3; (Equivalent weight of CaCO3 = 50)}$$

$$= T \times 10 \text{mg/L CaCO3}$$

$$\text{TA = Total Alkalinity (as mg/L } CaCO_3\text{) = mL of } \frac{N}{50} H_2SO_4 \text{ used} \times 1000/V \text{ in mL of sample}$$

(Bromocresol green Indicator).

Where,

V = volume of the water sample taken for measurement. T = volume of titrant.

Hence, the TA and HCO_3 values of each sample was given in mg/L as $CaCO_3$ and the CO_3 value in all the sampling sites of the UGC was recorded zero value.

Determination of Total Hardness (TH), Calcium Hardness (Ca) and Magnesium Hardness (Mg) as mg/l CaCO3.

Total Hardness

The total hardness is defined as the sum of calcium and magnesium concentrations, both expressed as $CaCO_3$ in mg/L. In alkaline conditions EDTA (Ethylene-Diamine-Tetra-Acetic Acid) and its sodium salts react with cations forming a soluble chelated complex when added to a solution. If a small amount of dye such as Eriochrome black-T is added to an aqueous solution containing calcium and magnesium ions at alkaline pH of 10.0 ± 0.1, it forms wine red colour. When EDTA is added as a titrant, all the calcium and magnesium ions in the solution get complexed resulting in a sharp colour change from wine red to blue, marking the end point of the titration. At higher pH (>12.0), Mg^{++} ion precipitates with only Ca^{++} in solution. At this pH, Murexide indicator forms a pink colour with Ca^{++} ion. When EDTA is added Ca^{++} gets complexed resulting in a change from pink to purple indicating end point of the reaction.

Method: EDTA ($C_{10}H_{16}O_8N_2$) Titrimetric Method

Apparatus:

1) Lab glassware-Burette
2) Pipette
3) Erlenmeyer flask/conical flask 100ml
4) beakers
5) Spatula

Reagents:

1. Buffer solution: 16.9 g of ammonium chloride (NH_4Cl) and 1.25g of magnesium salt of EDTA is dissolved in 143 ml of concentrated ammonium hydroxide and diluted to 250ml with distilled water (Ammonia buffer). Store the solution in polyethylene bottle tightly stoppered to prevent loss of ammonia or pick-up of carbon dioxide for no longer than one month. Diluyte10 ml of the solution to 100 ml with distilled water and check that the pH value is 10.0 ± 0.1.

2. Eriochrome black-T (EBT) ($C_2OH_{13}.N_3O_7S$) indicator: mixed 0.5g of Eriochrome black-T indicator is dissolved in 100g of Triethanolamine or 2-methooxyethanol.

3. Standard EDTA titrant: 0.01M or Ng AR grade EDTA (3.723g of $Na_2HC_{10}H_{12}ON_2.H_2O$ dried overnight in a sulphuric acid desiccator) is dissolved in distilled water and diluted to 1000 ml. The reagent is stable for several weeks and large volume is usually prepared. And standardise it against standard calcium solution, 1ml = 1mg $CaCO_3$. Check the reagent by titrating 25 ml of standard calcium solution. Store in polyethylene bottle.

4. Standard Calcium Solution: 1.0g of AR grade $CaCO_3$ (dry analytical grade of calcium carbonate) is weighed into a 250ml conical flask, to which 1+1 HCl is added till all $CaCO_3$ is dissolved completely. 200ml of distilled water is added and boiled to expel carbon-di-oxide, and diluted to 1000ml. 1ml = 1mg $CaCO_3$.

Procedure:

1. Standardization – pipette of 25 ml of standard calcium solution in a porcelain basin and adjust to 50 ml volume with deionized (distilled) water and add 1 ml of buffer solution.

2. Exactly 100ml of the well-mixed sample is pipetted into a 250 ml Erlenmeyer conical flask, to which 1ml of ammonium buffer and 2-3 drops of Eriochrome black -T indicator are added. This means, one content of manver to two hardness indicator powder pillow is added; the mixture is titrated slowly against the standard 0.01M EDTA until the reddish/ wine red colour of the solution turns to pale blue at the end point.

Calculation:

$$N_1V_1 \quad = \quad N_2V_2; \frac{1}{50} \times \frac{V1}{100} \quad = N2$$

$$\text{Hardness (mg/L } CaCO_3\text{): } \frac{1}{50} \times \frac{V1}{100} \times 50 \times 1000 = V1 \times 10 \text{ mg/L } CaCO_3$$

$$\text{Total hardness (TH) as mg /L CaCO3} = \frac{T \times 1000}{V} \text{ mg/L (Eriochrome indicator)}$$

Where, N1 = volume in ml of standard calcium solution taken for standardization,

N2 = volume of ml of EDTA solution used in titration

V1 = volume in ml of EDTA standard solution used in titration for the sample,

V2 = volume in ml EDTA solution used in the titration for blank,

V = volume of the water sample taken for measurement. T = volume of titrant.

Calcium Hardness (mg/l as $CaCO_3$)

Method: EDTA Titrimetric Method

Apparatus:

1. Burette
2. Pipette

3. Erlenmeyer flask/conical flask 100ml
4. Spatula

Reagents:

1. 12N NaOH
2. Murexide (Ammonia Puyrpurate) Indicator
3. EDTA (N/50)

Procedure:

1. Take 100 mL sample in 250 ml conical flask
2. Add 10 drops or 1mL NaOH to raise the pH to 12.0, and 2-3 crystals or a pinch of Murexide indicator.
3. Titrate immediately with EDTA till pink color changes to violet/purple and note the volume of EDTA required in one separate table (A`).
4. Run a reagent blank. Note the mL of EDTA required in another separate table (B`) and keep it aside to compare end points of same titrations.
5. Calculate the volume of EDTA required by sample, C`= A`- B`.
6. Standardize the EDTA (0.1m) solution following the procedure of calcium hardness from 1 to 4, using the standard calcium solution.
7. End point: Pink color is changed into Violet/Purple color. The same titration was done to all the 18 water samples.

Calculation:

$$N1V1 = N2V2;\ N2 = \frac{1}{50} \times \frac{V1}{100}.$$

Hardness (mg/L CaCO3): $N2 = \frac{N}{50} \times \frac{V1}{100} \times 50 \times 1000 = V1 \times 10$mg/L CaCO3

Calcium Hardness (mg/L CaCO3) = mL of EDTA used × 1000/mL of sample (Murexide indicator).

The calcium hardness of the UGC water samples was given in mg/L CaCO3.

Magnesium Hardness (mg/l as $CaCO_3$)

Mg is the second major constituent of hardness and it generally comprises 15-20 per cent of the total hardness expressed as CaCO3. Magnesium hardness can be calculated as the difference between the total hardness and calcium hardness.

Calculation:

Magnesium hardness = (TH - Ca) (as mg\L CaCO3).

Where, TH = Total hardness mg\L (as $CaCO_3$) titrated in mL of EDTA used × 1000/mL of sample (Eriochrome indicator) and Ca= Calcium Hardness (mg/L CaCO3) = mL of EDTA used × 1000/mL of sample (Murexide indicator).

Determination of Sodium (Na) and Potassium (K) using Flame Emission Photometer

Principle:

The principle of the flame photometer depends on the "Emission Spectroscopy" in which the electrons of the metals after absorbing energy get excited from ground state to higher energy level and return back to the ground state with emission of light. The sample under test is introduced into flame in solution by means of atomizer. The radiation from the flame enters a dispersing device and isolates it (radiation) from the flame to the desired region of the spectrum. The phototube measures the intensity of isolated radiation, which is proportional to the concentration of the element present in the sample. The filter of the flame photometer is set to 589 nm (marked for Sodium) and 766.5 nm (marked for Potassium). By feeding distilled water the scale is set to zero and maximum using the standard of highest value. A standard curve between concentration and emission is prepared by feeding the standard solutions. The sample is filtered through filter paper and fed into the flame photometer and the concentration is found from graph or by direct readings.

Apparatus:

1. Flame photometer (direct reading or internal standard type) or atomic absorption spectrometer in the flame emission mode (model el-380).
2. Lab glassware and Whatman filter papers (Ø 125mm, Cat No 1001 125).
3. Plastic bottles, to store all solutions.

Reagents:

Sodium (Na)

1. De-ionized Distilled water
2. Stock sodium solution 2.542g NaCl/L =1mg Na/mL=1000ppm
3. Intermediate sodium solution 100ppm (0.1mg Na/mL)
4. Standard sodium solution 10 ppm (0.01mg/mL).

Potassium (K)

1. De-ionized Distilled water
2. Stock Potassium solution 2.542g KCl/L =1mg K/mL=1000ppm
3. Intermediate Potassium solution 100ppm (0.1mg K/mL)
4. Standard Potassium solution 10 ppm (0.01mg/mL).

Procedure:

1. Prepare a blank and sodium (or Potassium) calibration standards in stepped amount in ranges 0 to 1.0 to 10 or 10 to 100 mg/mL
2. Start with highest calibration standard and working towards most dilute.
3. Construct a calibration curve from sodium standards. Determine sodium concentration of the sample from calibration curve. Dilute the sample if required.

Calculation:

Na (mg/L) = (mg Na/L in portion) x dilute Ratio

K (mg/L) = (mg K/L in portion) x dilute Ratio

Determination of Chloride (Cl)

The amount of chloride present in water can be easily determined by titrating the given water sample with silver nitrate solution. The silver nitrate reacts with chloride ion according to1 mole of $AgNO_3$ reacts with 1 mole of chloride. The titrant concentration is generally 0.02 M. Silver chloride is precipitated quantitatively, before red silver chromate is formed. The end of titration is indicated by the formation of red silver chromate from excess silver nitrate.

Method: Argentometric titration

Principle: In a neutral or slightly alkaline solution (pH 7-10) potassium chromate can indicate the end point of silver nitrate titration of chloride. Silver chloride is precipitated before red silver chromate formed.

Apparatus:

1. Erlenmeyer flask 250 ml capacity.
2. Burette – 50 ml with 0.01 ml graduation intervals.
3. A volume of 50 ml Conical Flask.
4. Beaker,
5. Pipette
6. Wash Bottle

Reagents:

1. Potassium Chromate Indicator Solution
2. Standard Silver Nitrate Titrant (0.028 N = N/35.5)
3. Standard Sodium Chloride (0.028 N) solution
4. Nitric acid -0.1N
5. Sodium hydroxide-0.1N
6. Reagents for chloride concentrations below 700 mg/L
7. Indicator-acidifier reagent
8. Strong standard mercuric nitrate titrant- 0.014N. Dissolve 2.3 g mercuric nitrate [Hg (NO3)2 or 2.5 g HG $(NO_3).12H_2O$] in 100ml distil water containing 0.25ml concentrated nitric acid. Dilute to 1000 ml. use replicates containing 5 ml standard sodium chloride solution and 10 mg sodium bicarbonate ($NaHCO_3$) diluted to 100 ml with distil water. Adjust the titrant to 0.0141N and make a final standardization; 1 ml = 500 µg Cl^-. Store away from light in a dark bottle.
9. Mixed indicator reagent- dissolve 0.50g diphenylcarbazone powder and 0.05g bromophenol blue powder in 75 ml 95 percent ethyl or isopropyl alcohol and dilute to 100ml with the same alcohol.

Procedure:

1. Take 100 ml distilled water;
2. 100 ml of water sample that the chloride content is less < 10 mg.

3. Adjust pH of the sample between 7 and 10 for highly alkaline or acid waters before adding indicator-acidifier reagent.
4. Add 0.5 mL K_2CrO_4 indicator solution.
5. Titrate with standard 0.41 1N mercuric nitrate ($AgNO_3$) to a definite purple end point. End point: Whitish yellow changed into Brick red /Orange color. Determine the blank by titrating 100 ml distilled water containing 10 mg of sodium bicarbonate.

Calculations

$$\text{Sample} \quad AgNO_3$$

$$N_1V_1 \quad = N_2V_2$$

$$N_1 = \frac{1}{35.5} \times \frac{V2}{100}$$

$$\text{Chloride } (Cl^-) \text{ (mg/L)} = (V1\text{-}V2) \times N \times 35000 = \frac{1}{35.5} \times \frac{V2}{100} \times 35.5 \times 1000$$

$$Cl^- = \quad V_2 \times 10 \text{ mg/L.}$$

Where,

V1 = volume in ml of silver nitrate used by the sample

V1 = volume in ml of silver nitrate used in the blank titration

N1 = volume in ml of sample taken for titration

N2 = normality of silver solution

Remarks: The pH of the water sample should be between 7 and 10.

At pH < 7; K2CrO4 → $K_2Cr_2O_7$ and $K_2Cr_2O_7$ obscures the end point of the titration.

At pH > 10; $AgNO_3$ → AgOH and $AgNO_3$ is used for chloride as well as OH^- at pH > 10 → error in results. Finally, the Chloride concentration values of each sample of the UGC were given in mg/L.

Determination of Sulfate (SO_4)

Method: Turbidimetric

Principle: Sulphate ions are precipitated in acetic acid medium with barium chloride to form barium sulphate crystals of uniform size. The scattering of light by the precipitated suspension (barium sulphate) is measured by a turbidimeter (model HACH 2100 AN) and the concentration is recorded. The turbidimetric method of measuring sulphates is based upon the fact that barium sulphate tends to precipitate in a colloidal form of uniform size and that this tendency is enhanced in presence of sodium chloride, hydrochloric acid and glycerol. The absorbance of the barium sulphate formed is measured by a spectrophotometer at 420 nm and the sulphate ion concentration is determined by comparison of the reading with a standard curve.

Apparatus: Turbidimeter, magnetic stirrer or shaker, Nessler's tubes and lab glassware.

Reagents:

1. Conditioning reagent /buffer solution: (30g $MgCl_2.6H_2O$, 5g $CH_3CooNa.3H_2O$, 1g KNO_3, 2ml 99% acetic acid in 1litre of water).
2. Barium Chloride crystals.
3. Standard sulphate solution: 147.9mg of AR grade sodium sulphate was dissolved in distilled water and made up to 1000ml, to give 1ml = 100 µg sulphate. Dilute 10.4 ml standard 0.02N $H2SO_4$ titrant (used for alkalinity determination) to 100ml or dissolve 0.147g anhydrous Na_2SO_4 in distil water.

Procedure:

1. 100ml of the sample is filtered into a Nessler's tube containing 5ml of conditioning reagent.
2. Add about 0.2ml buffer solution/ conditioning reagent
3. Put the conical flasks on the stirrer and mix the content
4. Add 1 spoonful of $BaCl_2$ crystals to each flask
5. Stir for exactly 1 minute
6. Measure turbidity within 3 to 10 minutes
7. Plot turbidity Vs SO_4^{--}concentration.

Calculation:

Sulphates (SO_4), (as mg/L) = (Turbidimeteric reading) × (0.4) ×Dilution Factor).

Since 100 mL of each water sample was taken, directly reading of the SO_4^{--} concentration from the plot/graph was recorded. In Sulfate determination by Turbidimetric Method, standardization and calibration was directly done and the Absorption is presented as **Table A-1 and Figure A-1.**

Table A-1 Standardization Table for Sulphate calibration curve

Sl. No.	Standard solution of N_2SO_4, conc., (mg/L)	Turbidity(NTU)	SO_4^{--}conc. of sample (mg/L) to be taken directly from the plot / graph
1	Blank	2.44	-
2	5	34.7	-
3	10	55.9	-
4	20	92.2	-
5	30	134	-
6	40	174	-
7	50	205	-

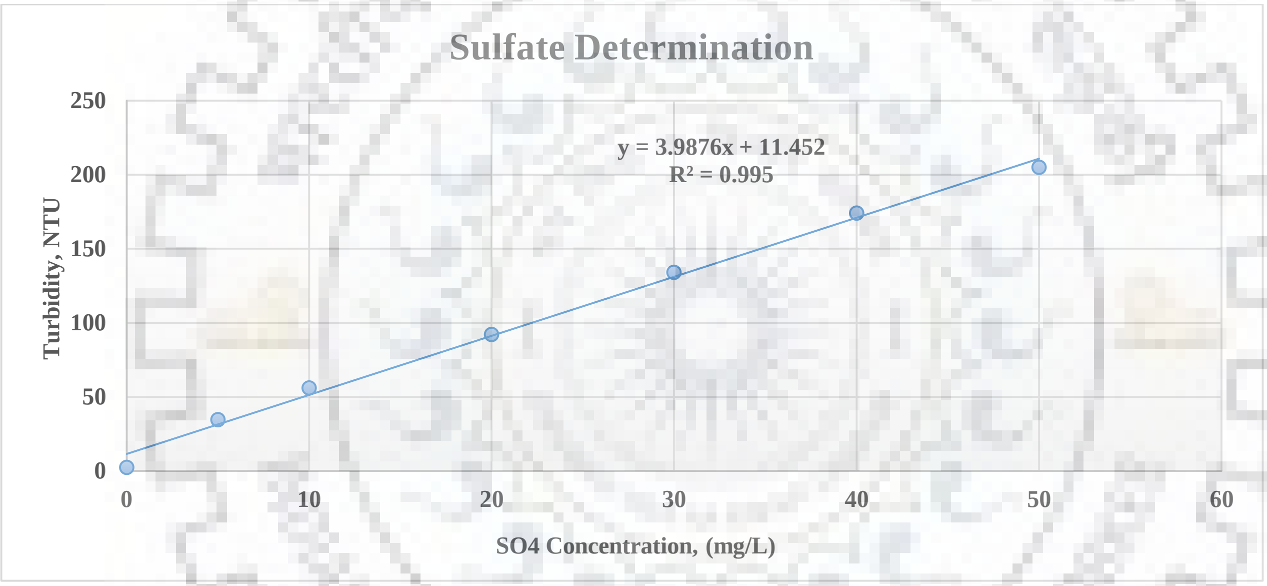


Figure A-1 Graph of Na_2SO_4/ SO_4 concentration mg/L) versus Turbidity (NTU).

Determination of Nitrate (NO_3)

Method: UV Spectrophotometer Screening

Apparatus: Nessler's tube, pipettes, beakers, spectrophotometer (wavelength = 220 nm and 275nm), cuvettes, measuring jar and hot water bath.

Reagents:

1. Nitrate free water
2. Stock nitrate solution (dried) in an oven 15℃, 24 Hrs.

3. Dissolve 0.721 gm KNO_3 in water and dilute to 1000 ml. 1 ml = 100 µg NO_3^--N (preserve with 2 ml $CHCL_3$/L).
4. Standard nitrate solution, 1ml = 10 µg NO_3^--N (0.01 mg).

Procedure: Prepare NO_3^- calibration standards in range 0 to 7 mg NO_3^-N/L

1. Take Nessler`s tubes and appropriate standard nitrate and make up to 50 ml.
2. Add 1 ml of 1N HCl (prepared) and mix thoroughly.
3. Note down the reading.
4. Treat 50 ml sample and all other samples in the similar manner for
5. Read absorbance (set distilled water to zero) at 220 and 275nm reading by 10 to obtain actual concentration in mg/l. The 220nm of UV absorption enables rapid determination of NO_3^-. Because dissolved organic matter also may absorb at 220 nm and NO_3- does not absorb at 275nm. Therefore, a second measurement made at 275nm is used to correct the NO3- value.
6. Plot absorbance Vs NO_3^- Concentration

KNO_3 Standardization and calibration of the DN-5000 UV Spectrophotometer machine was done by the solutions of KNO3. The Absorbance is presented in **Table** A-2.

Table A2- Standardization Table for Nitrate calibration curve

Standardization of KNO3 solutions	Standard of KNO_3, (mg/mL)	Difference of wavelengths between at 220 nm and at 275nm
Blank	Blank	0
1	0.5	0.225
2	1	0.403
3	1.5	0.612
4	2	0.823
5	2.5	1.008

Calculation:

Absorbance due to NO_3^- = A_{220} -2(A_{275}) and construct a standard curve.

$NO3^-$ (mg/L) = [(mg of NO_3^--N) /ml of sample)] x 1000 ml/L. The result of each water sample of the UGC was given in mg/L.

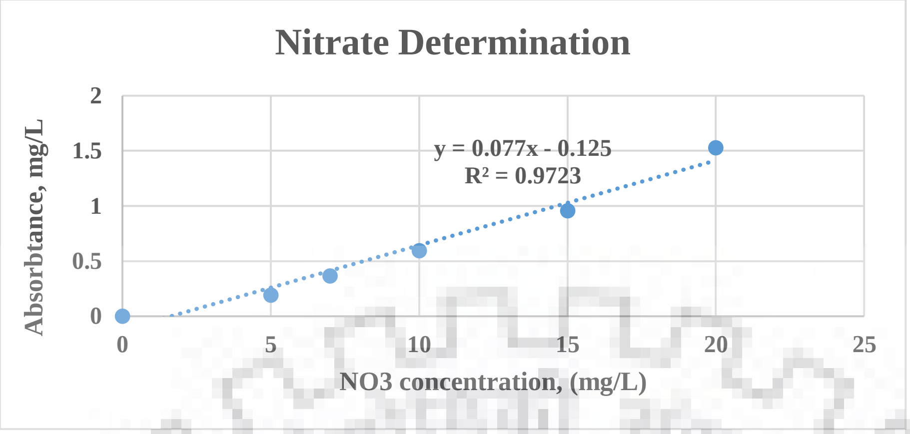


Figure A2. Plot/ graph of NO_3 Conc. versus Absorbance.

Determination of Chemical Oxygen Demand (COD)

Principle: The sample is digested (oxidized) with excess of known amount of potassium dichromate (K_2Cr_2O7) in acid medium. The residual $K_2Cr_2O_7$ (Cr^{+6}) or Cr^{+3} is determined spectrophotometrically. The oxygen equivalence of $K_2Cr_2O_7$ used is obtained from $Cr^{+}3$ or difference between initial and residual concentration of $K_2Cr_2O_7$.

$K_2Cr_2O_7 + 4H_2SO_4 + 1.5CH_2O$ (org.) gives $1.5\ CO_2 + Cr_2\ (SO_4)_3 + K_2SO_4 + 5.5H_2O$

Method: UV Spectrometer (Closed Reflux Method)

Apparatus:

1. Reflux apparatus, Nessler's tube,
2. Erlenmeyer flasks,
3. block heater (hot plate)
4. Lab glassware, Borosilicate culture tubes (16 x 100 mm) with screw caps.
5. DR-5000 UV spectrophotometer for use at 600nm.

Reagents:

1. Digestion solution standard potassium dichromate solution ($0.1NK_2Cr_2O_7 + H_2SO_4 + HgSO_4$): 12.25g of potassium dichromate dried at 103 °C for about 2 hours is dissolved in distilled water and made up to 1000ml.
2. H_2SO_4 reagent ($H_2SO_4 + AgSO_4$)
3. Potassium hydrogen phthalate (KHP: $HOOC-C_6H_4-COOK$) COD standard (500 µg /ml): Dissolved 425 mg KHP in 1L distilled water).

Procedure: Prepare standards of COD ranging from 100-500 µg/mL (dilute KHP standards in the ratio: 1:4. 2:3, 3:2 and 4:1).

1. Transfer 2.5 ml raw well mixed sample and standards (100-500 µg/mL) into clean and dried COD vials or culture tubes.
2. Add 1.5 ml digestion solution (dichromate solution).
3. Add 3.5 ml Sulfuric acid reagent carefully.
4. Place culture tubes in block digester preheated to 150°C and reflux for 2 hrs until it will automatically off.
5. After completion of digestion keep the vial in digester for 15-30 minutes and take out the vial for cooling until room temperature.
6. Take direct reading (mg/L) of the absorbance on a calibration graph prepared by you on spectrophotometer and measure the absorbance of the sample, blank and standards at 600nm. Use digested blank (No. 1) as the reference solution to measure absorbance due to chromic ion (Cr^{+3}).

The prepared calibration curve with KHP at 500mg standard was as: 0, 50, 100, 200, 300, 400, 500 mL (**Table A-3**) with empty culture tubes and COD veils by N1V1 = N2V2. Then, digestions with COD veils at 150°C for 120 minutes (2Hrs.) and after cooling at room temperature you are welcome to take for absorbance by DR-5000 UV spectrophotometer at wavelength of 600nm with Conc. Of COD Vs Absorbance which is the 2.5 ml KHP. Blanks/Standards of 0-500mg/L [2.5mL blank/sample+1.5mL K_2CrO_4 +3.5 mL H_2SO_4 Reagent] for natural water.

Table A-3 Standardization Table for COD calibration curve

Sl. No.	COD conc. (mg/L)	Absorbance at wavelength of 600nm
1	Blank	0.000
2	100	0.042
3	200	0.071
4	300	0.102
5	400	0.143
6	500	0.181

Calculation:

COD (mg/L) = COD (mg/L) from calibration curve x sample dilution.

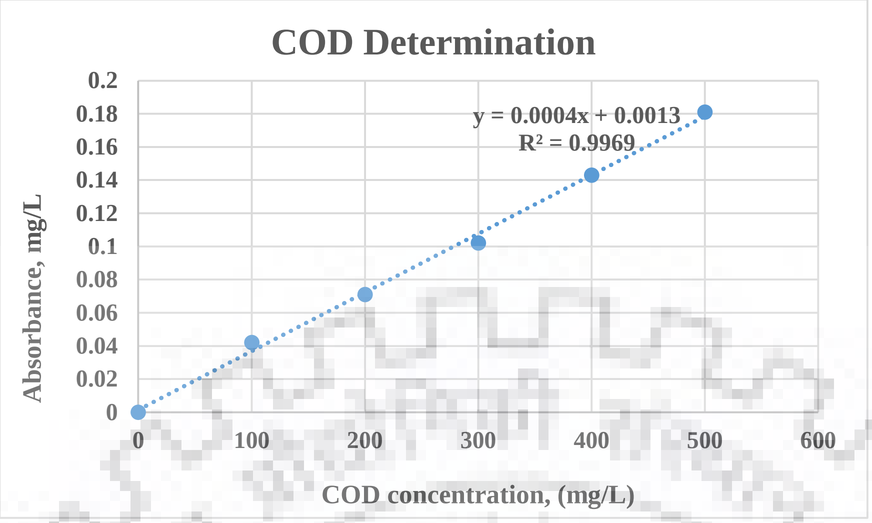


Figure A-3. COD Concentration versus Absorbance

The results of all water samples were given in mg/L.

Determination of Boron, (B)

Method: Carmine (UV Spectrophotometric)

Apparatus:

1. Spectrophotometer, or porcelain with a green filter, for use at 540nm.
2. High-silica glass or porcelain evaporating dishes, 100-150mL
3. Water - bath, set at 55 °C
4. Glass-stoppered volumetric flasks, 25-50 mL capacity
5. Ion-exchange column 1.3cm diameter, 50cm length
6. Containers, boron free or polyethylene.

Reagents:

1. Stock boron solution: Dissolve 571.6mg anhydrous boric acid, in distilled water and dilute to 1L, 1mL=100microgB.
2. Standard boron solution: Dilute 10mL stock boron solution to 1L with distilled water; 1mL=1microgB.
3. Curcumin reagent: Dissolve 40mg finely ground curcumin and 5g oxalic acid in 80mL 95% ethyl alcohol, add 4.2 mL concentration HCl, make to 100mL with ethyl alcohol-store in refrigerator stable for several days).
4. Ethyl alcohol, 95%

5. Strongly acidic cation exchange resin.
6. Concentrated Hydrochloric acid HCl (1+1)

Procedure:

1. Preparation of calibration Curve: Take 0, 0.25, 0.50, 0.75 and 1mL boron standard solution into same size of evaporating dishes, make volume to 1mL with distilled water, add 4mL curcumin reagent to each, mix. Heat the dishes on water bath at 55+ /or- 2 ℃ for 80min, cool, add 100mL 95% ethyl alcohol and mix the red colored product with a polythene rod.
2. Use 95% ethyl alcohol to transfer the dish contents to 25mL Volumetric flasks, make up to the mark with 95% alcohol and mix.
3. Sample treatment: For water expected to have 0.1-1mg B/L use 1mL sample. For higher concentration take appropriate sample to make dilutions to mL with distilled water. Run the sample with the standard and blank.
4. Removal of hardness and cation interference for samples containing more than 100mg/L hardness as $CaCO_3$. Use a column with strongly acidic cation-exchange resin, backwash with distilled water pass 50mL 1+5 HCl at a rate of 0.2mL acidic/mL resin in column/min. Wish column free of acidic with distilled water. Add 25mL sample to resin column, adjust flow to 2 drops/s and collect in 50mL, volumetric flask and wash column with distilled water to make up the volume. Alternatively, filter the final solution in step "b" above if any turbidity appears due to hardness of the sample.
5. Make photometric measurements at 585nm.

Calculation:

Plot calibration curve giving absorbance versus mg B. Read weight of Boron in mg in the sample from the curve. Calculate mg B/L by dividing the weight by the volume of the sample in ml.

Table A-4 Standardization Table for Boron calibration curve

Sl. No.	Boron conc.(mg/L)	Absorbance at wavelength of 585nm
1	Blank	0.000
2	0.5	0.275
3	1	0.403
4	1.5	0.62
5	2	0.83
6	2.5	1.008

Graph of Calibration: c = a + bΔ

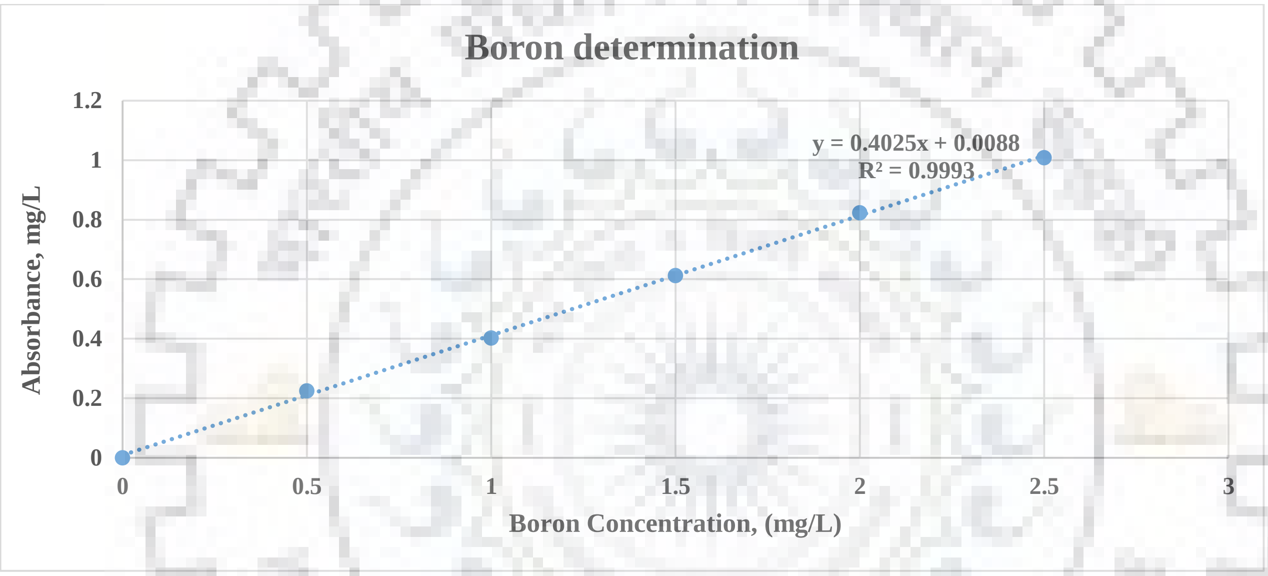


Figure A-3 Plot calibration curve giving Absorbance versus mg/L of Boron

Determination of trace heavy metals (Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Pb, and Zn)

METHOD: Flame Atomic Adsorption Spectrophotometry (AAS)

The spectrophotometer has component parts such as Atomic adsorption spectrometer, Burner, Readout part, Lamps, Pressure reducing valves and vent. The metals can be determined at specified wavelengths by AAS, with aspiration of the sample into an oxidising air-acetylene flame.

Apparatus:

1. Sampling plastic bottles - polyethylene
2. Volumetric flasks- one lite capacity
3. Beaker- 250 ml capacity
4. Watch glass

5. Hotplate

Reagents:

1. Nitric acid, HNO_3, Conc.
2. Hydrochloric acid, HCl, Conc. And 1+1.
3. Nitric acid, HNO_3, 1+1.
4. Distilled water

Procedure: An open digestion is carried, which converts metals from combined state to their free state so that their individual concentration can be determined. For this, an aliquot of 5 ml concentrated nitric acid was added to 100 ml of sample collected in a 250 ml conical flask. The mixture was heated slowly to evaporate to a lower volume of 10-15 ml. 10 ml of concentrated nitric acid (HNO_3) was again added to the 10-15 ml and heating continued for 30 minutes. A final 5ml of nitric acid was used to rinse sides of the conical flask. The solution was poured into a 50 ml volumetric flask and topped with distilled water to the mark. A blank solution was similarly prepared to serve as control for analyses. After the completion of open digestion, the samples were taken to heavy metal analyses which were performed on Atomic Absorption Spectrophotometer (A.A. Spectrophotometer (GBC-AVANTA), using acetylene gas as a fuel and air as oxidizer. Calibration curves were prepared separately for all the metals by running a suitable concentration of the standard solutions. The digested 18 samples were aspired in fuel rich air-acetylene flame and the concentrations of metal were determined from the calibration curves. Average values of the three replicates were taken for each determination. The blank absorbance was taken before the testing of the samples.

ANNEXURE B

OBSERVED DATA (PHYSICOCHEMICAL PARAMETERS)

Table B1: Results of analyzed physicochemical parameters of eighteen water sampling sites of the study area (UGC) during winter season from November 2014 to October 2015

Parameters	**Water sampling sites during winter season**																		**Statistical parameters**			
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**Min.**	**Max.**	**Avg.**	**±SD**
T_w	17.300	16.500	17.100	18.800	17.400	17.800	17.100	17.000	17.600	16.700	16.700	17.300	18.200	17.100	18.700	16.700	16.700	17.300	16.500	18.800	17.333	0.670
pH	8.30	8.40	8.40	7.10	6.80	8.30	6.90	8.30	8.30	8.30	8.20	8.30	8.30	8.30	8.40	8.30	8.30	8.30	6.80	8.40	8.08	0.53
EC	200.00	187.00	181.00	1316.00	984.00	193.00	985.00	199.00	185.00	182.00	183.00	195.00	186.00	238.00	243.00	242.00	241.00	195.00	181.00	1316.00	351.94	348.88
TDS	128.00	120.00	121.00	826.00	637.00	124.00	636.00	127.00	118.00	116.00	117.00	125.00	119.00	152.00	156.00	155.00	154.00	125.00	116.00	826.00	225.33	221.91
TA	76.250	76.250	83.500	257.500	260.500	79.750	215.250	75.250	73.000	78.500	89.750	83.750	84.750	82.750	81.500	86.500	86.250	86.750	73.000	260.500	108.764	63.185
TH	57.800	64.000	67.500	219.000	364.300	64.300	220.800	60.300	61.800	63.300	60.800	64.000	58.800	56.500	66.800	55.500	58.500	59.800	55.500	364.300	95.767	84.338
Ca^{2+}	2.10	2.30	2.08	6.05	16.76	2.16	6.88	1.89	1.95	2.05	2.21	1.81	1.80	1.78	2.20	1.65	1.65	1.71	1.65	16.76	3.28	3.67
Mg2+	1.30	1.78	1.86	8.10	2.40	1.74	6.88	1.86	1.88	1.84	1.84	2.02	2.09	1.74	1.88	2.33	2.27	2.31	1.30	8.10	2.56	1.82
Na^+	0.12	0.14	0.12	1.84	2.38	0.19	1.87	0.17	0.12	0.14	0.15	0.18	0.14	0.14	0.15	0.15	0.14	0.15	0.12	2.38	0.46	0.73
K^+	0.04	0.04	0.04	0.37	0.80	0.57	0.06	0.04	0.10	0.07	0.05	0.05	0.05	0.05	0.07	0.05	0.05	0.07	0.04	0.80	0.14	0.21
Cl^-	0.45	0.30	0.40	3.31	9.72	0.40	4.17	0.32	0.46	0.42	0.43	0.39	0.51	0.44	0.68	0.33	0.42	0.42	0.30	9.72	1.31	2.36
SO_4^{2-}	2.36	2.42	2.43	2.23	2.34	2.52	4.41	2.45	2.53	2.55	2.50	2.61	2.50	2.58	2.88	2.59	2.58	2.90	2.23	4.41	2.63	0.47
NO_3^-	0.07	0.06	0.08	0.03	0.04	0.10	0.04	0.10	0.07	0.06	0.07	0.07	0.05	0.06	0.08	0.05	0.05	0.05	0.03	0.10	0.06	0.02
HCO_3^-	1.25	1.25	1.37	4.22	4.27	1.31	3.53	1.23	1.20	1.29	1.47	1.37	1.39	1.36	1.34	1.42	1.41	1.42	1.20	4.27	1.78	1.04
CO_3^{2-}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO	9.720	9.690	9.670	2.160	1.540	9.750	2.110	9.870	9.770	9.690	9.640	9.700	9.510	9.740	9.640	9.850	9.680	9.500	1.540	9.870	8.402	2.979
COD	25.17	39.01	32.98	202.06	491.09	260.88	28.89	22.39	31.59	16.74	26.30	18.48	22.42	16.10	48.53	27.49	22.14	30.49	16.10	491.09	75.71	123.45
B	0.45	0.57	0.67	0.94	0.99	0.69	0.95	0.83	0.83	0.83	0.83	0.83	0.84	0.95	1.53	0.84	0.83	0.88	0.45	1.53	0.85	0.22

Table B2: Results of analyzed physicochemical parameters of eighteen water sampling sites of the study area (UGC) during summer season from November 2014 to October 2015

Parameters	Water sampling sites during summer season																		Statistical parameters			
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**Min.**	**Max.**	**Avg.**	**±SD**
Tw	22.300	22.700	23.200	22.000	23.100	21.300	24.700	22.200	21.700	21.200	21.800	21.900	23.000	23.300	25.300	23.600	22.700	22.800	21.200	25.300	22.711	1.085
pH	7.80	7.70	7.80	7.40	7.10	7.60	7.30	7.80	7.80	7.80	7.70	7.70	7.60	7.70	7.70	8.00	7.80	7.70	7.10	8.00	7.67	0.21
EC	198.00	201.00	202.00	1226.00	1237.00	209.00	1029.00	208.00	180.00	195.00	164.00	180.00	243.00	161.00	249.00	168.00	196.00	170.00	161.00	1237.00	356.44	374.54
TDS	127.00	129.00	129.00	653.00	713.00	134.00	679.00	133.00	115.00	124.00	105.00	115.00	155.00	103.00	160.00	108.00	125.00	108.00	103.00	713.00	217.50	214.39
TA	52.750	62.530	72.500	100.850	177.250	66.500	110.500	65.250	67.750	69.750	71.250	70.250	74.250	70.750	90.250	88.550	72.500	70.250	52.750	177.250	80.760	27.856
TH	64.500	67.800	71.500	202.300	247.800	67.800	224.500	65.800	65.000	66.300	65.300	65.300	66.300	65.500	76.000	66.800	64.800	65.500	64.500	247.800	93.267	61.123
Ca2+	2.15	2.18	2.21	6.63	8.69	2.13	6.81	2.10	2.28	2.11	2.10	2.11	2.19	2.21	2.69	2.09	2.16	2.10	2.09	8.69	3.05	2.03
Mg2+	1.78	2.31	1.94	5.76	6.12	2.09	7.29	1.96	1.61	1.98	1.92	1.90	1.86	1.76	1.84	2.07	1.78	1.86	1.61	7.29	2.66	1.75
Na+	0.05	0.08	0.12	0.54	0.73	0.11	0.58	0.05	0.06	0.13	0.14	0.14	0.09	0.11	0.08	0.09	0.09	0.09	0.05	0.73	0.18	0.20
K+	0.04	0.06	0.04	0.52	0.33	0.72	0.04	0.03	0.04	0.05	0.03	0.04	0.04	0.05	0.12	0.04	0.04	0.04	0.03	0.72	0.13	0.20
Cl-	0.44	0.47	0.48	3.35	4.76	0.47	3.98	0.46	0.46	0.48	0.49	0.49	0.49	0.50	0.64	0.56	0.51	0.46	0.44	4.76	1.08	1.38
SO42-	5.49	3.59	3.15	5.24	5.13	2.16	4.84	2.63	2.93	2.30	2.14	2.06	2.14	1.99	2.36	2.10	1.90	2.18	1.90	5.49	3.02	1.27
NO3-	0.08	0.10	0.07	0.08	0.08	0.06	0.11	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.16	0.06	0.07	0.07	0.06	0.16	0.08	0.03
HCO3-	0.86	1.03	1.19	1.65	2.91	1.09	1.81	1.07	1.11	1.14	1.17	1.15	1.22	1.16	1.48	1.45	1.19	1.15	0.86	2.91	1.32	0.46
CO32-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO	8.770	9.050	9.020	2.510	1.520	8.950	2.240	9.020	9.120	9.260	9.220	9.280	9.280	9.120	9.380	8.760	8.760	8.900	1.520	9.380	7.898	2.685
COD	2.98	3.09	3.55	218.73	295.98	170.75	18.86	3.00	8.73	20.88	21.21	16.61	29.26	6.98	15.85	4.55	6.15	5.24	2.98	295.98	47.35	86.47
B	0.53	0.61	0.65	1.25	1.35	0.66	1.25	0.66	0.73	0.83	0.83	0.83	0.87	0.92	0.85	0.85	0.84	0.85	0.53	1.35	0.85	0.23

Table B3: Results of analyzed physicochemical parameters of eighteen water sampling sites of the study area (UGC) during monsoon season from November 2014 to October 2015

Parameters	**Water sampling sites during monsoon season**																		**Statistical parameters**			
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**Min.**	**Max.**	**Avg.**	**±SD**
Tw	21.800	22.100	21.800	27.000	26.900	27.800	23.000	23.100	23.600	21.500	21.500	22.700	23.000	22.300	24.100	24.600	25.000	23.200	21.500	27.800	23.611	1.948
pH	7.30	7.20	7.00	7.10	7.30	7.30	7.50	7.20	7.10	7.40	7.30	7.40	7.30	7.20	7.10	7.40	7.50	7.40	7.00	7.50	7.28	0.14
EC	166.00	198.00	153.00	1020.00	667.00	205.00	1064.00	224.00	209.00	213.00	256.00	215.00	246.00	250.00	240.00	200.00	213.00	219.00	153.00	1064.00	331.00	281.01
TDS	106.00	127.00	98.00	734.00	427.00	131.00	681.00	143.00	133.00	136.00	168.00	142.00	158.00	160.00	153.00	127.00	136.00	140.00	98.00	734.00	216.67	192.08
TA	58.750	63.000	63.000	335.000	179.250	62.750	208.750	63.250	61.750	62.250	61.750	62.250	61.750	61.750	138.250	78.750	63.350	64.250	58.750	335.000	97.214	74.205
TH	78.000	78.300	77.000	184.000	178.700	70.300	157.800	73.000	77.300	86.800	82.500	86.000	78.800	72.500	118.800	92.300	87.500	83.800	70.300	184.000	97.967	36.654
Ca2+	2.49	2.54	2.59	6.22	5.69	2.60	5.59	2.66	2.70	2.71	2.78	2.74	2.80	2.75	3.40	2.85	2.86	2.76	2.49	6.22	3.26	1.20
Mg2+	2.33	2.28	2.09	4.92	5.36	1.51	3.81	1.63	1.93	2.69	2.23	2.58	1.88	1.45	4.20	2.92	2.50	2.36	1.45	5.36	2.70	1.14
Na+	0.10	0.11	0.10	2.14	2.50	0.14	2.10	0.13	0.12	0.14	0.14	0.14	0.15	0.15	0.48	0.13	0.16	0.16	0.10	2.50	0.51	0.81
K+	0.07	0.07	0.07	0.42	0.27	0.46	0.08	0.07	0.08	0.08	0.09	0.08	0.08	0.09	0.28	0.09	0.09	0.09	0.07	0.46	0.14	0.13
Cl-	0.63	0.64	0.66	2.92	2.70	0.70	3.40	0.70	0.70	0.70	0.70	0.70	0.71	0.70	1.11	0.77	0.74	0.70	0.63	3.40	1.10	0.89
SO42-	2.76	2.87	2.96	3.49	3.42	2.98	3.61	3.02	3.06	3.18	3.26	3.21	3.32	3.29	3.41	3.40	3.47	3.23	2.76	3.61	3.22	0.24
NO3-	0.02	0.03	0.03	0.05	0.06	0.02	0.09	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.09	0.03	0.02
HCO3-	0.96	1.03	1.03	5.49	2.94	1.03	3.42	1.04	1.01	1.02	1.01	1.02	1.01	1.01	2.27	1.29	1.04	1.05	0.96	5.49	1.59	1.22
CO32-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO	8.560	8.560	8.520	2.510	1.880	8.400	2.190	8.560	8.520	8.440	8.610	8.520	8.280	8.440	8.180	8.520	8.360	8.480	1.880	8.610	7.418	2.409
COD	12.97	12.81	20.88	96.00	272.54	205.19	19.23	24.50	11.54	12.80	30.94	11.22	41.16	48.26	58.66	13.02	7.80	38.47	7.80	272.54	52.11	72.36
B	0.67	0.73	0.71	0.91	0.91	0.71	0.95	0.74	0.75	0.82	0.82	0.82	0.82	0.84	0.87	0.93	0.81	0.83	0.67	0.95	0.81	0.08

Table B4: Statistical summary of seasonal variations of the physiochemical parameters of the study area (UGC)

Parameters	Results of analyzed parameters during winter, summer and monsoon seasons											
	Winter				Summer				Monsoon			
	Range		Avg.	± SD	Range		Avg.	± SD	Range		Avg.	± SD
	Min.	Max.			Min.	Max.			Min.	Max.		
Tw	16.50	18.80	17.33	0.67	21.20	25.30	22.71	1.09	21.50	27.80	23.61	1.95
pH	6.80	8.40	8.08	0.53	7.10	8.00	7.67	0.21	7.00	7.50	7.28	0.14
EC	181.00	1316.00	351.94	348.88	161.00	1237.00	356.44	374.54	153.00	1064.00	331.00	281.01
TDS	116.00	826.00	225.33	221.91	103.00	713.00	217.50	214.39	98.00	734.00	216.67	192.08
TA	73.00	260.50	108.76	63.19	52.75	177.25	80.76	27.86	58.75	335.00	97.21	74.21
TH	55.50	364.30	95.77	84.34	64.50	247.80	93.27	61.12	70.30	184.00	97.97	36.65
Ca2+	1.65	16.76	3.28	3.67	2.09	8.69	3.05	2.03	2.49	6.22	3.26	1.20
Mg2+	1.30	8.10	2.56	1.82	1.61	7.29	2.66	1.75	1.45	5.36	2.70	1.14
Na+	0.12	2.38	0.46	0.73	0.05	0.73	0.18	0.20	0.10	2.50	0.51	0.81
K+	0.04	0.80	0.14	0.21	0.03	0.72	0.13	0.20	0.07	0.46	0.14	0.13
Cl-	0.30	9.72	1.31	2.36	0.44	4.76	1.08	1.38	0.63	3.40	1.10	0.89
SO4 2-	2.23	4.41	2.63	0.47	1.90	5.49	3.02	1.27	2.76	3.61	3.22	0.24
NO3-N	0.03	0.10	0.06	0.02	0.06	0.16	0.08	0.03	0.02	0.09	0.03	0.02
HCO3-	1.20	4.27	1.78	1.04	0.86	2.91	1.32	0.46	0.96	5.49	1.59	1.22
CO32-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DO	1.54	9.87	8.40	2.98	1.52	9.38	7.90	2.69	1.88	8.61	7.42	2.41
COD	16.10	491.09	75.71	123.45	2.98	295.98	47.35	86.47	7.80	272.54	52.11	72.36
B	0.45	1.53	0.85	0.22	0.53	1.35	0.85	0.23	0.67	0.95	0.81	0.08

OBSERVED DATA (TOXIC TRACE METALS)

Table B5: Results of Toxic trace metals of eighteen water samples of the study area (UGC) from November 2014 to October 2015 (winter season)

Parameters (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	±SD
Al	0.532	0.134	0.131	0.152	0.165	0.236	0.153	0.136	0.136	0.166	2.327	0.166	0.136	0.186	0.186	1.184	1.168	2.157	0.131	2.327	0.525	0.707
As	0.002	0.003	0.003	0.014	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.014	0.0045	0.0038
Cd	0.001	0.001	0.002	0.005	0.009	0.001	0.003	0.002	0.002	0.002	0.006	0.001	0.019	0.003	0.005	0.002	0.001	0.006	0.001	0.019	0.004	0.004
Co	0.035	0.035	0.036	0.056	0.085	0.037	0.064	0.038	0.039	0.039	0.040	0.040	0.041	0.041	0.042	0.042	0.042	0.042	0.035	0.085	0.044	0.012
Cr	0.021	0.027	0.028	0.042	0.030	0.028	0.037	0.029	0.029	0.029	0.041	0.025	0.032	0.087	0.081	0.080	0.030	0.039	0.021	0.087	0.040	0.020
Cu	0.047	0.037	0.031	0.037	0.020	0.067	0.063	0.051	0.036	0.059	0.051	0.059	0.057	0.061	0.071	0.064	0.077	0.092	0.020	0.092	0.054	0.018
Fe	1.151	1.973	2.962	3.922	3.911	2.972	3.918	2.978	2.971	2.973	2.973	2.974	2.983	2.982	2.983	2.983	2.976	2.986	1.151	3.922	2.976	0.641
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0211	0.0022	0.0011	0.0028	0.0034	0.0039	0.0021	0.0022	0.0011	0.0012	0.0023	0.0021	0.0011	0.0211	0.0052	0.0066
Mn	0.035	0.043	0.056	0.213	0.214	0.045	0.213	0.070	0.055	0.097	0.098	0.097	0.102	0.102	0.105	0.106	0.102	0.106	0.035	0.214	0.103	0.056
Pb	0.012	0.020	0.021	0.057	0.050	0.021	0.055	0.024	0.024	0.024	0.024	0.024	0.029	0.029	0.030	0.029	0.024	0.029	0.012	0.057	0.029	0.012
Zn	0.567	0.621	0.072	2.054	2.064	0.801	2.074	0.822	0.861	0.986	1.013	1.013	1.023	1.023	1.034	1.034	1.012	1.021	0.072	2.074	1.061	0.521

Table B6: Results of Toxic trace metals of eighteen water samples of the study area (UGC) from November 2014 to October 2015 (summer season)

Parameters (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	±SD
Al	0.134	0.234	0.335	1.152	1.165	0.336	1.153	0.446	0.456	0.548	0.547	0.548	0.766	0.757	0.859	0.735	0.548	0.843	0.134	1.165	0.642	0.311
As	0.002	0.003	0.003	0.013	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.013	0.0041	0.0035
Cd	0.002	0.002	0.003	0.008	0.008	0.003	0.008	0.003	0.004	0.004	0.004	0.004	0.007	0.007	0.007	0.007	0.004	0.006	0.002	0.008	0.005	0.002
Co	0.035	0.040	0.041	0.078	0.085	0.043	0.085	0.046	0.046	0.051	0.051	0.051	0.052	0.052	0.051	0.050	0.051	0.051	0.035	0.085	0.053	0.014
Cr	0.021	0.024	0.024	0.092	0.086	0.026	0.098	0.028	0.038	0.038	0.038	0.046	0.048	0.049	0.047	0.046	0.039	0.048	0.021	0.098	0.046	0.023
Cu	0.023	0.035	0.065	0.073	0.036	0.176	0.040	0.051	0.049	0.049	0.092	0.053	0.042	0.045	0.044	0.052	0.052	0.053	0.023	0.176	0.057	0.033
Fe	1.151	2.329	2.337	2.429	2.336	2.556	2.922	2.322	2.416	2.416	2.413	2.413	2.414	3.007	3.016	2.413	2.412	2.414	1.151	3.016	2.429	0.392
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0199	0.0022	0.0012	0.0028	0.0034	0.0039	0.0021	0.0022	0.0012	0.0012	0.0023	0.0021	0.0012	0.0199	0.0049	0.0061
Mn	0.103	0.083	0.116	0.179	0.172	0.171	0.113	0.106	0.104	0.127	0.157	0.138	0.108	0.132	0.133	0.131	0.137	0.154	0.083	0.179	0.131	0.027
Pb	0.022	0.024	0.024	0.042	0.099	0.026	0.048	0.029	0.030	0.030	0.030	0.030	0.033	0.034	0.035	0.034	0.030	0.034	0.022	0.099	0.035	0.017
Zn	0.570	0.762	0.788	2.986	3.141	0.798	2.606	0.888	0.888	0.988	0.988	0.988	0.889	1.122	1.122	1.223	1.111	1.121	0.570	3.141	1.277	0.775

Table B7: Results of Toxic trace metals of eighteen water samples of the study area (UGC) from November 2014 to October 2015 (monsoon season)

Parameters (mg/L)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	Min	Max	Avg	±SD
Al	0.131	0.142	0.142	1.106	1.142	0.152	1.175	0.204	0.205	0.324	0.324	0.324	0.326	0.329	0.329	0.326	0.326	0.326	0.131	1.175	0.407	0.347
As	0.002	0.003	0.003	0.017	0.013	0.004	0.011	0.003	0.004	0.002	0.002	0.002	0.005	0.004	0.002	0.002	0.003	0.002	0.002	0.017	0.0051	0.0042
Cd	0.001	0.001	0.001	0.004	0.005	0.002	0.004	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.005	0.005	0.004	0.004	0.001	0.005	0.003	0.001
Co	0.025	0.020	0.021	0.064	0.065	0.021	0.065	0.021	0.021	0.021	0.021	0.022	0.031	0.031	0.032	0.032	0.023	0.026	0.020	0.065	0.031	0.016
Cr	0.020	0.024	0.025	0.055	0.054	0.026	0.053	0.026	0.026	0.029	0.029	0.029	0.035	0.037	0.037	0.036	0.030	0.034	0.020	0.055	0.033	0.011
Cu	0.020	0.022	0.023	0.056	0.069	0.027	0.063	0.028	0.030	0.038	0.041	0.040	0.035	0.035	0.038	0.039	0.043	0.039	0.020	0.069	0.038	0.013
Fe	1.299	1.363	1.377	2.424	2.244	1.387	2.438	1.767	1.777	1.823	1.815	1.828	2.019	2.088	2.142	2.089	1.839	2.158	1.299	2.438	1.882	0.354
Hg	0.0021	0.0029	0.003	0.0192	0.0181	0.0035	0.0222	0.0022	0.0011	0.0028	0.0034	0.0039	0.0021	0.0022	0.0011	0.0012	0.0023	0.0021	0.0011	0.0222	0.0062	0.0071
Mn	0.062	0.086	0.115	0.149	0.135	0.088	0.145	0.112	0.114	0.115	0.116	0.115	0.020	0.021	0.022	0.021	0.119	0.115	0.020	0.149	0.093	0.044
Pb	0.011	0.015	0.016	0.042	0.041	0.015	0.045	0.017	0.019	0.021	0.021	0.021	0.023	0.024	0.024	0.022	0.016	0.024	0.011	0.045	0.023	0.010
Zn	0.370	0.551	0.588	1.873	1.834	0.592	1.954	0.677	0.678	0.688	0.688	0.688	0.776	0.756	0.777	0.738	0.688	0.758	0.370	1.954	0.871	0.478

Table B8: Statistical summary of seasonal variations of the toxic trace metals over study area (UGC)

Parameters	**Results of analyzed toxic metals during winter, summer and monsoon seasons**											
	Winter				**Summer**				**Monsoon**			
	Range		**Avg.**	**± SD**	**Range**		**Avg.**	**± SD**	**Range**		**Avg.**	**± SD**
	Min.	**Max.**			**Min.**	**Max.**			**Min.**	**Max.**		
Al	0.131	2.327	0.525	0.707	0.134	1.165	0.642	0.311	0.131	1.175	0.407	0.347
As	0.002	0.014	0.0045	0.0038	0.002	0.013	0.0041	0.0035	0.002	0.017	0.0051	0.0042
Cd	0.001	0.019	0.004	0.004	0.002	0.008	0.005	0.002	0.001	0.005	0.003	0.001
Co	0.035	0.085	0.044	0.012	0.035	0.085	0.053	0.014	0.020	0.065	0.031	0.016
Cr	0.021	0.087	0.040	0.020	0.021	0.098	0.046	0.023	0.020	0.055	0.033	0.011
Cu	0.020	0.092	0.054	0.018	0.023	0.176	0.057	0.033	0.020	0.069	0.038	0.013
Fe	1.151	3.922	2.976	0.641	1.151	3.016	2.429	0.392	1.299	2.438	1.882	0.354
Hg	0.0011	0.0211	0.0052	0.0066	0.0012	0.0199	0.0049	0.0061	0.0011	0.0222	0.0062	0.0071
Mn	0.035	0.214	0.103	0.056	0.083	0.179	0.131	0.027	0.020	0.149	0.093	0.044
Pb	0.012	0.057	0.029	0.012	0.022	0.099	0.035	0.017	0.011	0.045	0.023	0.010
Zn	0.072	2.074	1.061	0.521	0.570	3.141	1.277	0.775	0.370	1.954	0.871	0.478

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1. Bahita, T.A., Pandey, A., Jha, P.K., & Khare, D. (2018). Physicochemical parameters Assessment of Water Quality of Canal Surface Water for irrigation purpose and pollution status - A Review. **Accepted:** Proc. of *International Conference on Sustainable Technologies for Intelligent Water Management, IIT Roorkee, India*, February 16-19.

2. Bahita, T.A., Maurya, A., Jha, P.K., & Pandey, A. (2018). Numerical modelling of pollutant dispersion at Upper Ganga Canal. **Accepted:** Proc. of *International Conference on Sustainable Technologies for Intelligent Water Management, IIT Roorkee, India*, February 16-19.