POLLUTION PROFILE OF DAMODAR RIVER IN A PARTICULAR STRETCH

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
CONSERVATION OF RIVERS AND LAKES

By

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CANDIDATE'S DECLARATION

I, hereby, declare that the work which is being presented in this dissertation entitled "**POLLUTION PROFILE OF DAMODAR RIVER IN A PARTICULAR STRETCH**", in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in "**Conservation of Rivers and Lakes**", submitted in Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee, is an authentic record of my own work carried out during the period between July 2007 and June 2008 under the guidance of **Dr. M.P. Sharma**, Associate Professor and **Sh. S. K. Singal**, Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee.

The matter embodied herein has not been submitted by me for the award of any other degree or diploma.

Date :30th June, 2008
Place: Roorkee, Uttarakhand

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CERTIFICATE

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

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ABSTRACT

Damodar River, a rain fed tributary of lower Ganga and one of the major rivers in East India, originates from Chotanagpur plateau of Jharkhand and ends at the confluence of Hoogly river in West Bengal. The river plays a key role in providing a source of drinking water, water for irrigation and power, industrial needs and coal mining activities in the Damodar River Basin. The river, once known as the 'River of Sorrow' because of the flood havoc it used to cause, has now turned into a 'River of Agony' due to the environmental degradation of the river resulting from the indiscriminate discharge of domestic, industrial and mining wastes from the basin.

A river stretch of approximately 68 km from the downstream of Panchet Dam to the upstream of Durgapur Barrage in West Bengal passing through main industrial belt of the state and covering important cities like Kulti, Asansol, Raniganj and Durgapur has been selected for the study. The stretch is receiving a large number of point and non-point sources of pollution from thermal power plants, coalieries and coal based industries, steel, cement, fertilizers, chemical and other plants as well as domestic and agricultural areas that lead to the pollution to river either directly or through a numerous drains and nullahs.

In the present study, 45 grab samples were collected from the main river, its tributaries, nullahs, industrial drains and municipalities and analyzed *in situ* / in laboratories for different water quality parameters in the month of January and February 2008. The work also involved the assessment of population, land use pattern, agriculture, industry and mining activities quantitatively and qualitatively in the study area.

The work further involved in transformation of the measured WQ parameters into a single value index using original as well as modified NSF WQI system. The result reveals a good WQ profile of the river stretch, but meagre conditions of nullahs. Based upon the results, a WQ map of the study area has been prepared which shows the locations and extent of polluted stretches. When compared with CPCB and Indian standards for individual parameters, it is found that coliform and BOD are the most critical parameters indicating sewage pollution in the study stretch.

Existing conservation measures are identified and future management plan is suggested including installation of 2 x 100 MLD STPs and 1 x 60 MLD STP, CETPs, low cost toilets, solid waste management system etc. along with non-technical aspects like public awareness, enforcement of laws etc. to improve the overall quality of the river water.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

NOTATIONS AND ABBREVIATIONS

Symbol / Abbreviation	Explanation
ASP	Alloy Steel Plant
BPM	Bengal Paper Mill
BOD_3	3 days Biological Oxygen Demand at 27°C
BOD_5	5 days Biological Oxygen Demand at 20°C
CETP	Common Effluent Treatment Plant
CFU	Colony Forming Unit
CIL	Coal India Limited
CM	Coal Mine
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CTPS	Chinakuri Thermal Power Station
D	Depth
DAP	Damodar Action Plan
DBU	Designated Best Use
DCL	Durgapur Chemicals Limited
DO	Dissolved Oxygen
DPL	Durgapur Project Limited
DSP	Durgapur Steel Plant
DTPS	Durgapur Thermal Power Station
d/s	downstream
DVC	Damodar Valley Corporation
EC	Electrical Conductivity
ECL	Eastern Coalfields Limited
ETP	Effluent Treatment Plant
FC	Faecal Coliform
HFC	Hindusthan Fertilizer Company
IISCO	Indian Iron & Steel Company Limited
IS	Indian Standards
ISO	International Organization for Standardization
lpcd	Litre per capita per day

m	metre
µ-mho/cm	Micro mho per centimetre
MINARS	Monitoring of Indian National Aquatic Resources Series
M km^3	Million cubic kilometer
MGD	Million Gallons per Day
MLD	Million Litres per Day
MPN	Most Probable Number
mg/L	Milligram per Litre
MW	Mega Watt
NEERI	National Environmental Engineering Research Institute
NH_4^+ - N	Ammoniacal Nitrogen
NRCD	National River Conservation Directorate
NSF WQI	National Sanitation Foundation Water Quality Index
NTU	Nephelometric Turbidity Unit
O&G	Oil and Grease
O&M	Operation and Maintenance
O/A	Overall
pH	Negative Logarithm of Hydrogen Ion Concentration
STP	Sewage Treatment Plant
TC	Total Coliform
TDS	Total Dissolved Solids
Temp	Temperature
TKN	Total Kjeldhal Nitrogen
TS	Total Solids
TSS	Total Suspended Solids
TUR	Turbidity
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
u/s	Upstream
v	Velocity
W	Width
WQ	Water Quality
WQI	Water Quality Index

CHAPTER 1

INTRODUCTION

1.1 GENERAL

"Everything originated in water and everything is sustained by water" – Goethe.

The remarkable combination of hydrogen and oxygen eventually become an indispensable component of the earth's environment. Water, the most essential for life, is significantly linked with social, economical and ecological intricacies. Rivers, a potential source of surface water, have many attributes in human civilization. They provide a myriad of in-stream and consumptive uses, support flora and fauna, improve aesthetic and landscape quality, moderate climate and provide hydropower.

The growth of civilization and subsequent needs for better living standard of human being has caused great impact on the environment. Utilization of natural resources for development has created various environmental problems. One of the major environmental problems today, is the pollution of surface water body due to discharge of domestic and industrial effluents. According to ecologist Odum, "Pollution is an undesirable change in the physical, chemical or biological characteristics of our air, water and land that may or will harmfully affect human life or that of desirable species or industrial processes, living conditions and cultural assets, or that may or will waste or deteriorate our material resources". As per Water Act 1974, water pollution means such alteration of the physical, chemical or biological properties of water or discharge of any sewage or industrial waste or of any other liquid, gaseous or solid substances into water which may or is likely to create a nuisance or render such water harmful or injurious to public health or safety or to domestic, commercial, industrial, agricultural or other legitimate uses or to the life and health of animals or plants or of aquatic organisms.

Conservation of water implies making the best use of available water resources for human benefits while not only preventing and controlling its degradation but also developing it in view of the present and future needs. Water is a multipurpose resource and it can be enjoyed in its totality.

1.2 GLOBAL WATER SCENARIO

Three fourth of the surface of earth is covered with water. It is estimated that the total water resource on the earth is about 1386 million cubic kilometers (M km^3) out of which 97.5% is saline water and 2.5% is fresh water. Major portion of the fresh water is either locked in the form of polar ice, snow picks and glaciers or remains deep under the ground and inaccessible for human consumption. Effectively, only 0.121 M km^3 of fresh water is available in rivers, lakes, wetlands, soil moisture, shallow ground water and reservoirs to meet the demands of all the plants, animals and humans inhabiting this planet. This constitutes only about 0.009% of all the water on earth out of which only 0.006% constitute flow in the rivers. Table 1.1 gives the total quantities of world's water as estimated by United Nations Educational, Scientific and Cultural Organization (UNESCO).

Table 1.1 Estimated world water quantities

Sl No	Item	Volume (M km^3)	% of total water	% of fresh water
1	Oceans	1338.00000	96.5379	-
2	Ground water			
	a) fresh	10.53000	0.7597	30.073
	b) saline	12.87000	0.9286	-
3	Soil moisture	0.01650	0.0012	0.047
4	Polar ice	24.02350	1.7333	68.609
5	Other ice & snow	0.34060	0.0246	0.973
6	Lakes			
	a) fresh	0.09100	0.0066	0.260
	b) saline	0.08540	0.0062	-
7	Marshes	0.01147	0.0008	0.033
8	Rivers	0.00212	0.0002	0.006
9	Biological water	0.00112	0.0001	0.003
10	Atmospheric water	0.01290	0.0009	0.037
Total	a) All kinds of water	1385.98461	100.0	
	b) Fresh water	35.01519	2.5264	100.0

Source: World water balance and water resources of the earth, UNESCO (Subramanya 2006)

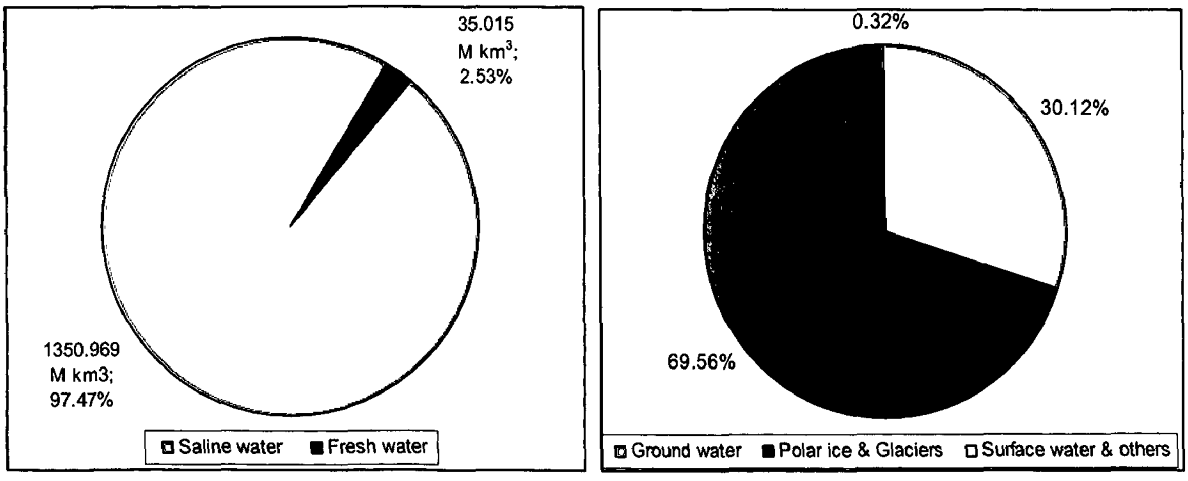


Figure 1.1: Total water on the earth and fresh water distribution

Figure 1.1 shows the total water availability and distribution of fresh water on earth respectively. The small amount of available fresh water is constantly being renewed by the hydrological cycle in the form of rain. However, a large portion of rain water either flows back into the sea as run-off or gets evaporated back to the atmosphere.

As of June 2008, the world's population is believed to be just under 6.7 billion. In line of current growth trajectory, this figure is expected to reach 9 billion by the year 2042 (Wikipedia 2008). With the increase in world population, the demand for clean and fresh water also increases. At the same time, human activities are putting pressure on the nature leading to changes in climate and hydrologic cycle. Urbanization and industrialization generate wastewater that causes pollution of fresh water bodies. The World Wide Water Development Report estimates that by 2050, at worst, 7 billion in 58 countries and at best, 2 billion in 48 countries will face water scarcity due to population growth. As per this report, there is an estimated 12,000 km^3 of polluted water world wide which is more than the total amount of water contained in the world's 10 largest river basins at any given moment (Bansil 2004).

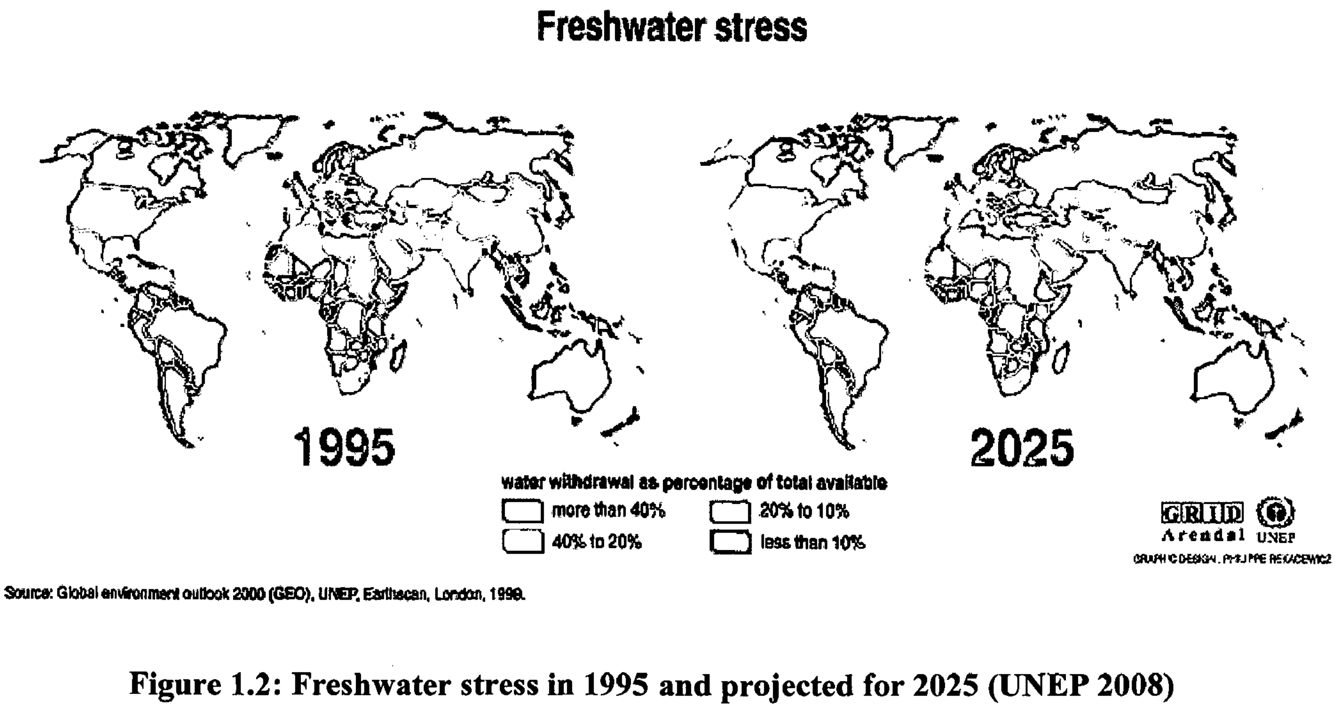


Figure 1.2: Freshwater stress in 1995 and projected for 2025 (UNEP 2008)

United Nations Environment Programme (UNEP) has estimated that in the year 1995, freshwater withdrawal was less than 10% of the total water available in most parts of the world. However, by 2025, the situation will be highly stressed with many countries, as the withdrawal will be over 40% of the total water available in the North Africa and the Middle East Asia including India. These areas will be converted into water scarce regions. Figure 1.2 reveals a very grim picture of the world. As predicted by Ismail Serageldin, World Bank Vice President for Environmental Affairs, "The wars of the twenty first century will be fought over water".

1.3 WATER SCENARIO OF INDIA

India is basically an agrarian society with its economy highly dependant on agriculture. The largest use of fresh water in India is for irrigation. Geographical area of India is 328 million hectare which occupies about 2% of the world's land area. It has only 4% of average annual runoff in the rivers but supports 17% of the world population. Unfortunately, due to improper planning of water conservation, today India is ranked 122 for its water quality and 132 for its water availability (Tikoo 2008). Table 1.2 and 1.3 show the water availability and utilization in India.

Table 1.2: Water availability in India (Bansil 2004)

Sl	Source of water availability	Quantity ($x10^9$ m^3)
1	Average annual precipitation	4000
2	Average annual water run-off potential	1869
3	Utilizable surface water potential	690
4	Ground water resource	432

Table 1.3: Annual utilization of water resources in India (Tikoo 2008)

Sl	Water resources uses	Utilization ($x10^4$ m^3)
1	Irrigation using surface source	31.12
2	Irrigation using ground source	12.80
3	Community water supply (urban and rural areas)	2.50
4	Industrial use	1.50
5	Energy	0.45

Data shows that India has a good supply of fresh water but it is far from the truth. With increase in population, the demand of fresh water has increased resulting in the increased generation of wastewater. Rapid urbanization and industrialization has been creating environmental problems such as fresh water scarcity, wastewater and solid and hazardous waste generation. Water quality has deteriorated steadily with time. Almost 200 million Indians do not have access to safe and clean drinking water and an estimated 90% of the country's water sources are polluted to a large extent. Ground water has been grossly exploited at a number of places in the country. In the coastal areas, salt water intrusion into empty aquifers is a serious problem. In view of the above problems, it has been predicted that by 2025, India will become a water stressed nation as demand for fresh water will far exceed the availability (Bansil 2004).

1.3.1 Fresh Water Bodies in India

1.3.1.1 Surface Water: Inland water resources of the country are classified as rivers and canals, reservoirs and tanks, lakes, ponds and wetlands. Other than rivers and canals, surface water bodies cover an area of about 7 million hectare. Most of the lakes and wetlands in India are directly or indirectly linked with major river systems such as the Ganges, Cauvery, Krishna, Godavari and Tapti. India has totally 27,403 lakes and wetlands, out of which 23,444 are inland water bodies and 3,959 are coastal water bodies. Out of them, 19 lakes and wetlands have been categorized for seeking international assistance to save them from ecological destruction under Ramsar convention.

1.3.1.2 Ground Water: Groundwater resources exist in the form of springs, wells and infiltration galleries. In India, ground water is extensively used in domestic including drinking purposes, irrigation and agriculture related activities and in industries both in consumptive and non-consumptive ways. It is estimated that about $3/4^{th}$ of the rural and half of the urban population depends on ground water for their drinking needs. Ministry of Water Resources, India has estimated the ground water potential as 432 km^3 per year.

1.3.2 Indian River System

Total 113 river basins form the lifeline of thousands of cities, towns and villages in India. These are either ice melt or rain fed river. There are also a few desert rivers, which flow for some distance and get lost in the desert. The rivers are classified as major, medium and minor based on drainage basin area. The major river basins are Brahmaputra, Ganga, Indus, Godavari, Krishna, Mahanadi, Narmada, Cauvery, Brahmani, Tapi, Mahi, Damodar, Pennar and Sabarmati. Ganga basin is the largest covering northern India, followed by Godavari, Indus, Krishna and Brahmaputra basins. Damodar basin is one of the major river basins in eastern India. Drainage and river basin map of India is shown in figure 1.3.

There are 14 major river basins in the country which occupy 83% of total drainage basins, contribute 85% of total surface flow and house 80% of the country's population. Table 1.4 shows catchment details of the Indian river system.

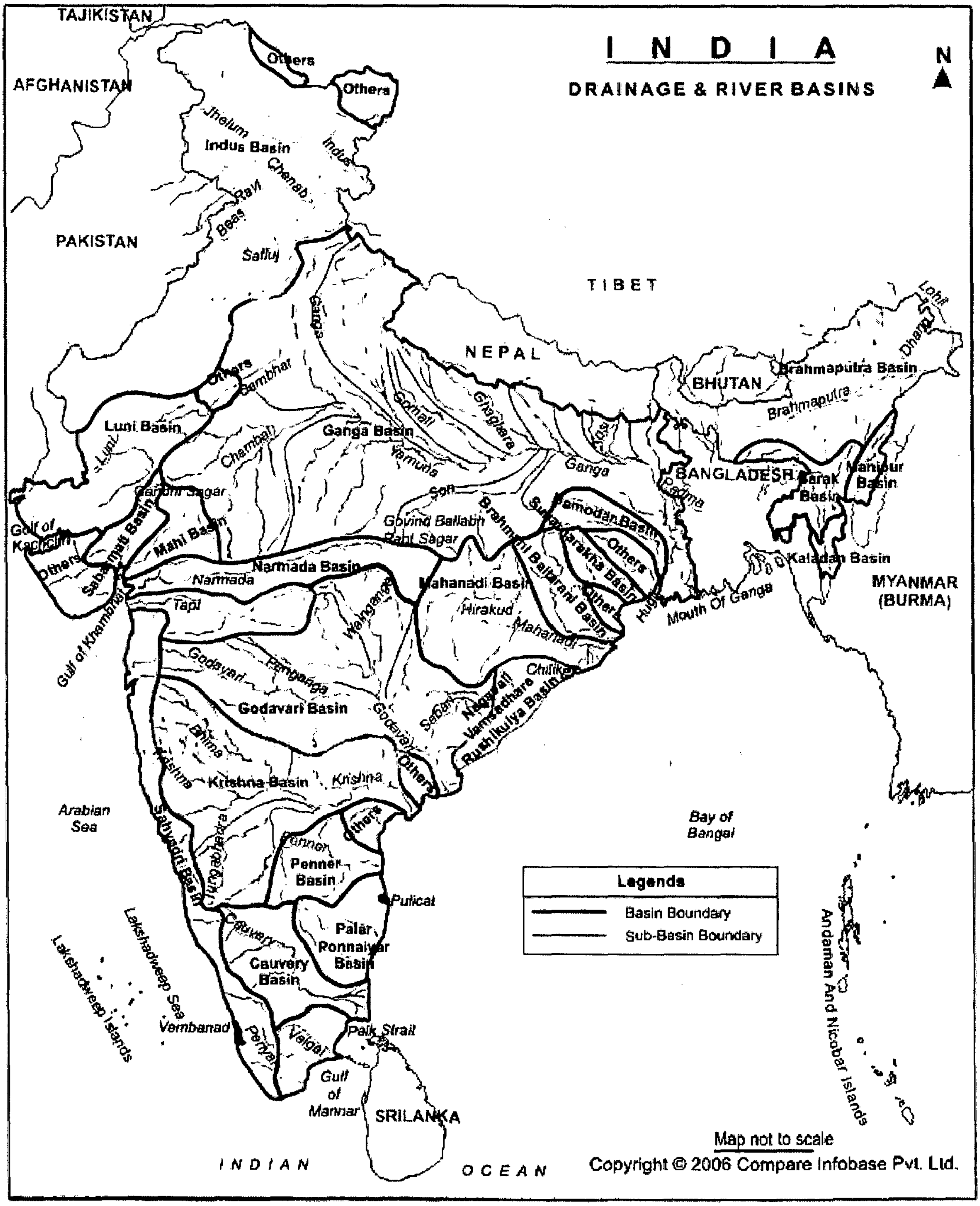


Figure 1.3: River basin map of India

Table 1.4: Catchment details of major, medium and minor rivers

Category of Basin	Drainage Area (km^2)	No. of rivers	% Basin area of total area	% flow contribution	% of total Population
Major	> 20,000	14	83	85	80
Medium	2,000 to 20,000	44	8	7	20
Minor and Desert river	< 2,000	55	9	8	

Source: Status of water supply, wastewater collection, treatment and disposal in Class I cities, 1989-90, CPCB, India. (Tikoo 2008)

1.3.3 Pollution Stresses of Rivers

The pollution potential in a catchment area depends on various human activities and can be categorized into two groups: Point sources of pollution and Non Point sources of pollution. Point sources of pollution are domestic sewage discharge, effluent from factories, refineries, wastewater treatment plants etc. that directly impact water bodies. While non point or diffuse sources of pollution cover agricultural runoff, in-stream water uses, bathing, cattle wading, open defecation and clothes washing. In addition, other sources of river pollution are soil erosion, atmospheric fall out of pollutants, accidental cases of shipment and river damming effects.

1.3.4 River Conservation in India

To improve the water quality of rivers through the implementation of pollution abatement works, the river cleaning programme of Government of India was started in 1985 with the launching of Ganga Action Plan popularly known as GAP Phase-I. Central Ganga Authority (CGA) was set up under the Prime Minister with the members being the Chief Ministers of the concerned states, Union Ministers and Secretaries of the concerned Central Ministries along with experts in the field of water quality. GAP Phase-I was a 100% centrally funded scheme. The main objective was to improve the water quality of the River Ganga to acceptable standards by preventing the pollution load from reaching the river. Under GAP Phase-I, conservation works were taken up in 21 Class-I towns in Uttar Pradesh, Bihar and West Bengal.

Subsequently GAP Phase-II was approved in April, 1993 for pollution abetment of remaining works of river Ganga that was left in GAP-I along with its major tributaries, viz. Yamuna, Gomati and Damodar. This plan covered pollution abatement works in 95 towns along the polluted stretches of these 4 rivers spread over 7 states. The total approved cost of this action plan was approved on 50:50 cost sharing basis between the

Centre and the State Governments. It was later felt that the river conservation activity needed to be extended to other rivers in the country as well. Accordingly, GAP was merged into a National River Conservation Plan (NRCP) in 1996 with an objective to improve the water quality of major rivers as the major fresh water source in the country.

The Ganga Project Directorate (GPD) was converted into the National River Conservation Directorate (NRCD) for servicing the National River Conservation Authority and the Steering Committee. The CGA was renamed as National River Conservation Authority (NRCA) with a larger mandate to cover all the programmes supported by the NRCD. NRCP was converted into a 100% centrally funded scheme in November 1998 with only the land cost to be borne by the states. However, in March 2001, it was decided to adopt an integrated approach for the river cleaning programme and that all future programmes will be shared on a 70:30 cost sharing basis between the Centre and State Governments respectively. Presently NRCP scheme covers 34 polluted river stretches in 160 towns spread over 20 states (PC 2007).

The activities covered under the NRCP include the following:

(1) Interception and diversion works to capture the sewage flowing into the river through open drains and divert them for treatment.
(2) Sewage treatment plants for treating the diverted sewage.
(3) Low cost sanitation works to prevent open defecation on river banks.
(4) Electric crematoria and improved wood crematoria to conserve the use of wood and help in ensuring proper cremation of bodies brought to the burning ghats.
(5) River front development works such as improvement of bathing ghats.
(6) Human resource development, capacity building, training and research in the area of river conservation.
(7) Other miscellaneous works like plantation and public participation and awareness.

The Govt. of India is implementing a scheme parallel to NRCP called National Lake Conservation Plan (NLCP) which was approved in May 2001 with the objective to take up conservation of urban lakes. The thrust under the plan is to undertake in-situ remedial measures for the lakes together with measures like interception, diversion and treatment of sewage discharged into the lakes and lake front development and beautification. Presently as many as 42 lakes spread over 12 states have been taken up for conservation and improvement under NLCP (PC 2007).

National Wetland Conservation Programme (NWCP) is also initiated that presently covers 94 wetlands, 39 mangrove ecosystems and 4 coral reefs (PC 2007).

1.4 THE DAMODAR RIVER BASIN

Damodar river is one of the major tributaries of river Ganga. It is a rain fed river of 541 km length. It originates from Khamerpet Hill (elevation 1,068 m) at Chandwa village of Palamau district of the Chotanagpur Plateau of eastern India. Broadly, the location is the tri-junction of Palamu, Ranchi and Hazaribag districts of Jharkhand. It flows eastward through the cities Ramgarh, Bokaro, Dhanbad, Asansol, Durgapur, Bardwan and Howrah, before ultimately joining the lower Ganga (Hooghly estuary) at Shayampur, 55 km downstream of Howrah (Wikipedia, 2008).

River Barakar is the main tributary of Damodar river. It originates in Hazaribagh district and flows through Jharkhand and with Damodar it trifurcates the Chotanagpur plateau. The rivers pass through the area with great force, sweeping away whatever lies in their path. Barakar meets Damodar near Dishergarh in West Bengal. Other tributaries and sub tributaries are Konar, Guaia, Jamania, Usri, Bokaro, Haharo, Khudia and Bhera.

The Damodar river flows through granites and granite-gneisses of Archeans, sandstones and shales of the Gondwanas and the recent alluvials. The lithology of the river basin is dominated by the quartzite, mica-schist, biotite-gneisse, biotite-schist, garnetiferous gneiss and schist, acid granulites with hornblende and amphibolites (Singh *et al* 2005). Figure 1.4 shows the geological formation of the river basin.

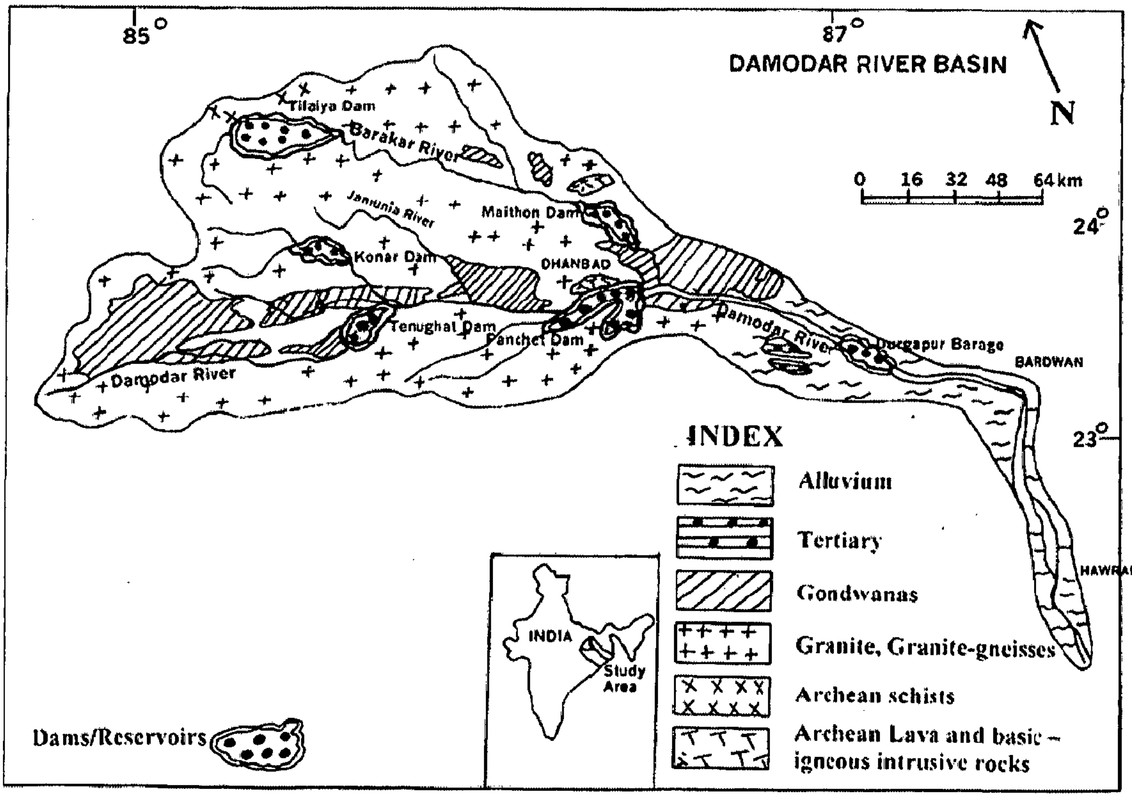


Figure 1.4: Damodar river basin map

The river Damodar, once known as the "River of Sorrow" because of the flood havoc it used to cause, has now turned into "River of Agony" due to the environmental degradation of the river resulting from the indiscriminate discharge of domestic, industrial and mining wastes from the basin. It is a typical flashy river primarily derives its flow from immediate surface run off resulting from rainfall. Its annual discharge is 12,210 million cubic meter (M m^3) and about four fifth of its flow occurs during monsoon period (NEERI 1994). There is a wide seasonal fluctuation in the river flow depending upon the variation of rainfall, occasional storms and resultant surface run off.

The Damodar is not a free flowing river. Flow in the river system is mostly regulated by the release of water from the storage reservoirs (Figure 1.4). Hydrologically, the river system may be looked upon as linear assemblage of impounded water bodies with successive impediments in the natural flow regime. The carriage, transport and transformation of pollutants discharged into the river depend greatly on the conditions either water is stagnant or flowing. This typical fluvial aspect of the river must be kept in mind while considering the quantitative and qualitative assessment of the river water.

The Damodar River Basin extends from 22°45'N to 24°30'N and 84°45'E to 88°00'E circumscribing parts of Jharkhand and West Bengal, which is about 11.77% and 8.57% of the total geographical area of these two states (Singh *et al* 2005). Total catchment area of the basin is 23,371 sq. km. is shown in table 1.5.

Table 1.5: Constituents of Damodar river basin

Sl. No	District	Total Area (Sq. km)	Area in the Basin (Sq. km)	% Area of district in the Basin	% Share in the basin
(A) Jharkhand Sub-Region					
1	Palamau	12677.0	736.84	5.81	3.15
2	Ranchi	18311.0	910.33	4.97	3.90
3	Hazaribagh	11152.0	6631.56	59.47	28.38
4	Giridih	6908.0	5376.81	77.83	23.01
5	Dhanbad	2996.8	2996.80	100.00	12.82
6	Santhal Pargana	14129.0	571.05	4.04	2.44
Sub Total		-	**17223.39**	-	**73.70**
(B) West Bengal Sub-Region					
1	Purulia	6259.0	1383.28	22.10	5.92
2	Bankura	6881.0	1564.67	22.74	6.69
3	Burdwan	7028.0	2113.61	30.07	9.04
4	Hooghly	3145.0	359.87	11.44	1.54
5	Howrah	1474.0	726.16	49.29	3.11
Sub Total		-	**6147.59**	-	**26.30**
Grand Total		-	**23370.98**	-	**100.00**

Source: http://envfor.nic.in/divisions/cltech/Damodar/1.1.htm (MoEF 2008)

As the total catchment area of the basin is more than 20,000 sq. km., the river falls under major river basin category. It is also seen from the above table that almost one forth of the total basin area falls in West Bengal.

A unified two-stage development scheme for construction of a series of dams across the Damodar and its tributaries was implemented in the early 1950s. Dams at Tenughat and Panchet and barrage at Durgapur on the Damodar mainstream have been constructed for the purpose of flood control, power generation, soil conservation and irrigation. Three more dams namely Tilaiya, Maithon and Konar on the tributaries - Barakar and Konar River have been constructed later (Singh *et al* 2005). In the upper valley area, mining and mine-based industries are the dominant economic activity with low agricultural productivity. These have made the valley vulnerable to soil erosion. More than 50 major and medium industries and over 400 small industrial units occupy the valley (CSE 2008).

Though not rich in metallic minerals, the Damodar basin is the storehouse of Indian coal. Other than coal, fire clay, bauxite, mica, limestones are associated with the geological formation of the basin. Besides domestic effluents, these reservoirs receive the pollution load from the various sources like coal washeries, coal mining effluent, mining dumps, coke industries, thermal power plants, mining machineries and vehicular sources. These point and non-point sources of pollution severely affect the quality of the water and sediment.

Damodar Valley Corporation (DVC) is the regulatory body of the basin since 1948. They have are five thermal power plants and three hydel power stations in this valley. Table 1.6 details the water management system taken by DVC in the basin.

Table 1.6: Water management system of the Damodar basin

Sl	Features	Quantity
1	Major Dams and Barrage	Tilaiya, Konar, Maithon and Panchet and Durgapur Barrage
2	Irrigation Command Area (gross)	5.69 lakh hectares
3	Irrigation Potential Created	3.64 lakh hectares
4	Flood Reserve Capacity	1,292 million m^3
5	Canals	2,494 km
6	Soil conservation & land treatment	4 lakh hectares (approx)
7	Check Dams	16,000 nos (approx)

Source: http://www.dvcindia.org/dvcwatermanagement.htm (DVC 2008)

1.5 THE STUDY AREA

The stretch selected for the dissertation work is bounded on the west by Panchet dam and on the east by Durgapur barrage. It is about 61 km by straight line between the reservoirs and 67.5 km length by the curvilinear path along the river. Total area of the stretch is about 1,950 sq. km. It is mainly located in West Bengal where the dominant industrial belt of state is situated. It also lies within the major mining area of the state. The cumulative impact of this commercial zone associated with agricultural and municipal impacts on the main water source i.e. Damodar river is an interesting subject matter of the study. The stretch is easily approachable through roadway via Grant Tank road and National Highway-2 and south eastern railway. Figure 1.5 shows the key location map of the study area within the Damodar river basin.

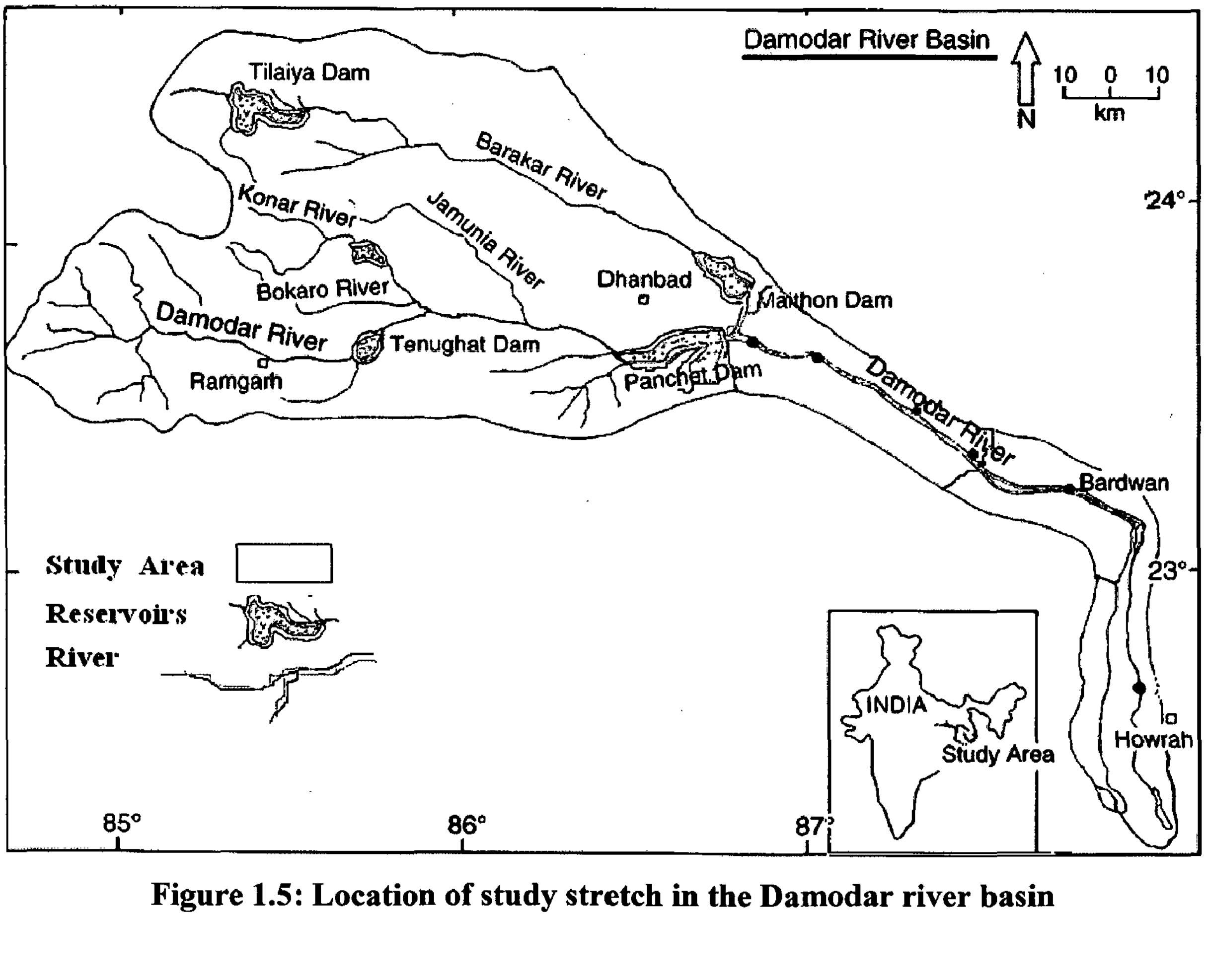


Figure 1.5: Location of study stretch in the Damodar river basin

1.6 OBJECTIVES AND SCOPE OF THE STUDY

As suggested by NRCD, the dissertation has the following objectives:

- To select a stretch of Damodar river in West Bengal and to assess the water quality (WQ) status at various locations in this stretch.

- To determine the quantity and quality of domestic and industrial wastewater generation in selected stretch as well as spatial distribution of drains meeting the river.
- Preparation of the schematic line diagram of the river system in this stretch.
- To assess the water pollution loads vis-à-vis present status of surface water environment of the study area and to develop water quality index for the water bodies.
- To prepare WQ map on Google map for better understanding and interpretation of polluted stretches in the study area.
- To develop the DO, BOD and coliform profile and trend of the river stretch.
- To evaluate and propose the conservation measures/recommendations that may help appropriate agencies in implementing the pollution control measures for overall improvement of the WQ of the river.

The study has been carried out for the upper stretch of river Damodar in WB. The impact of industrial effluent and municipal/domestic sewage discharged into the river through 15 major drains has been studied. Reconnaissance survey was done in September 2007 for identification of pollution sources and WQ analysis/flow measurements were carried out in the months of January and February 2008. WQ index is calculated and based on it, WQ map is prepared to determine the prevailing WQ/pollution status for the selected stretch. Polluted stretches are identified to take appropriate conservation measures.

1.7 ORGANIZATION OF THESIS

The thesis is divided into six chapters. The first chapter deals with water use scenario of the world with the highlight of future threat. Indian river system and Damodar river basin is also described. The second chapter includes reviews of work done for the pollution profile study of Damodar and tools available to assess the pollution profile. The third chapter deals with brief outline of the study area with WQ status of the river stretch and its probable causes of pollution. The next chapter includes the assessment of river quality in the selected stretch with respect to selected parameters. The fifth chapter discusses the results and WQ status using different standards and WQ index at different sampling stations and then the pollution profile of the river is determined. Conservation measures already taken in the selected stretch are identified and further plans are suggested. Final chapter gives the conclusions of the study and future recommendations to maintain the water body in good health.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

In ancient time, man naturally settled near source of water and thus, communities grew besides lakes and along rivers. Water bodies were pristine then. During the Industrial Revolution of the 19th century, western countries grew at a tremendous rate simultaneously generate pollution in all means. Rapid population growth accelerated the threat. By the early 20th century, connection between diseases and sewage-borne microorganisms had been recognized. Luis Pasteur and Robert Koch postulated the Germ theory of disease. This focused attention of the scientific community to the safe disposal of domestic sewage and a need to practiced sanitation. Accordingly, need for safe water supplies were established. As a result, water borne diseases had been reduced in developed countries. However, those are still very common in under developed or developing countries, where waste disposal systems are often inadequate or non-existent. In industrialized nations, contamination with hazardous chemicals has become the main threat to the surface water body.

In view of the anthropogenic pollution problems to the surface water body, it becomes necessary to monitor and assess the water quality of rivers to determine their acceptability for the different intended uses. If the level of pollution increases above the acceptance level, necessary control measures have to be established. However, before setting any control measure, we need to know the effectiveness of such measures and to develop water quality assessment tools for the surface water quality which will help in predicting water quality status or pollution profile. If the quality deteriorates with respect to desired criteria, conservation measures need to be implemented to bring the criteria below permissible limits for making intended use of water.

Intensive literature survey on the various aspect of river pollution profile has been conducted and it is worthwhile to review the whole literature under the three headings namely (1) Study of pollution status of rivers, (2) Study of pollution status of Damodar river and (3) Tools for assessment of pollution profile of a river.

2.2 STUDIES ON POLLUTION PROFILE OF RIVERS

Considerable research has been carried out by different authors in assessing water quality profile of rivers using different pollution stress parameters.

Paul *et al* (1978) have studied the pollution profile of Periyar river in Kerala focusing the problem of heavy industrial pollution. The parameter like pH, PO_4, SO_4, Na, Ca, K, Cl, Mg, Cu, Mn, Zn, Cd, Hg and ^{228}Ra were determined to study water as well as sediment pollution status. It was found that Cd, Hg and ^{228}Ra were significant in sediment whereas Cu, Mn and Zn in water. Acid discharges further complicated the problem of water utilization from this river.

Sinha *et al* (2000) have reviewed the literature on the physico-chemical characteristics of river Ganga and its tributaries (Yamuna, Gomti and Sai) in Uttar Pradesh and found that the water quality of these major rivers have deteriorated due to overexploitations and become unfit for human use. Sahu *et al* (2000) have studied the effect of pollutants on the DO concentration of the Ganga river at Kanpur in 1994 and it was found that DO level was below permissible limit at the right bank upto the middle of the river.

Sharma (1993) studied the water pollution of Yamuna river for its influence on drinking water supply in Arga city. He found that the average BOD and COD in river water were 110 and 1300 mg/L respectively indicating severely polluted state of the river. Kumar (2002) studied the pollution problem of Yamuna river with critical parameters like TC, FC, DO and BOD and found that TC is twice of the permissible limit at the entry of Delhi segment and 25 times when exit out of Delhi and declared that river water is entirely unfit for drinking.

Central Pollution Control Board (CPCB) in collaboration with concerned State Pollution Control Boards (SPCB) and Pollution Control Committees (PCC) established a nationwide network of water quality monitoring comprising 1,019 stations in 27 States and 6 Union Territories. The monitoring is done on monthly or quarterly basis for surface waters covering 200 Rivers stations. Presently, the inland water quality-monitoring network is operated under a three-tier programme i.e. Global Environment Monitoring System (GEMS), Monitoring of Indian National Aquatic Resources Series (MINARS) and Yamuna Action Plan (YAP). Water samples are being analyzed for 28 parameters consisting of 9 core parameters, 19 other physico-chemical and bacteriological parameters apart from the field observations. Besides this, 9 trace metals and 22 pesticides are also analyzed in selected samples. Bio-monitoring is also carried out on specific locations. In view of limited resources, limited numbers of organic pollution related parameters are monitored i.e. toxic metals and few micro pollutants are analyzed once in a year to assess the water quality (CPCB 2008).

2.3 STUDIES ON POLLUTION PROFILE OF RIVER DAMODAR

Damodar River, a tributary of river Ganga and one of the major rivers in eastern India, originates from Chotanagpur plateau of Jharkhand and ending at the confluence of Hoogly river in West Bengal. The river plays a key role in providing a source of coal mine based industries as well as water for drinking and irrigation in those states but gets huge pollution in return.

2.3.1 Damodar River in Jharkhand

Gupta and Singh (2000) studied water quality status of 50 km river stretch along Dugda – Sindri industrial belt of Jharia coalfield during May 1992 to October 1992. They observed alkaline and moderately hard water with increasing trend of pollution including high value of coliform from u/s to d/s of the stretch. But Cl, SO_4, TDS and trace elements were found below permissible limits. They further studied the overall pollution profile of Damodar river due to effluents from Dugda Sindri industrial stretch of Jharia coalfield region in the year 1995 and found that the domestic and industrial pollution has affected the river quality seriously and the water was unsatisfactory for drinking purpose and fallen to the 'C' class category in that stretch (Singh and Gupta, 2000).

Gupta and Singh (2000) scrutinized the pollution, particularly due to coal washeries in this region. Composite samples were analyzed for pH, EC, TDS, TSS, DO, COD, O&G, heavy metals and trace elements. It was found that uncontrolled & untreated discharge from coal washeries impart grayish/ brownish black color and oil film over the surface of river water impeding seriously on the carrying capacity.

Pande *et al* (2000) studied the pollution status of the river due to industries and related uncontrolled human settlement nearby Ramgarh town. Wastewater characteristics of two nearby nullahs viz. Harihar and Sotia, was determined and found polluted. They worked on design considerations and cost estimates for the pollution abetment schemes using low cost sanitation system, interception, diversion and treatment of wastewater for natural drains and nullahs through cost effective methods like stabilization and settling pond system.

River Damodar when flows through the coal belt of Jharkhand, gets polluted seriously due to discharge of industrial effluents from fertilizer factory, cement factory, coal washeries, mica factory, steel plants etc. This has led to undertake research work to assess the effects of effluents to the biotic community in a limited stretch of river Damodar at Sindri, Dhanbad (Singh *et al*, 2007).

2.3.2 Damodar River in West Bengal

De *et al* (1980) studied the impact of industrial effluents on the Damodar river near Durgapur city during 1978 - 1979. The parameters investigated were pH, total NH_3 (free plus dissolved), total hardness, TDS, TSS, phenol, sulphide, cyanide, Hg (free and total), COD, and DO. It was found that Tamla nullah, which carries the waste of major industries like DPL and DCL, constantly contaminates the river d/s of the barrage. De (1993) later studied the growth of water pollution in Asansol to Durgapur industrial belt and its impact on the river water quality during January 1982 to December 1984. He monitored the effect of pollution on aquatic plants and paddy husk and found that Asansol Raniganj region contaminates the u/s of barrage water while Tamla nullah and industrial drains of Durgapur region contaminate it's d/s. River water is not safe for drinking purpose as it has lost its self purification capacity.

De *et al* (1985) further determined the pollution profile of Damodar river sediment in Raniganj – Durgapur industrial belt. The parameters measured include silica, mixed oxide, Ca, Mg, total water-soluble exchangeable cation and anion, COD and some toxic and other elements such as Na, K, As, Cd, Cr, Hg, Mn, Pb, Zn, Co, Cu, Fe, Ni, P, S and V. High values were found at Tamla nullah, Singaron nullah, BPM and HFC drain confluences. Damodar river sediment from Raniganj to Panagarh was found polluted with toxic elements and water is unfit for domestic purposes.

Paria and Konar (2003) studied the water quality of 13 rivers in West Bengal including Damodar to assess their ecological degradation due to pollution. They observed highest percentage of phytoplankton and lowest percentage of *Bacillariophyceae* diatom and *Desmidiaceae* algae among the total organisms in Damodar river. The river falls under 'C' category with respect to plankton diversity which indicates that the river system is not equally productive as per as the primary productivity potential is concerned.

CPCB (2005) has been regularly monitoring Damodar river in West Bengal through 5 MINARS stations. Water quality of the river, Tamla nullah, village ponds, groundwater and various industrial units were monitored and river quality was found within the stipulated limits with respect to the general parameters and also for the heavy metals. The Tamla nullah, the sink of all discharges, was having the COD in the range of 40 - 80 mg/L; BOD as 11 - 25 mg/L and TSS as 50 - 160 mg/L. Sediment of the river in the downstream of confluence of Tamla nullah was having maximum iron content of about 21,000 mg/kg, zinc 45 mg/kg, copper 16 mg/kg, total chromium 28 mg/kg, nickel 17 mg/kg and lead as 5 mg/kg, whereas in Tamla nullah, sediment have maximum iron content of about 22,000 mg/kg, zinc 121 mg/kg, copper 24 mg/kg, total chromium 18 mg/kg, nickel 14 mg/kg and lead as 33 mg/kg. The pond sediments were also monitored and found contaminated with metals.

2.3.3 Entire Damodar River Basin Study

Tiwary and Dhar (1994) had studied both the surface and ground water for environmental pollution from coal mining activities in the basin. They found high concentrations of TDS, SO_4, hardness, Fe and coliform in underground mines that affects the river ecosystem and biodiversity.

NEERI (1994), a pioneer Institute of environmental engineering research had conducted extensive field study on the Damodar river basin during May 1993 to March 1994 under the sponsorship of Ganga Project Directorate and made a feasibility report on pollution abatement of Damodar river. They identified the critical stretches, major sources of pollution and formed the basis of design of various pollution abatement schemes. They recommended oxidation pond for BOD > 30ml/L and settling pond for TSS > 50mg/L for sewage treatment. Total estimated cost for the schemes to implement in 11 major towns was Rs. 23.9 crores.

Singh and Hasnain (1999) had studied the environmental geochemistry of Damodar river basin with special emphasis to weathering during February 1994 to November 1995. High concentrations of Na, Ca and HCO_3, SO_4, PO_4 indicate the mining and soil erosion impact on water quality. Singh *et al* (1999) simultaneously worked on the grain size and geochemical partitioning of heavy metals in river bed sediments. The order of abundance of metals was found as Zn>Cu>Mn>Fe. The exchangeable fraction of sediments contains very low amounts of heavy metals. Singh *et al* (2005) selectively studied the six reservoirs in Damodar river basin for ion chemistry, weathering processes and water quality assessment during March 2003 to October 2003. The derived parameters like Sodium Adsorption Ratio, %Na and Residual Sodium Carbonate show water quality is excellent to good for irrigation.

A WQ map of India was prepared by CPCB for river and coastal WQ for the year 2001 (Figure 2.1). The map also indicates the polluted condition of Damodar river.

From the above review, it is found that no work has been done previously with the index system on the Damodar river. The river particularly for its upper stretch in West Bengal seems to be polluted by industrial and mining activities and it will be an excellent work to prepare a water quality map based on WQI over the selected study stretch.

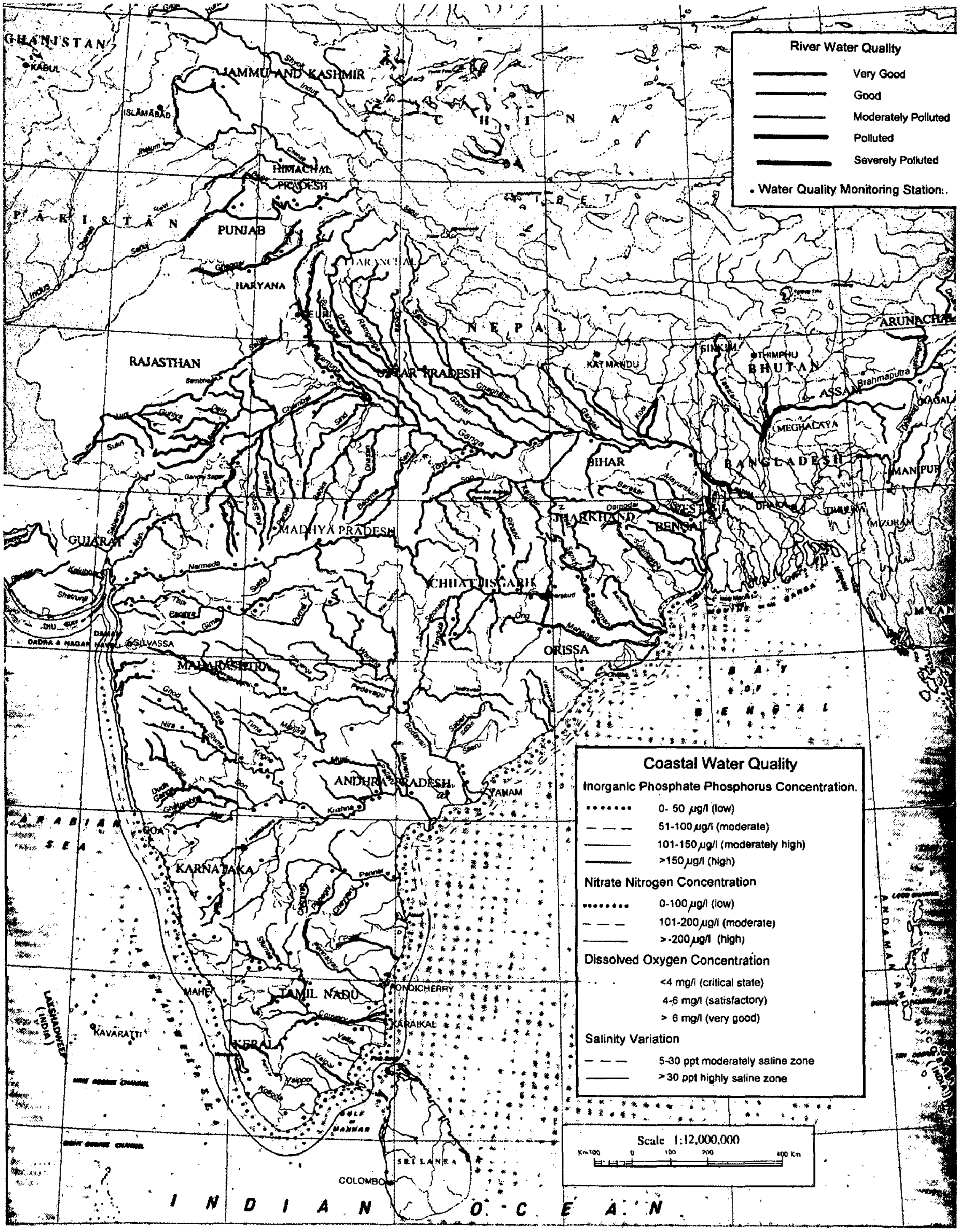


Figure 2.1: Water Quality Map of India, 2001 (CPCB 2001)

2.4 TOOLS FOR ASSESSMENT OF POLLUTION PROFILE OF A RIVER

There are a few procedures available to determine the pollution status of a river. Some of these are simple mathematical models and formulations calculated either manually or by software. It may be a simple map showing cumulative features of different WQ parameters.

2.4.1 BOD and DO Models

The mathematical modeling of water quality in a river has progressed from the pioneering work of Harold Streeter and Earle Phelps in 1925, who developed the relationship between the decay of an organic waste measured by BOD and DO resource of the river, produced the classical dissolved sag model.

The developed models are expressed by the following equations:

$$L = L_0 e^{(-K_1 t)}$$

Where,

L = BOD in the water (mg/L)

L_0 = initial BOD in the stream (mg/L)

K_1 = rate coefficient of biochemical decomposition of organic matter (T^{-1}, usually day^{-1})

t = time, that is the time of travel in the river interpreted as $t = X/U$, where X is the distance downstream of the point of effluent discharge (T, given usually in days). And U is the velocity of flow (m/s).

and

$$D = D_0 e^{-K_2 t} + \frac{K_1 L_0 \left(e^{-k_1 t} - e^{-K_2 t}\right)}{\left(K_2 - K_1\right)}$$

Where,

D_0 = initial oxygen deficit of water (mg/L)

D = oxygen deficit of water (mg/L)

K_2 = re-aeration rate coefficient (T^{-1})

Subsequent to Streeter and Phelps, several BOD-DO models and several concepts were introduced in the past viz. *Camp model* in 1963, *Bhargava model* in 1985, *Thomman and Muller model* in1987 etc.

Jha *et al* (2007) has recently developed a refined BOD and DO Model for highly polluted Kali river in India. The model minimizes error estimate and improves the correlation between observed and computed BOD and DO values for the river.

2.4.2 Water Quality Indices (WQI)

An index is a mean device to reduce a large quantity of data down to a simplest form. First, an environmental indicator or sub-index function is to be calculated which refers to a single quantity derived from two or more polluted variables/characteristic parameters (Ott, 1978). Then index is calculated by a mathematical aggregation of two or more indicators in some fashion. It is simply a numerical value having no unit. WQI is a comparison of water quality status to a prescribed base or to a scientific arbitrary standard. Various ranges of WQI may be used to classify the quality of water for a given use into various classes such as excellent, good, satisfactory, poor and unacceptable. Ott (1978) has identified the basic uses of indices in resource allocation, ranking of locations, enforcement of standards, trend analysis, public information and scientific research.

According to Abbasi (2002) water quality indices aim at giving a single value to the water quality of a source on the basis of one or the other system which translates the list of constituents and their concentrations present in a sample into a single value. One can then compare different samples for quality on the basis of the index value of each sample.

2.4.2.1 Basic requirements for WQI: General conditions to be satisfied by WQI are -

(a) It should change with the changes in the values of each of the water quality variables.

(b) The change should be greater due to a variable, which produces the more important quality impact.

(c) It should approach the poorest designated value when a critical variable, whose concentration beyond the permissible levels cannot be compromised, exceeds the permissible limits.

(d) It should remain unchanged when a variable's concentration changes within its permissible limits.

Criteria for formulation of WQI: as given by Council of Environmental Quality (CEQ) are -

(a) It should facilitate communication of environmental quality information to the public.

(b) It should be readily derived from available monitored data.

(c) It should strike a balance between over simplification and complex technical conceptualization.

(d) It should impart an understanding of significance of data represented.

It should be objectively designed but amenable to comparison with expert judgment so that their validity can be assed.

2.4.2.2 Different types of WQI: Attempts were made in Germany as early as 1848 to relate the level of water purity and pollution to the occurrence of certain biological organism. Since then, various European countries have developed and applied different systems to classify the quality of surface water. Indices, which use a numerical scale to represent the gradation in water quality levels, were first introduced by Horton in 1965 (Ott, 1978).

To present different indices found in the literature in an orderly fashion, Ott has classified them into four general categories (Ott, 1978).

1 *General Water Quality Indices* – Water has a variety of different uses, viz. public drinking water supply, irrigation, recreational etc. Water quality requirements vary depending upon the intended use. Some indices, however, are based on the assumption that "water quality" is a general attribute of surface water irrespective of the use to which the water is put. Such indices are termed as general water quality indices.

2 *Specific Use Indices* – Indices developed in consideration of the specific use of water are classified as per specific use indices.

3 *Planning Indices* – Indices designed specially for management decision-making are called planning indices. These indices usually don't depict ambient water quality or related conditions but often incorporate variables other than those routinely measured by water pollution monitoring programmes. For examples, a planning index designed for allocating water pollution abatement funds might include the cost of wastewater treatment facilities.

4 *Indices based on Statistical Approach* - These approaches usually employ some standard statistical procedure with the water quality data. The statistical approaches have the advantage that they incorporate fewer subjective assumptions than the traditional indices: however, they are more complex and often more difficult to apply.

There are two general types / forms of water quality index.

a) *Increasing scale form* – those in which the index numbers increase with increasing pollution level.

b) *Decreasing scale form* – those in which the index numbers decrease with increasing pollution level.

Some specialists in the field refer to the former as "Water Pollution Indices" and later as "Water Quality Indices". In an increasing scale form, an index of zero indicates no pollution, while, in a decreasing scale form, index of zero indicates maximum polluted or 100% polluted water. Both the terms are inter-related and, therefore, in practice both type of indices are called "Water Quality Indices".

One more type of water quality indices are "Biological Indices". These are generally developed after evaluating water quality in terms of its impact on aquatic life in some form. The biological indices are entirely dissimilar in approach to other categories.

In addition to the above, some agencies have developed their own indices with variation in parameters, ratings, weights and the form of aggregation of sub-indices. Some of them may, however, not fall exactly under the category of general WQI. These indices include (1) The Trend Monitoring Index of Georgia's Department of Natural Resources (Environmental Pollution Division), (2) Pollution Index of Illinois' Department of Transportation (Division of water Resources Management), (3) Nevada Water Quality Index, (4) Water Quality Index developed by Oregon's Department of Environmental Quality etc.

Bordalo et al (2006) applied a modified nine-parameter Scottish WQI to assess the water quality of the Douro River, an internationally shared basin between Spain and Portugal.

2.4.2.3 Indian WQI: Water quality indices have been used in India but not as extensively as the tool deserves. The first reported Indian WQI was suggested by Bhargava (1985) for zoning and classification of river Ganga with respect to specific issue of drinking water supply. He suggested that the public drinking water supplies should have a WQI larger than 90.

In 1990, Ved Prakash formulated River Ganga Index based on the Brown's WQI with slight modifications in terms of weightages to confirm to the water quality criteria for different categories of uses as set by Central Pollution Control Board, India (Abbasi 2002).

Sargoankat and Deshpande (2003) have proposed an overall index of pollution for surface water based on a general classification scheme in Indian context. It is basically an average value of all the pollution indices for individual water quality parameters to be considered in a study ranging from 0 to 16. Other indices have been mostly weighted sum indices, apparently inspired by Brown's WQI.

The table in the next page summarized the various WQI.

Table 2.1 Different WQIs at a glance (Ott 1978)

Sl	Index name	Yr.	No. of variables	Type of Scale	Range of Index value
1	**General Water Quality Indices**				
	Horton's Quality Index	1965	10	Decreasing	0 to 100
	National Sanitation Foundation's WQI	1970	9	Decreasing	0 to 100
	Prati's Implicit Index of Pollution	1971	13	Increasing	0 to 15+
	McDuffie's River Pollution Index	1973	8	Increasing	0 to 1000+
	Dinius Social Accounting System	1972	11	Decreasing	0 to 100
2	**Specific-Use Water Quality Indices**				
	O'Conner's Index for Fish & Wildlife	1972	9	Decreasing	0 to 100
	O'Conner Public Water Supply (PWS) Index	1972	13	Decreasing	0 to 100
	Deininger & Landwehr's PWS Index	1971	11/13	Decreasing	0 to 100
	Walski and Parker's Index for Reccreation	1974	12	Decreasing	0 to 1
	Stoner's Index for PWS & Irrigation	1978	31	Decreasing	-100to100
	Nemerow & Sumitomo's Index for Human contact, indirect contact & remote contact	1970	14	Increasing	0 to 1+
3	**Planning Indices**				
	MITRE's Prevalence Duration Intensity Index	1970	Any no	Increasing	0 to 1
	MITRE's National Planning Priorities Index	1975	Any no	Increasing	0 to 1
	MITRE's Priority Action Index	1975	Any no	Increasing	0 to 1
	Dee's Environmental Evaluation System	1973	14	Decreasing	0 to 1,000
	Inhaber's Canadian National Index	1974	Any no	Increasing	0 to 1
	Zoeteman's Potential Pollution Index	1973	3	Increasing	0to 1,000+
	Johanson & Johnson's Pollution Index	1976	Any no	Increasing	0 to 100+
4	**Statistical Approaches**				
	Shoji's Composite Pollution Index	1966	18	Increasing	-2 to 2
	Joung's Indices of Nutrients	1978	5	Decreasing	0 to 100
	Harkin's Index	1974	Any no	Increasing	0 to 1,000
	Beta Function Index	1977	Any no	Increasing	0 to 1

2.4.2.4 Selection of a particular WQI for this thesis: Different WQI show considerable variation in terms of number of variables, scales, ranges and aggregation method. National Sanitation Foundation's (NSF) WQI proposed by Brown (Brown 1970) meets all the five CEQ criteria. Out of the many general indices developed so far, the NSF WQI is the most effective and flexible and simple to formulate. Hence it is the most widely accepted WQI. The present work is associated with the NSF WQI modified by Ved Prakash and adopted by CPCB for Indian conditions (CPCB 2001). The mathematical structure of original NSF WQI and its calculations are given in the appendix-I.

2.4.3 Water Quality Maps

Readily available WQ map for a river basin is an instant tool for assessment of pollution status of the drainage system in a particular period. Such a map can be drawn for designated best use classification of streams, the impact assessment of priority industries or municipal wastewater. Color code helps to detect the nature and extent of the polluted stretches. As already shown in figure 2.1, CPCB prepares such WQ map in regular intervals based on the field monitoring data.

2.4.4 Computer Automated Tools

A number of software is available for water quality modeling of river and stream. These are QUAL2K, QUAL2E, WASP, CE-QUALM-ICM, HEC5Q, MIKE11, ATV MODEL, SALMON-Q, DUFLOW, AQUSIM and DESERT etc. Environmental Protection Agency (EPA), USA had developed many of them. The Center for Environmental Quality, Environmental Engineering and Earth Sciences in Wilkes University, USA has developed an online software/ calculator using NSF WQI which can be accessed at *www.water-research.net* (WU 2008). It is very easy and handy as compared to other tools.

CHAPTER 3

DAMODAR RIVER STRETCH AND CAUSES OF POLLUTION

3.1 GENERAL

General concepts about water quality and pollution, pollution profile and water quality standards are discussed briefly. Thereafter, the study stretch in Damodar basin is briefly described. WQ of the stretch and all probable causes of pollution (point as well as non point sources) are discussed. Finally, Damodar Action Plan taken by the National River Conservation Directorate is highlighted.

3.1.1 Water Quality and Pollution

Water quality is the physical, chemical and biological characteristics of water, in dissolved, colloidal or suspended form. Quality of the aquatic environment is expressed by set of concentration, speciation and physical partition of inorganic or organic substances, composition and state of aquatic biota in the water body and description of temporal and spatial variations due to factors internal and external to the water body.

Where as pollution of the aquatic environment is caused by man, directly or indirectly, due to introduction of substances or energy which results in such deleterious effects as harm to living resources, hazards to human health, hindrance to the aquatic activities, impairment of water quality with respect to its use in agriculture, industrial and often economic activities and reduction in amenities (Chapman 1996).

So water quality is a general term of which water pollution indicates 'undesirable water quality' - is a special case (Abbasi 2002).

3.1.2 Pollution Profile of a River

A profile of a river is similar to road and railway network. All features along the river can be assigned as km stone, from starting point to its ultimate confluence. The features which should be assigned in along length of river are (i) sampling stations (ii) point of confluence of tributaries (or point of confluence of sub tributaries in case of tributaries) (iii) annual average flow rate (iv) water quality status in brief and (v) cities/towns.

This will be very useful for people involved in river-monitoring and river-pollution control in various ways such as:

- It will help in plotting profile out of a set of pollutants in the longitudinal direction between consecutive sampling stations on the river and help true interpretation of river-monitoring data.
- It will help in better assessment of polluted length of the river.
- It will help in identifying sources of pollution (tributaries/sub tributaries and cities/towns) responsible for pollution in a particular stretch.
- It will help in annul upgradation of the most polluted stretches by taking suitable conservation measures after comparing a particular pollution parameter (say BOD or FC) for last few years in the same database.
- It will provide a large set of information for digitization by use of Geographical Information System (GIS).

Pollution profile assessment is the assessment of water quality and thereby to define the pollution status of a particular river for a particular stretch or for the whole stream along with its all tributaries, if necessary in the basin area of the identified or suspected location.

Generally both quantitative and qualitative assessment of the pollutants at the outfalls, river water at upstream and downstream monitoring stations as well as sediment is carried out to depict the pollution profile of that river. Several factors need to be considered such as pollution load, river discharge, mixing nature, carrying capacity, sampling techniques and the method of quantification. Results are generally expressed in the form of table, graph or indices.

3.1.3 Water Quality Standards

WQ standards are legal regulations established by the states, limiting the concentration of various constituents in water. WQ criteria, as distinguished from standards, are the levels of specific concentrations of constituents which are expected, if not exceeded, to assure the suitability of water for specific uses.

WQ standards are created for different types of water bodies and locations according to intended uses. In India, the Central Pollution Control Board (CPCB) has prescribed different WQ standards for different water uses by introducing the concept of "Designated-Best-Use (DBU)". This concept states that out of several uses, a particular water body is put to the use demanding the highest quality of water is called its "DBU" and accordingly, the water body has been designated. The Board has identified five DBU classes along with their prescribed WQ criteria (Appendix III).

3.2 DETALIS OF STUDY STRETCH

A river stretch of approximately 67.5 km from upstream of Durgapur barrage, passing through some important cities/towns of Burdwan, Bankura and Purulia districts of West Bengal, has been selected for study. The stretch is the major industrial and commercial belt of the state. Data from the official websites of these districts have been used to describe the study stretch (Bankura 2008, Bardhaman 2008 and Purulia 2008).

3.2.1 Location

The study stretch extends from 23°47' to 23°28' North latitude and from 86°41' to 87°19' East longitudes. Its major north portion lies within Burdwan district and southern part remains in Bankura and Purulia districts of West Bengal. The administrative blocks of West Bengal falling in this stretch is given in table 3.1.

Table 3.1: Administrative units of the study stretch

Sl	District	Sub-Division	Name of Administrative Blocks
1	Burdwan	Asansol	Salanpur, Barabani, Raniganj(M), Jamuria, Jamuria(M), Asansol(MC), Kulti(M)
		Durgapur	Andal, Faridpur, Pandabeswar, Durgapur (MC)
2	Bankura	Bankura	Saltora, Mejhia, Gangajal Ghati, Barjora
3	Purulia	Ragunathpur	Neturia, Santuri

M=Municipalities, MC=Municipal Corporation

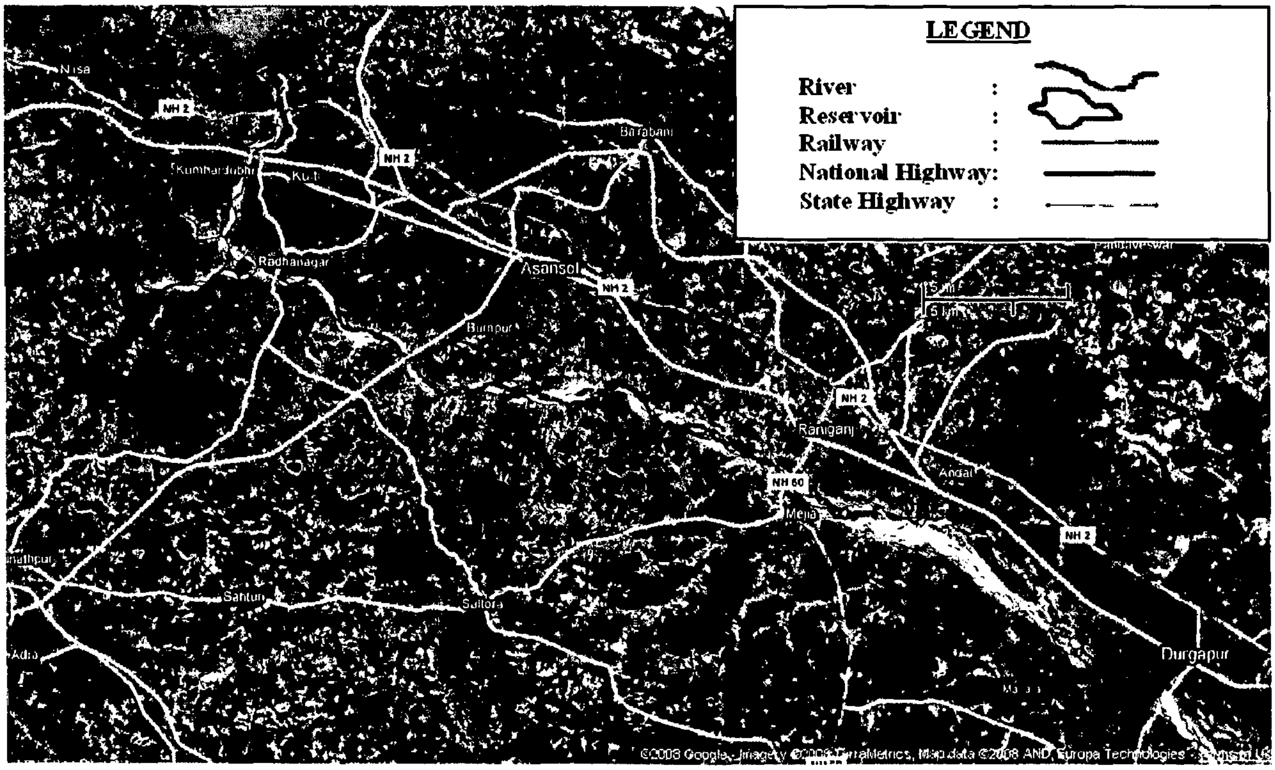


Figure 3.1: Satellite map of the study area

3.2.2 Geology

The lower basin of Damodar valley is more or less covered with a thick veneer of alluvium over the rocks of Tertiary age (Singh *et al* 1999). Gondwana rocks, consisting of sandstones, shales and fire clays with coal seams, are forming the upper part of the catchments between Panchet dam to Durgapur barrage (Singh 2005).

3.2.3 Climate

The area experiences a warm temperate rainy climate with mild winter. Average temperature in hot season is 30°C while at the cold season is 20°C. Annual average rainfall is 1,400 mm. The cold season starts from about the middle of November and continues till the end of February. March to May is dry summer intervened by tropical storms. June to September is wet summer while October and November is autumn.

3.2.4 Topography

The stretch has varied tectonic elements and riverine features. It is a transitional zone between Chotonagpur plateau that constitutes a portion of peninsular shield in the west and Ganga alluvial plain in the east. Towards south east, the alluvial plain merges with Damodar-Kasain-Subarnarekha deltaic plains. The stretch at the west consists of barren, rocky and rolling country with hillocks, the highest being 227 m. Otherwise low plain landscape prevails the surrounding area.

3.2.5 Drainage

The river system of Damodar comprises of a number of water bodies. The Durgapur barrage and Panchet and Maithon dams have formed large reservoirs. Main canals of the area for irrigation originate from Durgapur barrage. Khudia and Barakar are the main tributary and sub-tributary of Damodar in the stretch. Natural drains are known as *Nullahs*. The notable nullahs from the north are Nunia, Singaran and Tamla. There are four nullahs from the south including Kadamda. Many small municipal/industrial drains are connected to the river directly or indirectly. There are many tanks, wells, swamps and bills are found all over the area. Within the Damodar Valley region, there are around 17,000 tanks. Thus, a complicated drainage network is formed in the study area.

3.2.6 Soil and Minerals

The stretch comprises different kind of soils and minerals. Upper part consists of reddish-yellow soil which is a combination of coarse gritty soil blended with rock fragments and sandy soil formed by the weathering of pegmatite, quartz veins and conglomeratic sandstones. It can be characterized by medium to course in texture, acidic in reaction, low in nitrogen, calcium, phosphate and other plant nutrients. Water holding capacity of this soil increases with depth as well as with the increase of clay portions. Alluvial soil is formed towards the low level plains besides the Damodar river. This soil is sandy, well drained and slightly acidic in nature.

The stretch is one of the premier zones in India in terms of mineral. Besides coal at Raniganj coalfield, important minerals found in the area are iron ores, calcium carbonate, abrasives, silica bricks and moulding sands, glass sands, building materials, manganese, bauxite, laterite etc.

3.2.7 Land Use Pattern

The land use pattern differs in a pronounced manner from west to east with varying soil conditions. The forest areas are mainly situated in the lateritic and red soil high lands. It is a part of the forest at Dumka district of Jharkhand. Downwards the forest areas are interspersed with paddy fields. The cultivation in the stretch has improved with the implementation of the irrigation projects undertaken by the DVC. The alluvial tract is well cultivated and most of the area is doubly cropped. Paddy covers maximum of the gross cropped area.

Mining is one of the major activities surrounding Asansol Raniganj area. Apart from famous bituminous coal, Raniganj coalfield also contains large reserves of iron ore, fire clay, calcium carbonate, manganese and bauxite. Open and under ground mining leads a poor land use pattern. There is also some culturable waste land, barren land, fallow land, permanent pastures and other grazing land found in this stretch.

3.2.8 Ecology

The flora of the stretch is characterized by the arborescent species and shrubby species. The uplands of laterite area of the stretch in places are covered with trees of high value wood.

Common fauna comprises of pigs, monkeys, harmless grass snakes etc. In the hilly areas poisonous snakes and a few small carnivores are found. A wide variety of avifauna is found here. The dam and barrage sites provide a good sheltering place for the migratory birds in winter. The river and rivulets constitute fisheries and it is huge at reservoir sites.

3.2.9 Demography

As per 2001 census report, total population of the study area is around 35 lakhs that is calculated after adding all the individual blocks/towns population of the stretch. The figure is almost 4.36% of the state's population and 0.34% of the country's total population (Census of India, 2001).

3.3 WATER QUALITY STATUS OF THE STUDY STRETCH

As Damodar is a flashy river, its WQ varies largely with seasons. National Environmental Engineering Research Institute (NEERI) had prepared a feasibility report on pollution abetment of Damodar River in 1994 under sponsorship of GPD. WQ data for pre, post and during monsoon were analyzed and it was found that the river in West Bengal is polluted with organics (BOD > 3 mg/L) and/or suspended solids (TSS > 100mg/L). Within our study stretch, pollution was found at:

- Damodar river d/s of confluence with Kadamda nullah (BOD = 3mg/L and TSS = 206mg/L) due to effluent from Bhojudih coal washeries and Santhaldih Thermal Power Station.
- Damodar at Raniganj (BOD = 6mg/L) due to discharge of domestic waste from the township.
- u/s and d/s of Tamla nullah confluence (BOD = 5mg/L) due to effluents from steel plants and chemical industries.
- u/s and d/s of DTPS outfall (BOD = 5mg/L) due to its effluent discharge.

Trend of existing WQ of Damodar river from 1997 to 2001 as per CPCB, shows that river in the stretch falls class 'D' category with BOD as critical parameter (CPCB 2003). State PCB and DVC also regularly monitor the WQ of the river.

3.4 CAUSES OF POLLUTION IN THE STUDY STRETCH

3.4.1 Industrial Effluents

The main industrial zone of West Bengal comprises areas under Asansol and Durgapur subdivisions of Burdwan district. Coal-based industries of all types have come up in the area because of locational advantages and the easy availability of water and power. There are a number of coal washeries, coke-oven and soft-coke plants. The traditional industries, chiefly supported by coal, iron and steel, have undergone a rapid diversification and new industrial ventures, which include mainly heavy engineering, fertilizers, coal-based chemicals, cement plants and thermal power generation, are making a dominant impact on the water resources of the Damodar. Some of the medium and small iron and steel industries located beside the Tamla nullah are Bhaskar Shanchi Alloy Ltd, Sova Ispat Alloy Ltd, Kartik Alloy Ltd, Adhunik Ispat Ltd, Dutta Iron & Steel (P) Ltd etc. None of them have proper effluent treatment facilities. The major industries and their individual treatment facilities are described in table 3.2.

Table 3.2: Details of major industries and their impact on the Damodar river stretch

Sl	Industry	Type of treatment available	Adequacy of facilities	Major pollutants	Receiving water body	Impact on the river*
1	Santaldih Thermal Power Station	Settling tank	Inadequate	SS, O&G	Kadamda Nullah	Significant
2	Bhojudih Coal Washeries	Settling ponds	Inadequate	SS, TDS, COD	Damodar River	Significant
3	Dishergarh Thermal Power Station	Settling tank	Not causing water pollution	SS	Damodar River	Insignificant
4	Indian Iron & Steel Co Ltd (IISCO) Burnpur	ETP with lagoons, ASP for coke oven by-product	Inadequate	Fe, SS, O&G	Damodar River	Significant
5	Ricket & Colman (I) Ltd, Asansol	ETP comprises: Aeration, Oxidation Flocculation, Settling tank, Polishing tank, Sludge lying land	Adequate	Phenol	Nunia Nullah	Insignificant
6	Carew & Philpson Co. Ltd, Asansol	No treatment	Treatment not required	BOD, TDS	Nunia Nullah	Insignificant
7	Indian Oxygen Ltd, Asansol	No treatment	Treatment not required	TDS, Cr	Nunia Nullah	Insignificant
8	Bengal Paper Mill Co Ltd, Raniganj	Only lagoon	Inadequate	TSS, BOD, COD	Damodar River	Significant
9	Alloy Steel Plant (ASP) Durgapur	Clarifier, Oil skimmer & separator Pre-neutralization with settler, Sludge pit	ETP working satisfactory	pH, TSS, COD, O&G, Cr, Ni	Tamla Nullah	Significant
						Contd...

Sl	Industry	Type of treatment available	Adequacy of facilities	Major pollutants	Receiving water body	Impact on the river
10	Durgapur Steel Plant (DSP)	ETP comprises: BOD plant, Settling ponds with re-circulation of coke oven & coal washeries, Clarifers in blast furnace & rolling mills, Ash ponds, Oil catch pit	ETP working satisfactory but farther improvement required	TSS, BOD, COD, O&G, Phenol, Cyanide	Tamla Nullah, Damodar River	Significant
11	Durgapur Chemicals Ltd. (DCL)	ETP for Hg control	Inadequate	TSS, BOD, COD, Phenol, O&G	Tamla Nullah	Significant
12	Durgapur Projects Ltd (DPL)	ETP comprises: Ash ponds, catch pit for tar arresting, Settling chamber, Oil separators Treatment units for phenol, cyanide,NH_4^+N	Grossly Inadequate	TSS, BOD, COD, Phenol, Cyanide, NH_4-N	Tamla Nullah	Significant
13	Hindusthan Fertilizer Corporation Ltd (HFC) Durgapur	ETP for removal of As & Cr	Inadequate	Cr, As, NH_4-N	Tamla Nullah	Significant
14	Durgapur Thermal Power Station (DTPS)	Ash Ponds	Inadequate	TSS, BOD, COD, O&G	Damodar River	Significant
15	East India Pharmaceuticals Ltd, Durgapur	ETP comprises: Settling chamber Equalization-neutralization Flash mixer Clariflocculator Aerated lagoon Sludge drying bed	Adequate	Nil	Tamla Nullah	Insignificant

Impact on the river due to industrial discharges is become significant when the river water has BOD > 3 mg/l or TSS > 250 mg/l (NEERI 1994). Figure 3.2 shows the location of principal industries while Plate 3.1 shows the photographs of those industries in the study area.

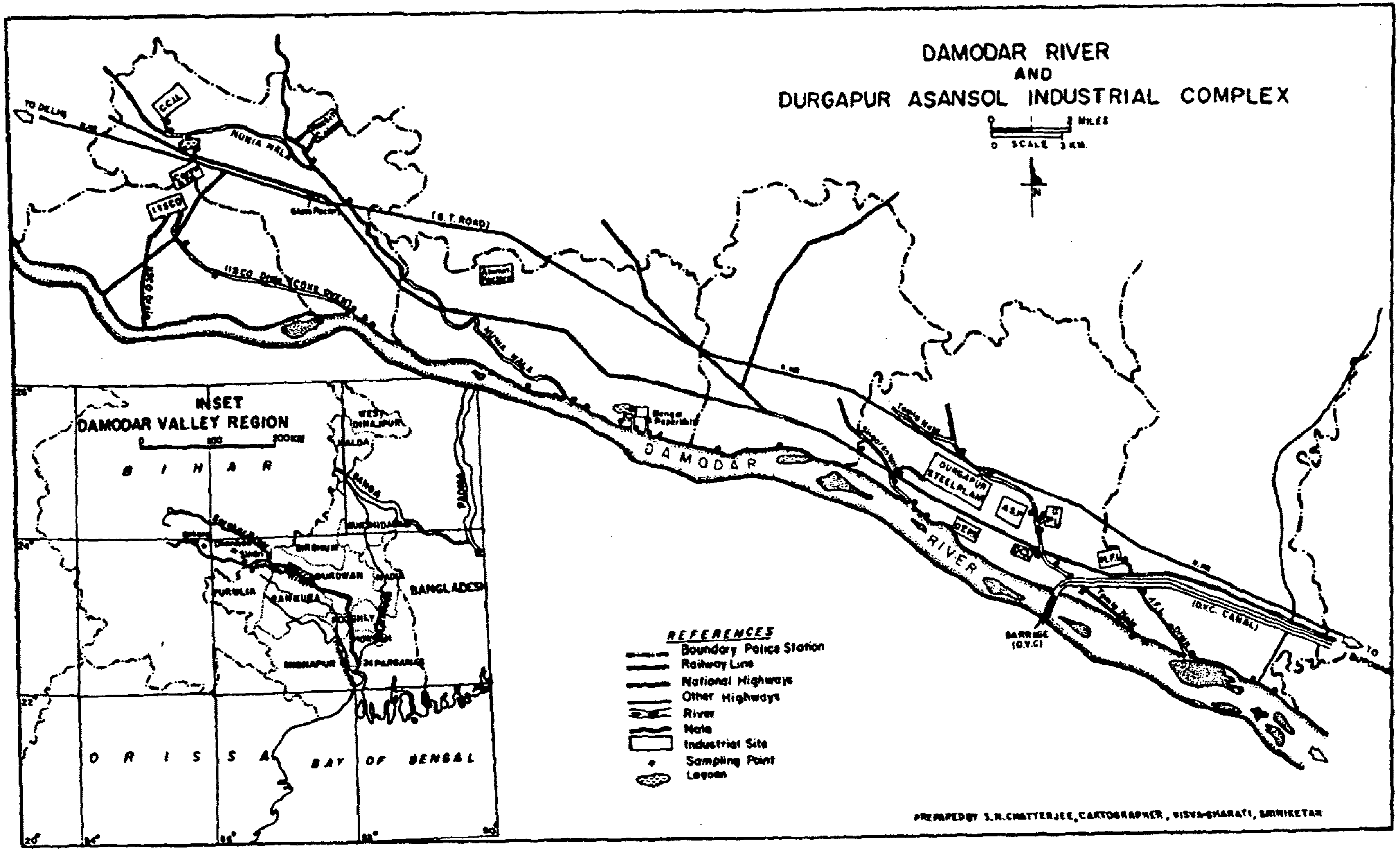
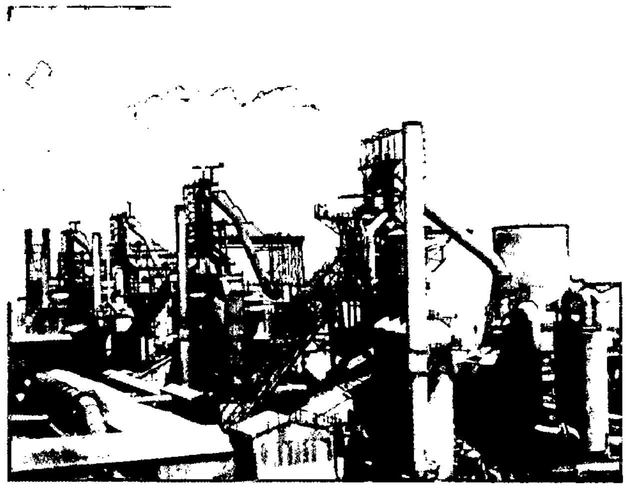


Figure 3.2: Location map of principal industries in the study stretch

Durgapur Project Limited

IISCO, Burnpur



Durgapur Steel Plant

Adhunik Ispat Limited, Durgapur

Durgapur Thermal Power Plant

Alloy Steel Plant, Durgapur

Plate 3.1: Major industries of the study stretch

3.4.2 Mining Activity

3.4.2.1 Coal reserves: As per Geological Survey of India, India has 2.7% of the world coal reserves are found occurring in Gondwana and Tertiary formations. Half of the Gondwana coals are confined to the Damodar river valley and out of these resources 12.3% falls in the study area, mainly in the Raniganj region having superior grade of coal at a depth of 1,200 m below ground level. Total coal reserve upto 600 m depth is about 23 billion tones in West Bengal. Out of this, proven extractable reserve is 6 billion tones (CPCB 2008).

Eastern Coalfields Limited (ECL), a subsidiary of the public sector Coal India Limited (CIL), inherits all the private sector coal mines of Raniganj coalfield since1975. Raniganj Coalfield of ECL has special characteristic containing the best type of non-coking coal reserves in the country. All the heat intensive industries like Glass, Ceramic, Refractory, Forging etc. are exclusively dependent on Raniganj Coal.

3.4.2.2 Type of coal mines: CIL is poised to produce 370 million tones of coal by the turn of the century. Underground mines can not keep pace with rising demand. Thus, about 60% of the coal extracted from the area comes from large, open-cast mines. Mainly two types of coal mining activity are found in the study area:

a) Opencast coal mine e.g. Mondmon coal mine discharging to Khudia river, Ningha Colliery discharging to Nunia Nullah and
b) Underground coal mine e.g. Moonudih coal mine.

3.4.2.3 Other mines: Raniganj coalfield also contains large reserves of iron ore. Good quality fire clay occurs from Barakar to Raniganj region. Other types of useful clays occur at several places in the Raniganj coalfield belt, of which, the pottery clays and the light coloured brick clays of Durgapur deserved special mention. Beside this the important minerals found in the district are calcium carbonate, manganese, mica, bauxite, laterite etc.

3.4.2.4 Impact on river water: Mines are serious sources of land degradation. The disposal of overburden rock and soil extracted with the coal is a big problem for the coal authorities. The rock mined just adds the volume of waste generated. The total volume of overburden, which is about 200 M m^3, is likely to be 500 M m^3 by the turn of the century (CSE 2008).

Opencast mining results in huge heaps of overburden. Removed loosely dumped earth results in the increase of turbidity, deposit of sediments in the river bed and ultimately choking the river. On the other hand, when the underground mines are in use, they have to pump to keep them dry. Now, water drips through the old mine shafts and fills the tunnels. The water reaches the surface by springs after coming into contact with rusty machinery. High concentration of COD, TSS, TDS, TS and O&G level is very common in the effluents.

3.4.3 Agricultural Runoffs

3.4.3.1 Agricultural production: The agricultural productivity in the study area is also notable. Except lateritic soil part at the west, the narrow valley and depressions have rich alluvium soil with good moisture content. Agriculture is largely regulated by rainfall. The cultivation in the area has improved with the implementation of the irrigation projects undertaken by the DVC.

Rice is the most important crop. The rice grown with its numerous varieties can broadly grouped under the three primary classes distinguished from one another by distinct characteristics and there are: The Aus or autumn, the Aman or winter and the Boro or the summer rice. Total food grain production is 3046 kg/hectare. Wheat, Barley Maize, Gram are other crops grown. Among commercial crops Jute and Sugarcane, potato, oil seeds are cultivated in marginal area. Irrigation through canals and river lift irrigation are common practice.

3.4.3.2 Impact on the river water: Burdwan district alone consume 119 kilo tones of fertilizer per year. Mainly Nitrogen, Phosphate and Potash fertilizers are used in the field. Apart from those, use of pesticides, fungicides and insecticides are common practice in the field. These substances, when applied in excess, deteriorate WQ of field channels and nullahs due to agricultural runoff. Being persistent in nature, it ultimately pollutes the Damodar river through numerous non-point sources.

3.4.4 Municipal Discharges

Five municipal towns of Burdwan district are located in the stretch within ten km from Damodar river. Based on population, Kulti, Asansol, Raniganj and Durgapur belong to Class I cities. Other small towns/ villages of the stretch are Andal, Burnpur, Mejhia, New Barakar, Chinakuri, Dishergarh etc. None of these towns/cities have proper treatment facilities for sewage of solid waste.

In 2000, wastewater generation from towns like Asansol, Durgapur and Raniganj were 22.6, 29.7 and 5.4 MLD respectively (CPCB 2003). Municipal discharge from these towns and its impact on the river quality are given in table 3.3.

Table 3.3: Details of municipal discharges in the study stretch

Sl	Cities/ Towns	Dist. from the river	Source of water supply	Drainage system	Sewage disposal	Impact on the river
1	Kulti	10 km	Water supply provided	Open drains	Through IISCO channel	Insignificant
2	Asansol	10 km	Surface & subsurface water of the river	Partly sewered & for Asansol & IISCO township	Partly treated through anaerobic system of a RCC chamber. Treated sewage & municipal effluents discharged into the river.	Significant
3	Raniganj	4.5 km	Surface water of the river, bore wells	Open drains	Disposed to open ground by trenching	Significant
4	Andal	5 km	Bore wells	Open drains	Disposed to river through open drains	Significant
5	Durgapur	8 km	Surface water of the river & wells	Bidhannagar township provided with drainage & sewerage	STP for Bidhannagar, septic tanks for other areas. Effluent & sullage drained into Tamla nullah	Significant

Impact on the river due to municipal discharges is become significant when the river water has BOD > 3 mg/l or TSS > 100 mg/l (NEERI 1994).

Population growth rate in these towns is high. Sewage is being generated at alarming rate. According to Bhardwaj (2005), the population of India is likely to be stabilized by 2050. The per capita wastewater generation shall be around 98 lpcd (by the conservative estimate for town class I&II) based on the average wastewater generation observed by CPCB. Population growth in last six decades, projected population and estimated sewage generation are shown in table 3.4, 3.5 and 3.6 respectively.

Table 3.4: Population growth of major cities/towns in the study stretch (modified after NEERI, 1994)

Sl	Cities/ Towns	Census Population					
		1951	1961	1971	1981	1991	2001
1	Kulti	41,803	44,289	48,454	75,031	1,08,518	2,90,057
2	Asansol	76,277	1,03,405	1,55,968	1,88,375	2,62,188	4,86,304
3	Raniganj	25,939	30,113	40,104	48,707	61,997	1,22,891
4	Andal	-	3,609	4,690	14,291	16,288	19,504
5	Durgapur	-	41,696	2,07,232	3,11,798	4,25,836	4,92,996

Table 3.5: Projected population of the major cities/towns in the study stretch

Sl	Cities/ Towns	Method adopted*	Projected Population for the year			
			2008	2015	2025	2050
1	Kulti	Arithmetic Mean Method	324813	359568	409219	533346
2	Asansol	Arithmetic Mean Method	543708	601112	683117	888130
3	Raniganj	Arithmetic Mean Method	136464	150038	169428	217904
4	Andal	Uniform Percent Method	21806	24108	27396	35616
5	Durgapur	Incremental Increase Method	563878	634761	736021	989173

* Garg (1999)

Table 3.6: Estimated sewage generation from major cities/towns in the study stretch

Sl	Cities/ Towns	Estimated Sewage Generation (MLD)*			
		2008	2015	2025	2050
1	Kulti	31.8	35.2	40.1	52.3
2	Asansol	53.3	58.9	66.9	87.0
3	Raniganj	13.4	14.7	16.6	21.4
4	Andal	2.1	2.4	2.7	3.5
5	Durgapur	55.3	62.2	72.1	96.9

* Estimated at the rate of 98 lpcd (Bhardwaj 2005)

3.4.5 Fly Ash Problems

In this stretch, three large thermal power plants viz. Santaldih (480 MW), Mejhia (1090 MW) and Durgapur (350MW) and two small power stations viz. Dishsergarh (12 MW) and Chinakuri (30MW), consume thousand tones of coal per day and as much as 50% of the total solids is generated in the form of fly ash. There is little effort to manage that waste. Though the plats have electrostatic precipitators (ESP), they can't control air pollution efficiently due to inadequate in number and traditional inefficient dust collectors. As these plants are located on the banks of the river, the fly ash eventually finds its way into the water. Disposal of bottom ash, from boilers degrades the river even more. The bottom ash is supposed to be mixed with water to form slurry which is then drained into ash ponds. Most of the ponds are full and in several cases drainage pipes are choked. The slurry is discharged into the river. Apart from that atmospheric fall out of fly ash, dust, smoke and smog are the common problem in this industrial belt.

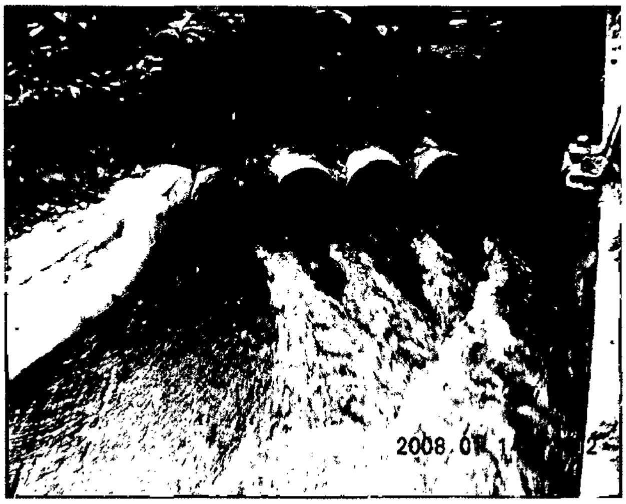
3.4.6 Other Sources of Pollution

An accidental cause of pollution is always a threat in industrial belts. On 2nd April 1990, about 0.2 million litres of furnace oil has spilled into the Damodar river from the

Bokaro Steel Plant. The oil traveled about 150 km downstream to Durgapur and for at least a week after the incident, the five million people in the area drank contaminated water (CSE 2008). Other sources of pollution include local coke production in slum areas, in-stream water uses, bathing, cattle wading, open defecation and clothes washing. Huge number of idol immersion during *Durga puja* festival and village fair at the river bank during *makar sankranti* are also notable causes of pollution. In addition, river damming and soil erosion due to cattle grazing affects river water quality to large extents.

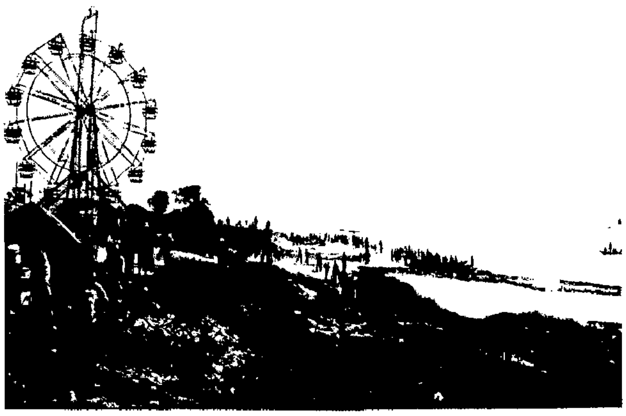
Plate 3.2 shows the different causes of pollution in the study area.

Agricultural run off near Kulti



Industrial effluent of DTPS

Rock blasting near Barakar R



Village fair beside Damodar R.

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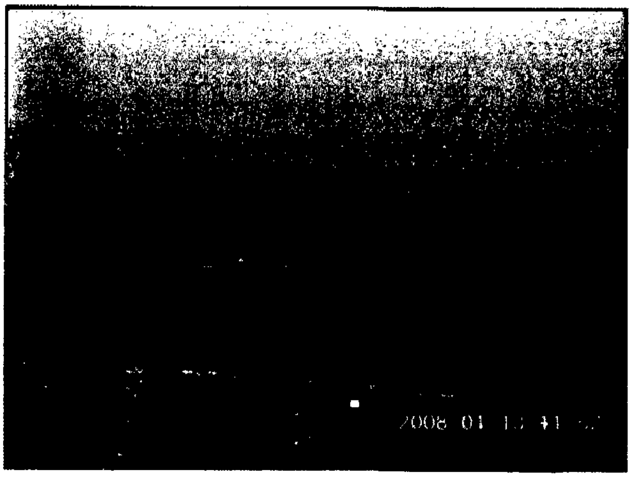
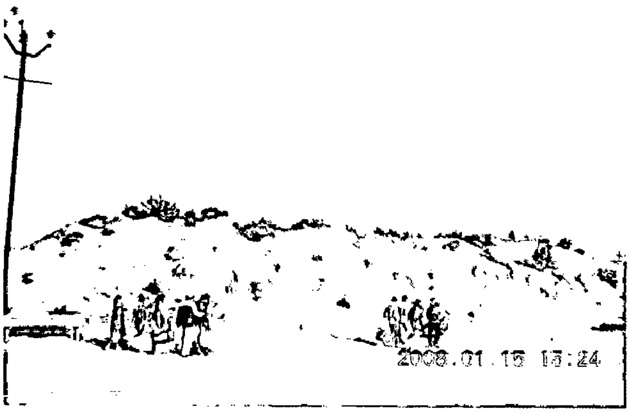
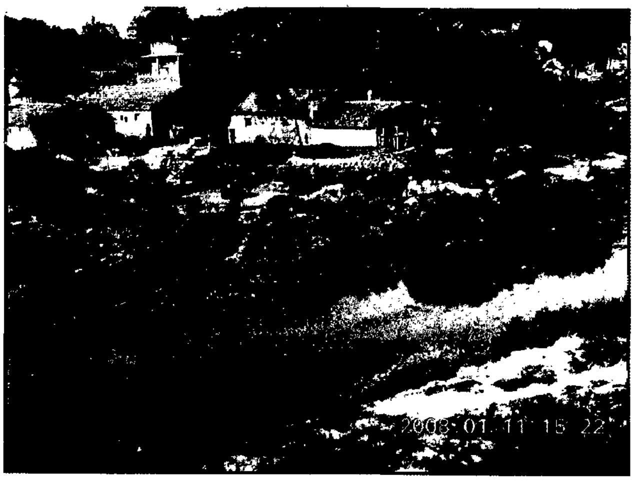
Hazardous chemical effluent in Durgapur



Open cast mining at Raniganj



Road side dumping yard near Asansol



Cattle farming beside Tamla nullah

Idol immersion in Khudia R.

Local coke production at *Munda Bosti*

Plate 3.2: Various causes of pollution observed in the study stretch

3.5 DAMODAR ACTION PLAN

In the second phase of GAP, the Damodar Action Plan (DAP) was approved in 1996. Under this Action Plan, pollution abatement works are being taken up in 12 towns. Out of these eight towns are in Jharkhand and four in West Bengal. So far 11 schemes have been sanctioned. The total approved cost for main works is Rs. 22.41 crores, out of which Jharkhand would receive Rs. 10.22 crores and West Bengal Rs. 12.19 crores (PIB 2007). It has opened its account with the approval of low cost toilet schemes recently. A number of schemes have been sanction in 1999-2000. About 68 MLD of sewage is targeted to intercepted, diverted and treated under DAP (MoEF 2008). Financial structure of DAP is shown below.

Table 3.7: Estimated cost of Damodar Action Plan

Town No.	Town Name	State Name	CCEA Cost (Cabinet Committee on Economics Affairs) in *lakhs*
1	Andal	West Bengal	141.34
2	Asansol	West Bengal	761.42
3	Bokaro-Kangali	Bihar	115.46
4	Chicunda	Bihar	172.12
5	Dugdha	Bihar	123.80
6	Durgapur	West Bengal	161.51
7	Jharia	Bihar	193.35
8	Ramgarh	Bihar	295.38
9	Raniganj	West Bengal	154.91
10	Sindri	Bihar	0.85
11	Sudamdih	Bihar	99.83
12	Telumochu	Bihar	21.27
Sub Total :			2241.24
Establishment cost & cost for R&D			117.00
O/A Total :			**2,358.24**

Source: http://envfor.nic.in/nrcd/rdap.html (MoEF 2008)

The targeted capacity for sewage treatment in DAP, is very low as compared to the average sewage generated from the individual towns of the stretch. Out of the approved cost of Rs. 23.58 crore, an expenditure of Rs. 6.43 crore has been incurred till date under this Action Plan. The work on the scheme has not yet began in right earnest due to low priority given by the State Governments to this plan.

CHAPTER 4

METHODOLOGY
FOR ASSESSMENT OF RIVER POLLUTION PROFILE

4.1 GENERAL

Wastewater sampling and analysis form an important part of any water pollution control programme, because the identification of the pollutants and pinpointing their concentration are vital to the selection of a proper treatment process. The sampling method should be one that gives a representative picture of the quality of the waste stream, otherwise the time and effort involved in the analysis will be completely wasted.

In the present work, total 45 grab samples were collected in the month of January 2008 from the different locations of the study stretch. Samples were analyzed either *in situ* or in laboratories for the selected pollution parameters. Materials and methods used for the sample collection, quantification of water quality through index system and chemical analysis are subsequently discussed in this chapter.

4.2 SELECTION OF WATER QUALITY PARAMETERS

For river water quality assessment, those general and vital parameters (WQI point of view) are selected that can be analyzed with ease considering laboratory accessibility, time boundness and cost effectiveness. Parameters like biological planktons, minerals and heavy metals are excluded from the present study due to the criticality in analysis. Table 4.1 gives the types of water sampling and corresponding WQ parameters.

Table 4.1: Parameter selection for different types of water sampling

Sl	Type of Water Sample	Selected Parameters
1	Damodar river with its tributary rivers	pH, Water & Air Temperature, Electrical Conductivity(EC), Total Alkalinity, Chloride, Total Hardness, Turbidity, TDS, TSS, TS, DO, BOD_3 at 27^oC, COD, Total Coliform(TC), Feacal Coliform (FC), NH_4^+ - N, Nitrate-N, Total Phosphate, Sulphate, Phenol and Cyanide
2	Drains/ Nullahs towards Damodar river	Above parameters plus Oil & Grease (O&G)
3	Industrial discharges	pH, Temp, TSS, TDS, TS, DO, BOD, COD, NH_4^+- N, Turbidity, EC, Phenol, Cyanide and O&G
4	Municipal discharges	pH, Temp, TSS, TDS, TS, DO, BOD, COD, TC and FC

Above selection also agrees with the stipulated WQ parameters as per NRCD's suggestion for M. Tech. dissertation work on Conservation of Rivers and Lakes.

4.3 SELECTION OF WATER QUALITY INDEX SYSTEM

Public awareness and consciousness about pollution in general and pollution of water bodies in particular has increased over the recent years. However, in spite of awareness of water quality and water pollution, the general public is at loss to understand the actual level of water quality as explained in technical parameters. In such circumstances, if the water quality is expressed in terms of numbers, the public as well as technologists and administrators can better understand it.

4.3.1 Modified Structure of NSF WQI

With a view to evaluating the water quality profile of a river and to identify the reaches where the gap between the desired and the actually existing water quality is significant enough to warrant urgent pollution control measures, a need was felt to translate the monitoring data in a form which is easily understood and effectively interpreted. Hence, it was deemed to develop water quality indices (WQI) adopted by the National Sanitation Foundation, USA with a slight modification in weightages suiting to the water quality criteria for different categories of uses as delineated by Central Pollution Control Board (CPCB), New Delhi, India. The procedure was adopted by Ved Prakash *et al* (1990) to evaluate the water quality profile of river Ganga. The National Sanitation Foundation Water Quality Index (NSF WQI) has the following mathematical structure: (Appendix – I)

NSF WQI = Σ_P Wi Ii

Where Ii = Sub index for ith water quality parameter

Wi = Weight (in terms of importance) associated with water quality parameter

And P = Number of water quality parameters.

The modified weights (Wi) and the equation for the sub indices (Ii) are shown in Table 4.2 and 4.3 respectively.

Table 4.2: Original and modified weights for the computation of NSF WQI based on DO, FC, pH and BOD

Water Quality Parameters	Original Weights	Modified Weights (Wi)
DO	0.17	0.31
Faecal Coliforms	0.15	0.28
pH	0.12	0.22
BOD	0.1	0.19
Total	0.54	1.00

Table 4.3: Sub-index equations for water quality parameters (NSF WQI)

Water Quality Parameters	Range Applicable	Equation
DO (Percent Saturation)	0-40% saturation	$I_{DO} = 0.18 + 0.66X(\%sat\ DO)$
	40^{+}-100% saturation	$I_{DO} = -13.55 + 1.17X(\%sat\ DO)$
	100^{+}-140% saturation	$I_{DO} = 163.34 - 0.62X(\%sat\ DO)$
	> 140% saturation	$I_{DO} = 50$
BOD(mg/L)	0-10	$I_{BOD} = 96.67 - 7.0X(BOD)$
	10^{+}-30	$I_{BOD} = 38.9 - 1.23X(BOD)$
	> 30	$I_{BOD} = 2$
pH	2-5	$I_{pH} = 16.1 + 7.35X(pH)$
	5^{+}-7.3	$I_{pH} = -142.67 + 33.5X(pH)$
	7.3^{+}-10	$I_{pH} = 316.96 - 29.85X(pH)$
	10^{+}-12	$I_{pH} = 96.17 - 8.0X(pH)$
	< 2 or >12	$I_{pH} = 0$
Faecal Coliforms (FC) (CFU/100ml)	1-10^{3}	$I_{FC} = 97.2 - 26.6\log(FC)$
	10^{3}-10^{5}	$I_{FC} = 42.33 - 7.75\log(FC)$
	>10^{5}	$I_{FC} = 2$

The summary of the NSF WQI corresponding to various designated best use classifications is presented in the following table:

Table 4.4: Water class as per index score

Sl No	NSF WQI Range	Description	Class by CPCB *	Colour Code	Remarks
1	63^{+}-100	Good to Excellent	A	Blue	Clean & Healthy
2	50^{+}-63	Medium to Good	B	Green	Non polluted
3	38^{+}-50	Bad	C	Yellow	Polluted
4	≤38	Bad to very bad	D / E	Red	Heavily polluted

* *Appendix III*

4.3.2 Calculation Procedure

Following steps are required:

Step 1: Measure the individual WQ parameters in standard unit

Step 2: Convert DO concentration into % saturation DO using following sub steps:

i) Determine the elevation of the sampling station using global positionig system (GPS) or from known location

ii) Find approx barometric pressure using standard conversion table (Appendix IV)

iii) Find 100% saturated DO capacity (in mg/L) using standard conversion table (Appendix IV)

iv) Calculate % saturated DO

Step 3: Convert FC from MPN/100ml to CFU/100ml using standard chart (Appendix IV) [or simply measure the FC in membrane filtration technique (MFT).]

Step 4: Calculate the sub indices using equations given in table 4.3

Step 5: Multiply each sub indices by corresponding weightages given in table 4.2

Step 6: Add them to get single value index

Step 7: Determine the WQ status using table 4.4.

The whole process is also depicted in a flow chart given in figure 4.1.

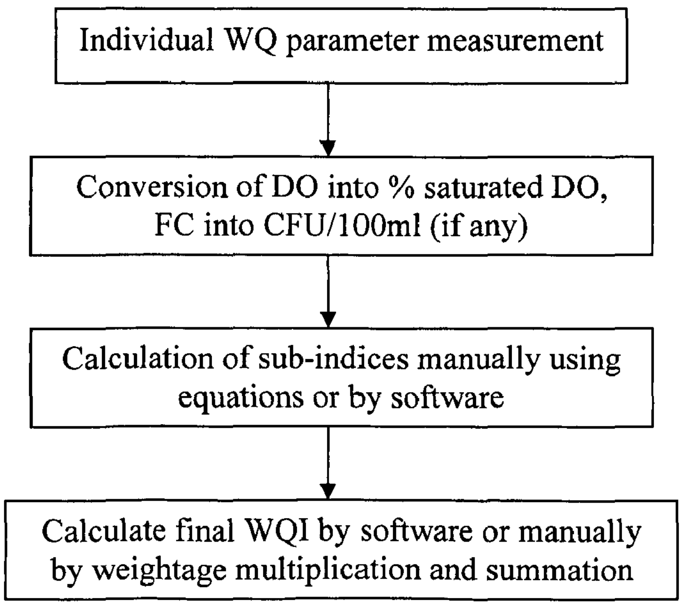


Figure 4.1: Flow chart for NSF WQI calculation

4.4 DETAILS OF SAMPLING

Sample collection is a very important part of river survey, because conclusions drawn are based only on the testing of collected samples. The purpose of taking samples is to obtain information, which in some way, typifies the aquatic system from which the samples are drawn. Based on the procedure of collection, samples are divided into three types: (i) Grab, (ii) Composite and (iii) Integrated samples. In this study, grab samples were collected from sampling stations, since time constraints and manpower available did not allow collection of integrated/composite samples. Field sampling protocol and format for data collection is given in Appendix II.

4.4.1 Types of Samples

Total 45 water samples from different discharge points were planned to collect from the field. The distribution of the sampling points is given below:

Table 4.5: Distribution of the sampling points

Sl.	Types of samples	Identification Code	Numbers
1	River samples	R	11
2	Tributary river samples	T	6
3	Samples from major drains/nullahs	D	21
4	Industrial samples including colliery	I	5
5	Municipal samples	M	2
		Total	45

4.4.2 Selection of Sampling Locations

The first stage of planning of the sampling programme is the selection of the most suitable site to provide a representative data. A reconnaissance survey of the study area was undertaken in September 2007 to identify and select the sampling points. Source of industrial and domestic discharges were identified and sampling locations were then finalized so as to include:

- Point u/s of the confluence of drains of industrial effluents/nullahs/tributaries of the river
- Point d/s of the confluence of drains of industrial effluents/nullahs/tributaries of the river
- Point d/s of dam and u/s of barrage on the river
- Point on drains of industrial effluents/nullahs/tributary river
- Points on towns and coal mine discharges

The co-ordinates of the sampling points are measured using Global Positioning System (GPS) and details are given in table 4.6. Figure 4.2 shows the line diagram of sampling locations in study stretch with discharge.

Table 4.6: Co-ordinates of the sampling points

Sl	Sampling ID	Sampling Location	Latitude	Longitude
1	R1	D/S of Panchet Dam	23°40'42.31"N	86°45'52.70"E
2	R2	Dishergarh Bridge after Barakar confluence	23°41'1.68"N	86°49'22.12"E
3	R3	After Chinakuri T.P.S Drains	23°40'2.51"N	86°51'30.88"E
4	R4	After confluence of Burnpur Drains	23°37'41.9"N	86°55'13.8"E
5	R5	After confluence of Tejab Nullah	23°37'56.33"N	87° 0'33.62"E
6	R6	After confluence of Nunia Nullah	23°35'0.42"N	87° 6'13.03"E
7	R7	Betn South Drains & Singaran Nullah	23°33'37.02"N	87°11'49"E
8	R8	After confluence of Singaran Nullah	23°32'7.54"N	87°13'57.75"E
9	R9	U/S of DTPS Hot water discharge	23°31'37.15"N	87°14'32.88"E
10	R10	D/S of DTPS Hot water discharge	23°31'14.25"N	87°14'52.26"E
11	R11	U/S of Durgapur Barrage	23°28'45.84"N	87°18'19.54"E
12	T1	Barakar River on GT Road Bridge	23°45'58.25"N	86°49'32.05"E
13	T2	Barakar River - Road Bridge	23°44'6.53"N	86°48'24.46"E
14	T3	Barakar River - at Damodar condluence	23°41'55.35"N	86°47'49.91"E
15	T4	Khudia River U/S at Road Bridge	23°46'38.61"N	86°41'52.45"E
16	T5	Khudia River at Chirkunda	23°43'11.75"N	86°45'58.00"E
17	T6	Khudia River at Barakar confluence	23°42'15.21"N	86°47'34.43"E
18	D1	Drain-I from Chinakuri TPS	23°40'53.79"N	86°51'0.87"E
19	D2	Drain-II from Chinakuri TPS	23°40'5.88"N	86°51'31.16"E
20	D3	South Drain - I	23°37'45.26"N	86°54'5.37"E
21	D4	Drain from Burnpur IISCO & Township	23°39'11.36"N	86°54'45.00"E
22	D5	South Drain - II	23°37'15.44"N	86°56'26.24"E
23	D6	Nullah D/S of Asansol	23°39'48.41"N	86°57'23"E
24	D7	Nullah D/S of Asansol - Tejab Nullah.	23°38'14"N	86°59'49"E
25	D8	Nunia Nullah entering Asansol	23°42'12.15"N	86°57'12.50"E
26	D9	Nunia Nullah crossing GT from Asansol	23°41'27.84"N	86°59'40.88"E
27	D10	Nunia nullah crossing GT Road	23°40'22.02"N	87° 0'57.67"E
28	D11	Nunia Nullah before Damodar	23°35'35.17"N	87° 5'38.25"E
29	D12	South Drain - III - near Mejia	23°32'58.37"N	87° 6'1.14"E
30	D13	South Drain - IV - near Mejia	23°31'18.68"N	87° 6'51.67"E
31	D14	U/S of Singaran Nullah	23°36'9.57"N	87°10'20.06"E
32	D15	Singaran Nullah before Damodar	23°33'6.64"N	87°13'17.75"E
33	D16	Common drain of DTPS & DSP	23°31'46"N	87°14'48"E
34	D17	Drain - Effluent from Cooling Tower	23°31'24.93"N	87°15'2.11"E
35	D18	Outlet of DTPS Ash Pond	23°31'36.80"N	87°14'47.23"E
36	D19	Tamla Nullah - Crossing GT Road	23°33'31.18"N	87°15'27.83"E
37	D20	Tamla Nullah - Crossing Link Road	23°32'8.74"N	87°16'4.66"E
38	D21	Tamla Nullah - Canal Syphon Crossing	23°29'0.22"N	87°18'28.48"E
39	I1	Durgapur Chemicals Ltd.	23°30'11"N	87°17'28"E
40	I2	Durgapur Projects Ltd	23°30'44"N	87°17'38"E
41	I3	Ningha Colliery near Raniganj	23°40'14"N	87°01'45"E
42	I4	DSP Major Drain through *Munda Bosti*	23°32'58"N	87°14'09"E
43	I5	Ricket & Colman (I) Ltd, Asansol	23°42'35"N	86°59'34"E
44	M1	New Barakar town discharge	23°44'6.53"N	86°48'24.46"E
45	M2	DTPS colony discharge, Durgapur	23°31'09"N	87°15'30"E

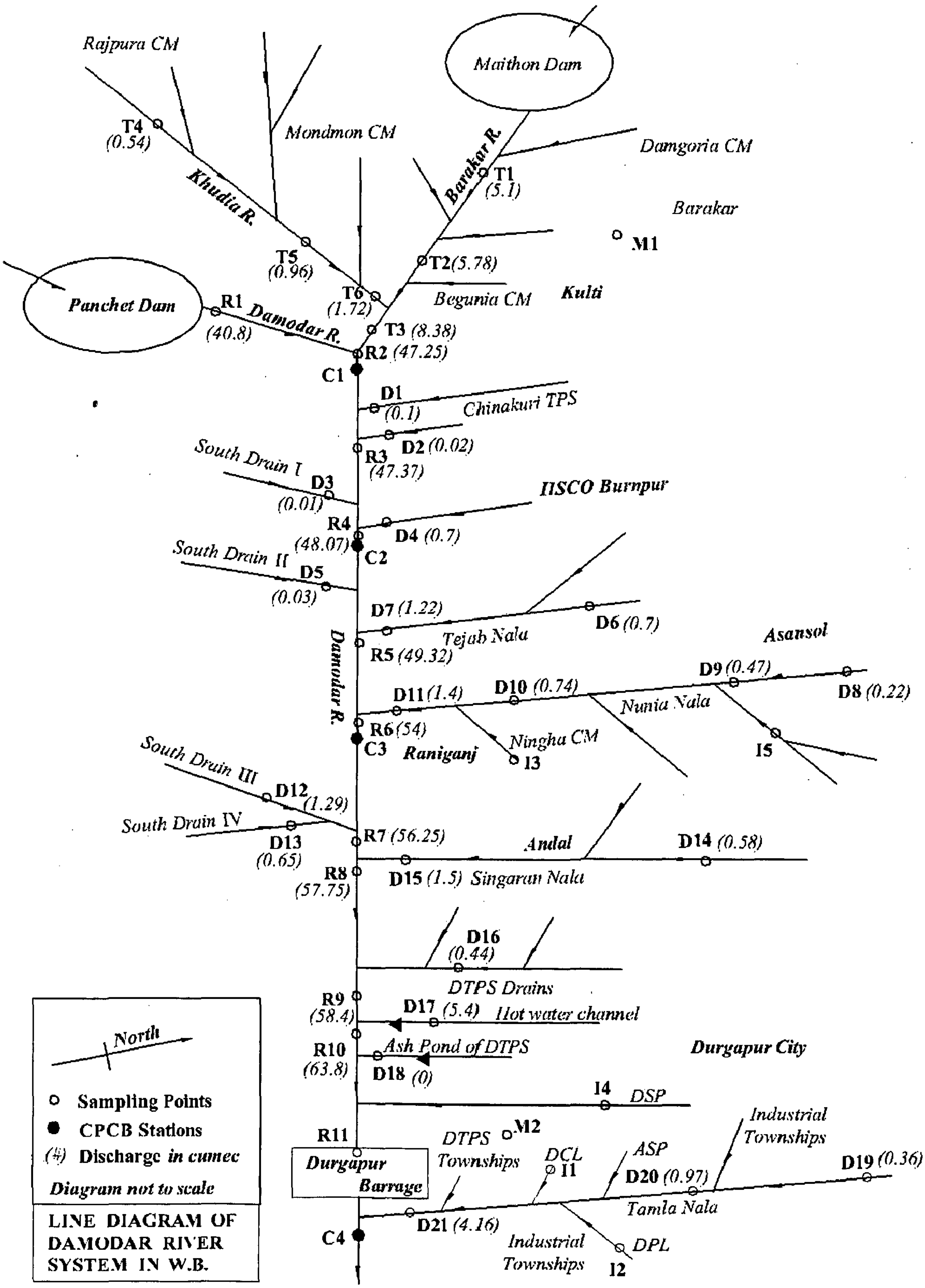


Figure 4.2: Line diagram of sampling locations in Damodar river stretch in WB

4.4.3 Sampling Period and Frequency

The post-monsoon cum winter water sampling was carried out during January 2008. This period is vital because it gives the lean season discharge having maximum concentration of pollutants. Grab samples were collected either in the morning (8 A.M. to 10 A.M.) or in afternoon (3 P.M. to 5 P.M.) time to avoid the heating effect of mid day sun.

4.4.4 Method of Sampling

River samples were collected either from boat by using sampler or by immersing the sample bottle into the water at a distance about 1 to 2 m from the bank and at a depth of 30 cm from the surface. Drain/nullah samples were collected from the road/foot bridge using sampler. All samples were collected facing u/s to avoid contamination by slowly drawing water from the source into the container. Standard portable laboratory equipment/instruments have been used to measure on site parameters. Conventional DO, BOD, bacteriology bottles have been used to collect samples. Sampling was done as per standard methods (IS: 3025(Part 1), NEERI 1986).

4.4.4.1 *In situ* determination of non-conservative parameters: pH, temperature and conductivity are measured on the spot as they changes rapidly with time and can not be stabilized. Conductivity and pH were measured by digital meters while temperature was measured by thermometer. NH_4^+- N was determined by colour comparison scale after using AQUAQUANT ® kit.

4.4.4.2 Sample preservation, handling and transport: By the time a sample is collected in the field and transported for analysis in the laboratory, some physical changes and chemical/biological reactions may take place which will change the intrinsic quality of the sample. Samples were fixed/preserved before transport to the laboratory. For non conservative WQ parameters, following instantaneous and on the spot fixations were done.

Table 4.7: Preservation of samples

Sl	Parameter	Sample size	Reagents used
1	DO	300ml	1 ml $MnSO_4$ & 1 ml alkali azide
2	Nitrogen & phosphate	100ml each	a pinch of $HgCl_2$
3	Sulphide	100 ml	few drops of zinc acetate
4	Cyanide	500ml	1 ml 2(N) NaOH
5	Phenol	500ml	1 ml conc. H_2SO_4
6	Coliforms	300ml each	sterilized bottles

Ice box was used for transshipment to the field laboratory and finally they were preserved in refrigerator in the site laboratory.

4.4.4.3 Flow measurements: Where river/waste water is flowing through some well shaped channel/nullah/drain, flow is measured by measuring the depth of water (D), width of channel (W) and velocity of water (v). Flow velocity is measured by surface float method. A correction factor of 0.8 is multiplied to achieve actual velocity. Finally flow or discharge is calculated as:

i) Flow, **Q** (in cumec) = $\boldsymbol{v}$ (m/s) * **W** (m) * **D** (m)

ii) Where well defined shape is not available (in most of the cases), at least three measurements of above are taken at two edges and at middle of the channel. Average value of D, W and v are used.

iii) Industrial discharges via circular pipe are calculated by measuring diameter (Ø) and then

Q (in cumec) = $\boldsymbol{\Pi\, Ø^2\, v / 4}$

iv) Flow through broad crested weir is calculated using standard formula of hydraulics as

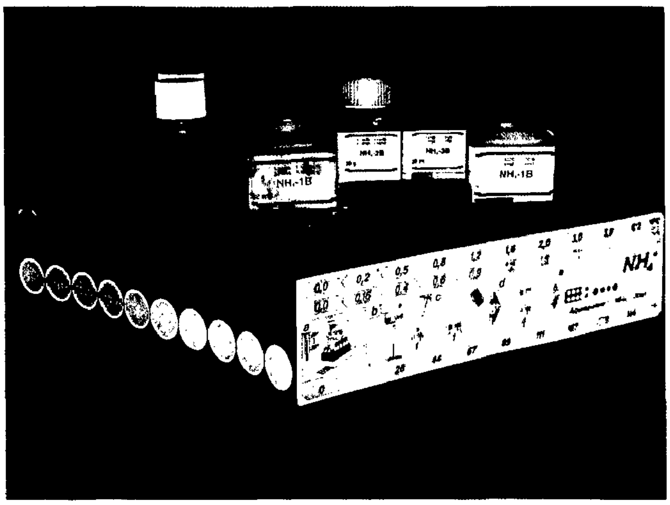
Q (in cumec) = $\mathbf{1.7 * C_d * W * H^{3/2}}$

where C_d – Co efficient of discharge taken as 0.9

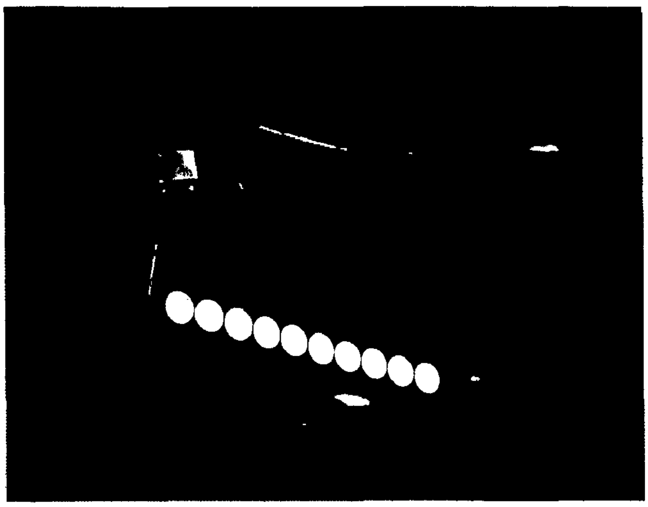
W – Width of the crest (m)

H – Head, height of water above the crest (m)

Measured discharges are shown in line diagram (Figure 4.2). The field sampling method is shown in plate 4.1 while the sampling from the river points, drains/nullahs and industrial effluent points are shown in plates 4.2, 4.3 and 4.4 respectively.



NH_4^+ - N kit



On the spot NH_4^+ - N measurement

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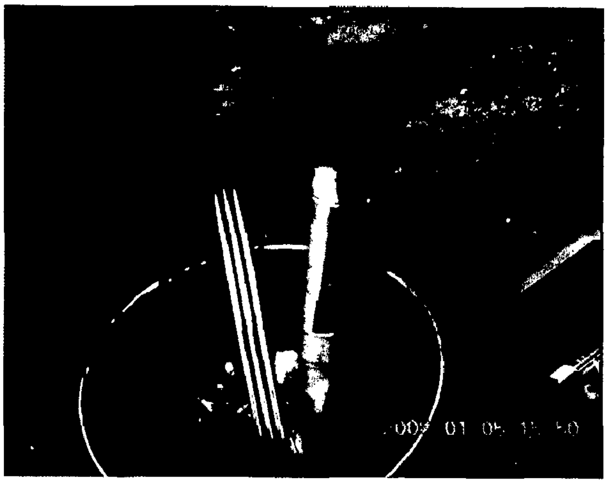
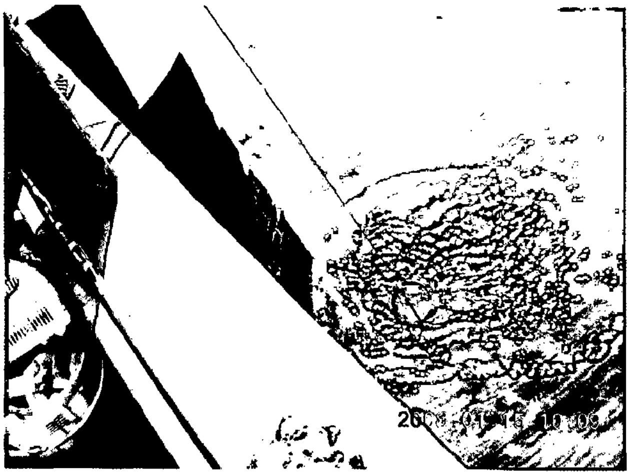
Conductivity meter



pH meter

Depth measurement

Velocity measurement

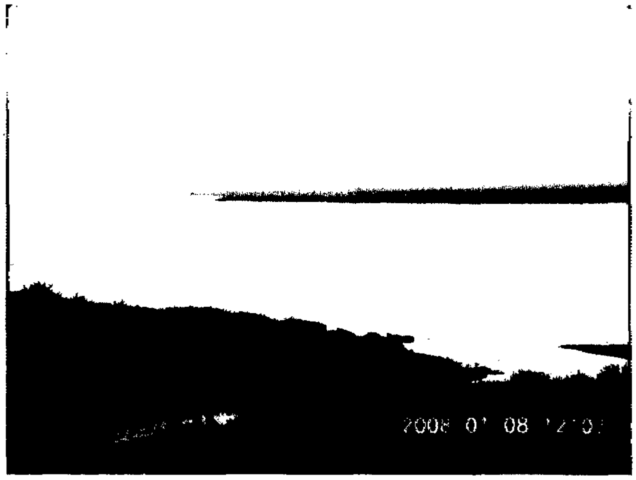


Sampling from bridge

On the spot DO fixation

Plate 4.1: Field sampling methods

Damodar at Dishergarh bridge (R2)



Damodar after CTPS drain (R3)

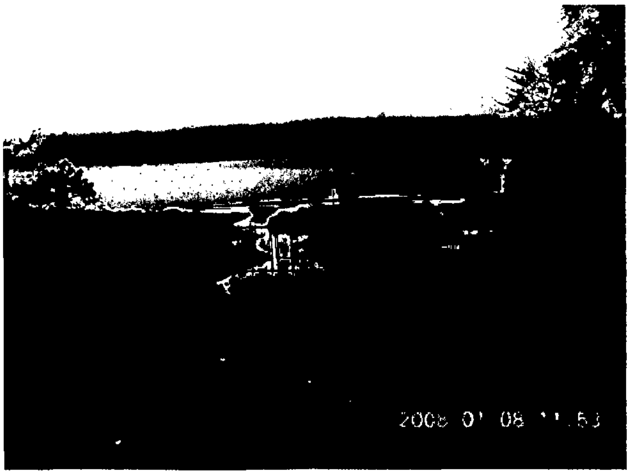
Hot water from DTPS to Damodar (R10)

Durgapur barrage (R11)

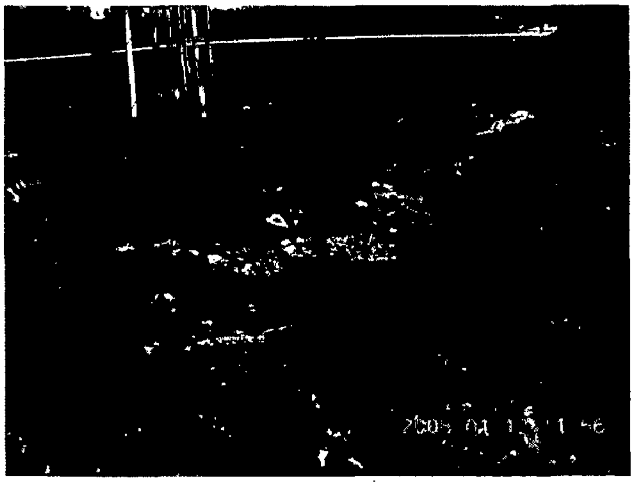
Barakar R confluence with Damodar (T3)

Khudia R confluence with Barakar (T6)

Plate 4.2: Sampling at river points



CTPS drain confluence to Damodar (D1)

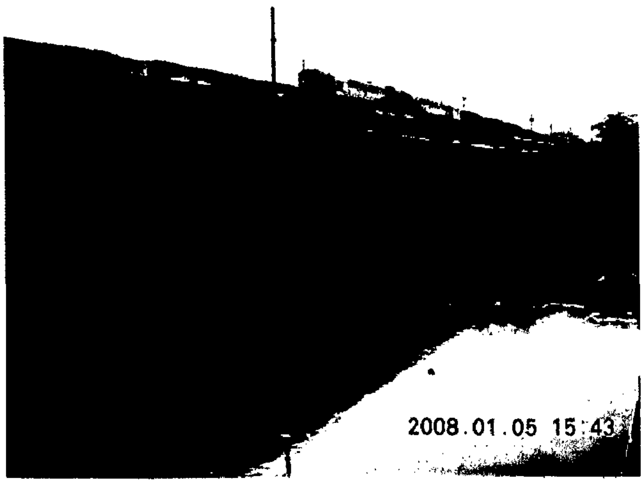


Drain from Burnpur (D4)

South drain – II (D5)

Tejab nullah (D7)

Nunia nullah (D10)



Singaran nullah (D15)

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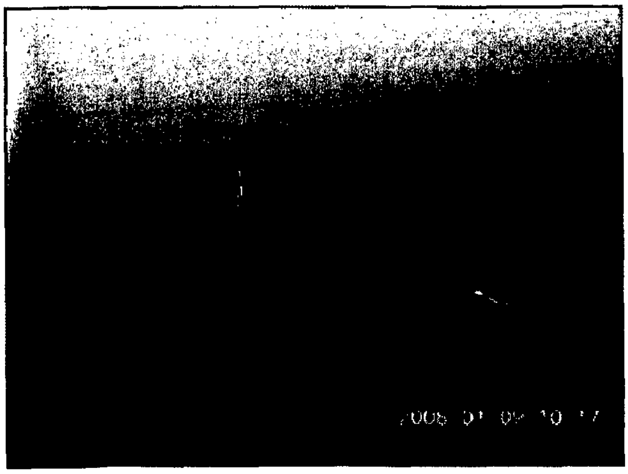
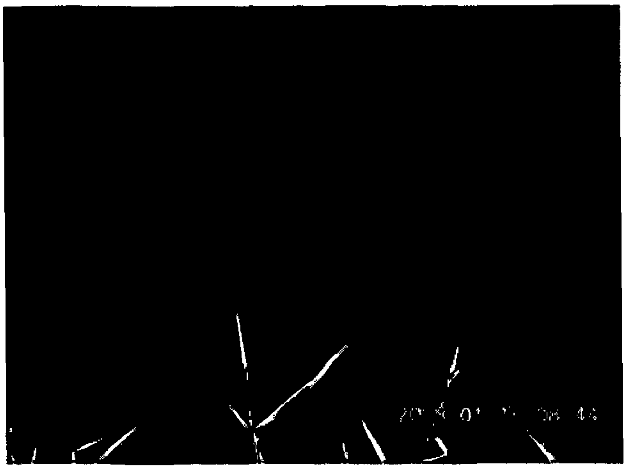


DTPS ash pond (D18) **Tamla nullah at canal syphon (D21)**

Plate 4.3: Sampling points at drains/nullahs

Durgapur Chemicals Ltd. (I1)

Ricket and Colman (I) Ltd. (I5)



DSP major drain (I4)

Nullah beside coal based industries

Plates 4.4: Sampling of industrial effluents

4.5 EXPERIMENTAL

Desired water quality parameters can be categorize as (i) Mineral parameters (pH, Temperature, Conductivity, Turbidity, Solids, Hardness, Alkalinity, Chloride and Sulphate), (ii) Demand parameters (DO, BOD and COD), (iii) Nutrient parameters (NH_4^+- N, NO_3 - N, Total N and Total P) and (iv) Bacteriological parameters (TC and FC) (NEERI 1986). All the samples were analyzed as per standard methods (IS: 2488, IS: 3025, APHA 1998). The parameters were measured in situ at sites, in field laboratory and Kolkata laboratory. The details of each type of analysis conducted are given below.

Table 4.8: Experimental programme

Sl	*In situ* determination	Field Laboratory Analysis	Kolkata Laboratory Analysis
1	pH	Total Alkalinity	Nitrate Nitrogen
2	Water & Air Temp	Chloride	Total Phosphate
3	NH_4^+- N	Total Hardness as $CaCO_3$	Total Sulphate
4	Conductivity	Turbidity	Phenol
5	DO Fixation	TDS, TSS & TS	Cyanide
6	Depth and Width	DO, BOD_3 at 27°C & COD	O&G
7	Velocity & Discharge	TC & FC	-

4.5.1 Field Laboratory Analysis

Non conservative parameters, which changes with time but can be stabilized for at least 24 hours by appropriate treatment, were analyzed in Durgapur field laboratory. Turbidity was analyzed by the method called Nephelometry using digital turbidity meter. Alkalinity and hardness were measured by titrametric method. Chloride was determined by Argentometric method while total hardness by EDTA method. Total Alkalinity was calculated by summing up of phenolphthalein and methyl orange alkalinity while total hardness was calculated by adding Calcium and Magnesium hardness.

DO fixed samples were tested for DO and BOD by modified Winkler method. BOD_3 was determined at a temperature of 27°C which is equivalent BOD_5 at 20°C. COD was determined by open reflux method.

Bacteriological parameters are analyzed by Membrane Filtration Technique (MFT) and results are expressed as colony forming unit (CFU) because MPN estimates are somewhat higher (on average basis) than CFU estimates, on split samples from the same water bodies (Gronewold and Wolpert 2008). NSF WQI also supports MFT.

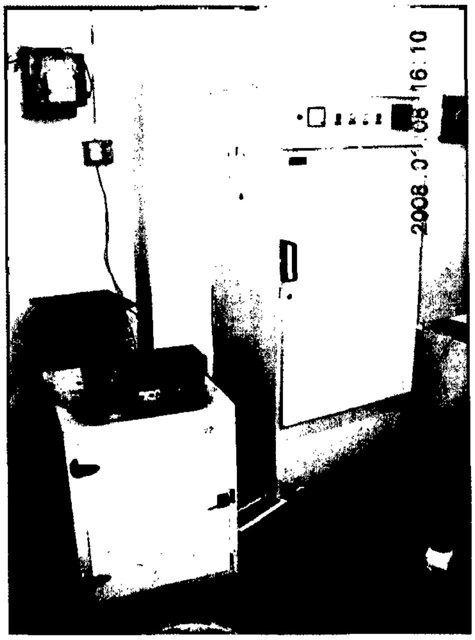
4.5.2 Kolkata Laboratory Analysis

Conservative and well stabilized non-conservative samples were analyzed in the Kolkata laboratory using sophisticated apparatus. Phosphate, sulphate, phenol and cyanide were determined by spectrophotometer. Nitrate and total nitrogen were determined using special Gerhardth Nitrogen digestion and distillation apparatus. Oil & Grease was tested using special separating funnel by gravimetric analysis. Instruments used in the two laboratories are given in table 4.9.

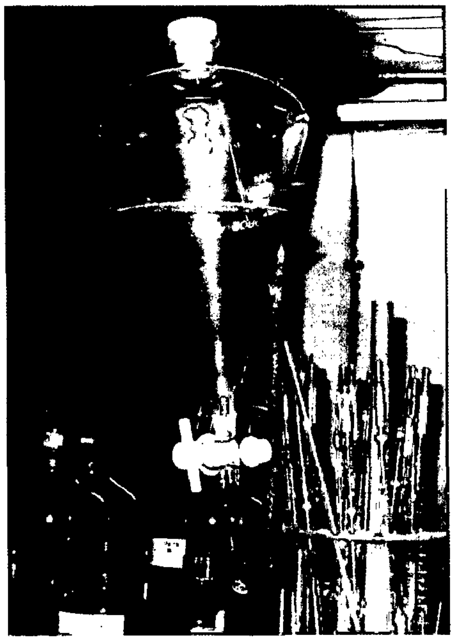
Table 4.9: Instrument used for laboratory analysis

Sl	Parameters	Unit	Instrument Details
1	Turbidity	NTU	Digital Turbidity Meter, Model 331
2	TS, TDS, TSS	mg/L	Millipore Assembly, Mityvac ® XH
3	TC and FC	CFU	Autoclave and Millipore Mityvac ® XH
4	Total Phosphate, Total Sulphate, Phenol, Cyanide	mg/L	SPECTRONIC GENESYS-2 Thermo Electron Corporation, USA
5	Nitrate, Total Nitrogen	mg/L	GERHARDTH digestion & distillation apparatus

Plate 4.5 shows the experimental set up in the laboratory. The results of analysis are given in table 4.10 to 4.14.



BOD & Coliform incubator



O & G separating funnel

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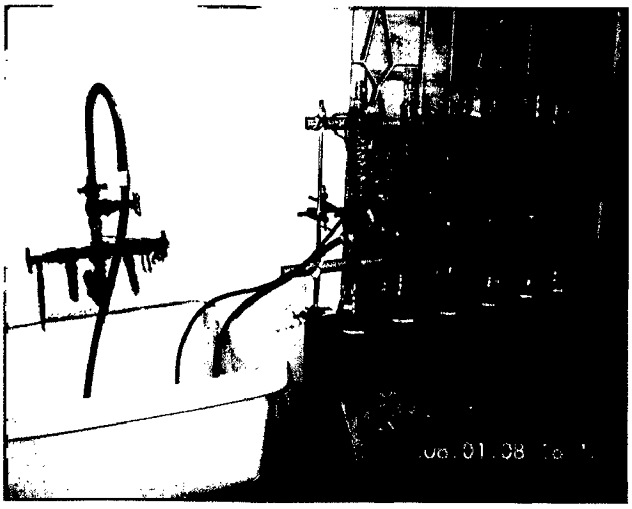
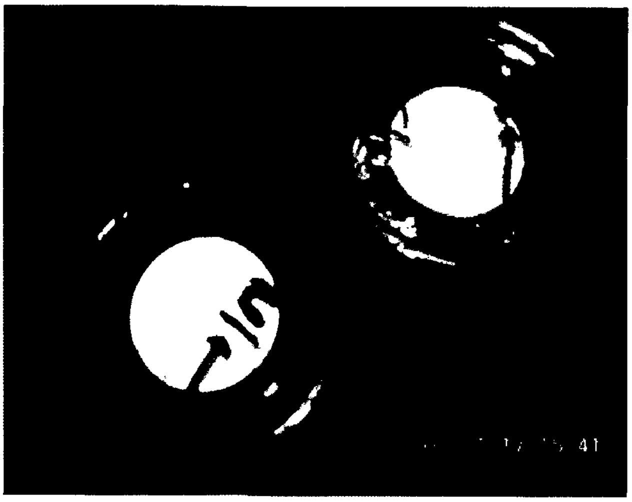
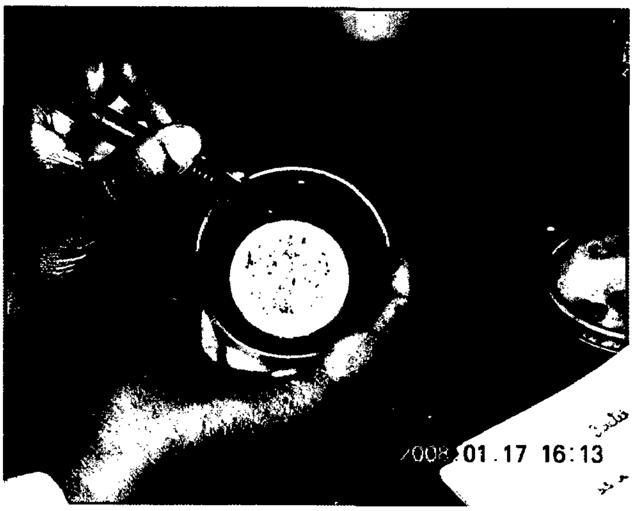


COD arrangements

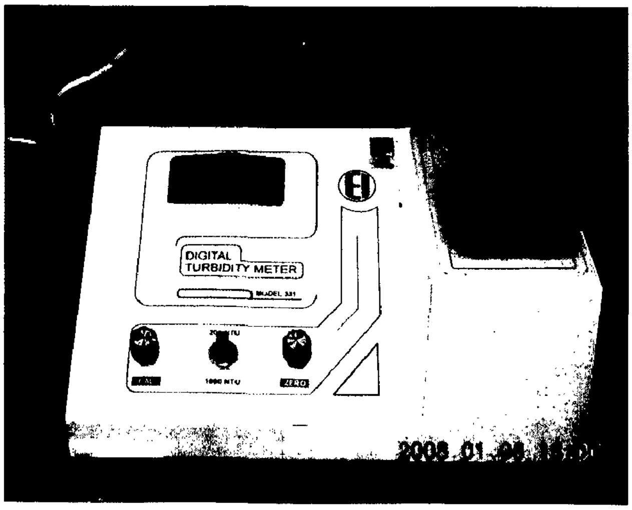
Millipore assembly



Petry dish with agar medium



Coliform colony counting



Turbidity meter

Gerhardth apparatus for Nitrogen

Plate 4.5: Experimental set up

Table 5.1: NSF WQI for the Damodar river sampling points

ID	DO (mg/L)	Temp (°C)	100% sat DO	% DO	I(do)	Wili	BOD (mg/L)	I(bod)	Wili	FC (CFU/ 100ml)	I(fc)	Wili	pH	I(pH)	Wili	WQI = Σ Wili	CLASS
R1	8.5	21	9.00	94.44	96.95	30.05	2.6	78.47	14.91	40	54.59	15.28	7.5	93.09	20.48	81	A
R2	8.8	20	9.17	95.97	98.73	30.61	2	82.67	15.71	500	25.41	7.11	8.2	72.19	15.88	69	A
R3	8.8	20	9.17	95.97	98.73	30.61	2	82.67	15.71	540	24.52	6.87	8.2	72.19	15.88	69	A
R4	8.7	20.5	9.08	95.81	98.55	30.55	2.2	81.27	15.44	680	21.86	6.12	8.2	72.19	15.88	68	A
R5	8.6	20.5	9.08	94.71	97.26	30.15	5.5	58.17	11.05	2470	16.04	4.49	8.1	75.18	16.54	62	B
R6	8.4	18	9.54	88.05	89.47	27.74	3	75.67	14.38	3650	14.72	4.12	8	78.16	17.20	63	B
R7	8.8	17	9.74	90.35	92.16	28.57	20	14.30	2.72	2800	15.61	4.37	8.1	75.18	16.54	52	B
R8	8.6	17	9.74	88.30	89.76	27.82	5	32.75	6.22	2700	15.74	4.41	8.1	75.18	16.54	55	B
R9	8.8	18	9.54	92.24	94.37	29.26	5	61.67	11.72	8000	12.08	3.38	8.5	63.24	13.91	58	B
R10	7.9	20	9.17	86.15	87.25	27.05	4	68.67	13.05	5000	13.66	3.83	8.1	75.18	16.54	60	B
R11	8.6	17	9.74	88.30	89.76	27.82	2	82.67	15.71	190	36.59	10.24	8.3	69.21	15.23	69	A

Table 5.2: NSF WQI (original) for Damodar river sampling points using software

ID	DO (mg/L)	100% sat DO	% DO	BOD (ppm)	TUR (NTU)	TS (ppm)	FC (CFU/ 100mL)	Temp (°C)	pH	NO_3 (ppm)	PO_4 (ppm)	Temp change(°C)	NSF WQI (9 parameters)	NSF WQI (4 parameters)
R1	8.5	9.00	94.44	2.6	5	185	40	21	7.5	18	0.03	0.5	78	81
R2	8.8	9.17	95.97	2	4	124	500	20	8.2	BDL	0.42	0	77	69
R3	8.8	9.17	95.97	2	4	125	540	20	8.2	BDL	0.40	0	77	69
R4	8.7	9.08	95.81	2.2	4	130	680	20.5	8.2	0.3	0.38	0	76	68
R5	8.6	9.08	94.71	5.5	4	132	2470	20.5	8.1	2.5	0.43	0	72	62
R6	8.4	9.54	88.05	3	20	138	3650	18	8	18	0.11	0.5	69	63
R7	8.8	9.74	90.35	20	14	129	2800	17	8.1	18	0.11	0.25	63	52
R8	8.6	9.74	88.30	5	14	139	2700	17	8.1	18	0.12	0	67	55
R9	8.8	9.54	92.24	5	8	132	8000	18	8.5	20	0.15	0.25	66	58
R10	7.9	9.17	86.15	4	14	190	5000	20	8.1	20	0.135	0.25	65	60
R11	8.6	9.74	88.30	2	9	135	190	17	8.3	36	0.33	0	70	69

Table 5.3: NSF WQI for Barakar river

ID	DO (mg/L)	Temp (°C)	100% sat DO	% DO	I(do)	Wili	BOD (mg/L)	I(bod)	Wili	FC (CFU/ 100ml)	I(fc)	Wili	pH	I(pH)	Wili	WQI= ΣWili	CLASS
T1	8.9	19	9.4	95.19	97.8	30.32	6	54.67	10.39	380	28.58	8.00	8.2	72.19	15.88	65	A
T2	9.7	17	9.7	99.59	103.0	31.92	6	54.67	10.39	900	18.62	5.21	8.4	66.22	14.57	62	B
T3	8.3	19	9.4	88.77	90.3	28.00	4	68.67	13.05	1600	11.97	3.35	8.2	72.19	15.88	60	B

Table 5.4: NSF WQI for Khudia river

ID	DO (mg/L)	Temp (°C)	100% sat DO	% DO	I(do)	Wili	BOD (mg/L)	I(bod)	Wili	FC (CFU/ 100ml)	I(fc)	Wili	pH	I(pH)	Wili	WQI = Σ Wili	CLASS
T4	8.6	20	9.2	93.78	96.2	29.81	2	82.67	15.71	1000	17.40	4.87	8.6	60.25	13.26	64	A
T5	7.2	21	9.0	80.00	80.1	24.82	6	54.67	10.39	520	24.95	6.99	8.4	66.22	14.57	57	B
T6	14.4	18	9.5	150.94	50.0	15.50	8	40.67	7.73	180	37.21	10.42	8.6	60.25	13.26	47	C

4.6 RESULTS OF THE ANALYSIS

Table 4.10: Water quality parameters of river points

Sample ID	Location	W	D	v	Flow	TUR	TDS	TSS	TS	Alkalinity	Chloride	Hard	EC	pH	Temp	DO	BOD	COD	TC	FC	NH_4^+-N	Nitrate	Phosphate	Sulfate	Phenol	Cyanide	Remarks
		m	m	m/s	cumec	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µ-mho/cm		°C	mg/L	mg/L	mg/L	CFU/100ml	CFU/100ml	ppm	mg/L	mg/L	mg/L	mg/L	mg/L	
R1	D/S of Panchet Dam	170	2	0.12	40.8	5	180	5	185	128	18	96	300	7.5	21	8.5	2.6	20	1150	40	0	18	0.029	51.23	NC	NC	
R2	Dishergarh Bridge	210	1.5	0.15	47.25	4	120	4	124	88	12	56	200	8.2	20	8.8	2	36	5300	500	0.2	BDL	0.419	38.15	0.001	BDL	After Barakar confluence
R3	After confluence of C.T.P.S drain	225	1.5	0.14	47.37	4	120	5	125	90	14	58	200	8.2	20	8.8	2	39	5500	540	0.2	BDL	0.40	NC	NC	NC	
R4	After confluence of Bumpur Drains	240	1	0.20	48.07	4	120	10	130	90	14	66	200	8.2	20.5	8.7	2.2	45	6000	680	0.2	0.3	0.38	NC	NC	NC	
R5	After confluence of Tejab Nullah	250	0.8	0.25	49.32	4	120	12	132	92	16	68	200	8.1	20.5	8.6	5.5	75	8600	2470	0.5	2.5	0.43	NC	NC	NC	
R6	After confluence of Nunia Nullah	150	0.8	0.45	54.0	20	120	18	138	96	16	64	200	8	18	8.4	3	68	11000	3650	0.5	18	0.112	35.84	0.001	BDL	
R7	Betn South Drains & Singaran	225	1	0.25	56.25	14	120	9	129	92	22	72	200	8.1	17	8.8	20	104	9600	2800	0	18	0.11	NC	0.112	NC	Local Mela
R8	After confluence of Singaran Nullah	200	1	0.29	57.75	14.5	120	19	139	102	20	80	200	8.1	17	8.6	5	60	9300	2700	0	18	0.12	NC	NC	NC	
R9	U/S of DTPS Hot water Discharge	200	1	0.20	58.4	8	120	12	132	108	22	92	200	8.5	18	8.8	5	42	27500	8000	0	20	0.15	NC	0.161	NC	After DTPS drains
R10	D/S of DTPS Hot water Discharge	200	1	0.22	63.8	14	180	10	190	108	22	96	300	8.1	20	7.9	4	40	28900	5000	0.5	20	0.135	NC	0.001	NC	
R11	U/S of Durgapur Barrage	ND	ND	ND	ND	9	120	15	135	96	16	60	200	8.3	17	8.6	2	24	580	190	2	36	0.326	42.61	0.169	BDL	

Table 4.11: Water quality parameters of tributary river points

ID	Location	W	D	v	Flow	TUR	TDS	TSS	TS	Alkalinity	Chloride	Hard	pH	EC	Temp	DO	BOD	COD	TC	FC	NH_4^+-N	Nitrate	Phosphate	Sulfate	Phenol	Cyanide	Remarks
T1	Barakar R on GT Road Bridge	300	0.17	0.10	5.10	10	60	5	65	76	16	44	8.2	100	19	8.9	6	44	900	380	0	18	NC	NC	0.001	NC	
T2	Barakar R - Road Bridge	210	0.11	0.25	5.78	7	60	2	62	76	18	48	8.4	100	17	9.7	6	40	2300	900	0	18	NC	NC	0.007	BDL	
T3	Barakar R - at Damodar Condluence	50	0.25	0.67	8.38	8	60	2	62	68	14	60	8.2	100	19	8.3	4	82	2600	1600	0.2	BDL	0.283	10.3	NC	BDL	
T4	Khudia R U/S – Road Bridge	7	0.5	0.16	0.54	8	240	3	243	180	26	128	8.6	400	20	8.6	2	76	13000	1000	0	90	0.001	81.38	0.048	NC	
T5	Khudia R at Chirkunda	9.4	0.41	0.25	0.96	8	300	6	306	180	28	148	8.4	500	21	7.2	6	40	2150	520	0.2	18	0.048	150.92	NC	NC	
T6	Khudia R at Barakar Confluence	20.5	0.35	0.20	1.72	6	300	6	306	164	30	140	8.6	500	18	14.4	8	68	200	180	0	54	NC	NC	0.035	NC	

Table 4.12: Water quality parameters of drain/nullah points

ID	Location	W	D	v	Flow	TUR	TDS	TSS	TS	Alkalinity	Chloride	Hard	pH	EC	Temp	DO	BOD	COD	TC	FC	NH_4^+-N	Nitrate	Phosphate	Sulfate	Phenol	Cyanide	O&G	Remarks
D1	Drain-I from Chinakuri TPS	4	0.2	0.12	0.10	14	480	18	498	344	44	108	8.4	800	22	9.2	14	80	25000	16000	1.6	18	0.414	58.3	NC	BDL	NC	
D2	Drain-II from Chinakuri TPS	2	0.1	0.10	0.02	37	600	10	610	428	64	116	8.1	1000	20	7.8	23	100	8700	1100	0.2	36	0.228	27.84	0.001	BDL	NC	
D3	South Drain -I	2	0.05	0.08	0.01	45	180	17	197	172	24	84	7.8	300	22	4.4	26	76	6800	3700	0	54	0.326	48.61	NC	NC	NC	Irrigation use
D4	Drain from Bumpur IISCO & Township	4	0.5	0.35	0.70	5	600	19	619	164	46	176	7.7	1000	24	4.3	28	108	23000	10000	3	54	0.414	254.3	0.064	BDL	13	Contains own discharge
D5	South Drain -II	4	0.15	0.05	0.03	7	300	2	302	220	30	108	8.1	500	19	8.2	2	20	280	220	0	18	0.288	38.3	0.001	NC	NC	
D6	Nullah D/S of Asansol	5	0.2	0.70	0.70	87	360	160	520	212	58	116	7.4	600	19	0.0	88	148	75000	50000	8	36	0.414	103.38	0.101	BDL	NC	
D7	Nullah D/S of Asansol - Tejab Nullah.	9.2	0.21	0.63	1.22	3	420	17	437	228	66	140	7.6	700	21	1.6	142	290	110000	73000	8	90	0.859	103.73	0.001	BDL	NC	Local name
D8	Nunia Nullah crossing entering Asansol	4	0.25	0.22	0.22	2	300	5	305	196	34	116	8.2	500	16	7.9	2	60	2500	470	0.2	54	NC	NC	0.081	BDL	NC	
D9	Nunia Nullah crossing GT from Asansol	15	1.25	0.03	0.47	45	480	306	786	336	72	144	7.8	800	17	0.0	190	392	10500	2000	8	BDL	0.412	104.46	0.070	BDL	NC	
D10	Nunia nullah Crossing GT Road	16.3	0.35	0.13	0.74	19	480	60	540	292	70	116	7.5	800	18	0.7	100	268	9400	1500	0	72	0.412	141.53	0.002	NC	NC	
D11	Nunia Nullah before Damodar	20	0.28	0.25	1.40	17	540	29	569	312	54	132	7.9	900	19	6.4	5	48	1800	480	8	18	0.390	314.76	NC	BDL	NC	
D12	South Drain - III - Road to Mejia	8	0.85	0.19	1.29	6	240	36	276	208	22	92	8.2	400	18	9.6	5	68	ND	8700	0	36	0.160	84.15	NC	NC	NC	
D13	South Drain - IV - Road to Mejia	3	0.7	0.31	0.65	4	240	22	262	232	26	106	8	400	19	8.4	3	28	ND	15300	0	18	0.235	23.53	0.001	NC	NC	
D14	U/S of Singaran Nullah	8	0.3	0.24	0.58	8	420	13	433	212	34	128	8.5	700	19	10.7	16	92	2750	2100	0	BDL	0.465	168.92	0.018	BDL	0	
D15	Singaran Nullah before Damodar	15	0.5	0.20	1.50	27	480	19	499	256	42	132	8.2	800	18	7.9	26	160	1020	870	0	18	0.048	180.46	NC	BDL	NC	
D16	Common drain of DTPS & DSP	1.4	0.3	1.05	0.44	44	180	86	266	ND	ND	ND	7.7	300	22	6.8	3	170	ND	200	3	54	NC	84.61	0.051	NC	NC	
D17	Drain - Effluent from Cooling Tower	7.2	1	0.75	5.40	14	180	21	201	96	10	64	8	300	28	7.1	4	52	ND	300	1.2	72	0.112	52.3	NC	BDL	0	
D18	Outlet of DTPS Ash Pond	3.4	0.1	0.00	0.00	146	180	1889	2069	96	16	64	8	300	27	6.4	3	308	ND	100	3	18	0.284	53.69	0.002	BDL	NC	
D19	Tamla Nullah - Crossing GT Road	5.5	0.15	0.44	0.36	57	420	352	772	192	66	104	7.8	700	19	3.6	38	124	ND	2300	8	180	0.016	68	0.110	BDL	0	
D20	Tamla Nullah - Crossing Link Road	9.2	0.3	0.35	0.97	137	360	306	666	128	34	72	7.5	600	20	3.8	26	136	ND	8900	8	216	0.194	66.76	0.119	BDL	8	
D21	Tamla Nullah - Canal Syphon Crossing	15	0.75	0.37	4.16	735	300	662	962	148	44	84	8.5	500	17	5.2	48	360	ND	11200	8	54	0.231	80.15	NC	BDL	0	Discharge by weir formula

BDL=Below Detection Level, NC=Not Collected, ND=Not Done

Table 4.13: Water quality parameters of industrial discharge

ID	Discharge	Temp	pH	TSS	TDS	TS	DO	BOD	COD	NH_4^+	TUR	EC	Phenol	Cyanide	O&G
	cumec	°C		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ppm	NTU	µ-mho /cm	mg/L	mg/L	mg/L
I1	0.128	24	9.6	ND	ND	ND	ND	ND	ND	1.6	ND	3600	0.011	BDL	0.01
I2	1.763	21	9.5	3405	360	3765	4.2	15	108	8	134	600	0.001	BDL	ND
I3	0.450	30	7.8	37	900	937	1.9	22	90	2	22	1500	0.048	BDL	ND
I4	0.30	22	8.9	23	1020	1043	0	105	512	0.2	26	1700	0.001	0.04	35
I5	0.187	19	7.8	9	780	789	7.7	3	20	0.5	2	1300	ND	BDL	ND

Table 4.14: Water quality parameters of municipal discharge

ID	Township	Discharge	Temp	pH	TSS	TDS	TS	DO	BOD	COD	TC	FC
		cumec	°C		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/ 100ml	CFU/ 100ml
M1	New Barakar	0.002	17	7.4	1148	840	1988	0.0	180	416	16700	10100
M2	DTPS, Durgapur	0.043	20	7.6	12	240	252	1.0	30	224	14600	7600

BDL=Below Detection Level, ND=Not Done

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 GENERAL

After getting the analytical results as shown in clause 4.6 of chapter 4, an attempt has been made to converge them into a single value number. NSF WQI has been applied for this purpose. The NSF WQI has been used to prepare water quality map of the study stretch. CPCB's data has been used to check the reproducibility of the results. Permissible limits of each individual WQ parameters were verified to detect the extent of pollution stress. A relative trend of water quality over the years has been analyzed and presented. Finally, conservation and management plan has been suggested for the stretch.

5.2 COMPUTATION OF NSF WQI FOR THE STUDY STRETCH

5.2.1 Modified NSF WQI Method for the River and Nullahs

Modified NSF WQI as adapted by CPCB, has been used to obtain a single value WQI for each sampling points. Four main parameters viz. pH, DO, BOD and FC were used for manual calculation. Water quality class has been categorized conforming to CPCB's "BDU" primary criteria. Calculations of modified NSF WQI for the river stretch are given in table 5.1. Figure 5.1 gives the bar chart of the WQI values for the sampling points along the river.

The modified NSF WQI values for the other tributaries, nullahs and drains and municipal discharges are given in table 5.3 to 5.10, which shows that Khudia river and Singaran nullah are discharging class 'C' category water to river Damodar. Though the Nunia nullah deteriorated at the middle stretch, it improves before discharging to Damodar. While in the case of Tamla nullah, the condition is worst.

5.2.2 Comparison with Original NSF WQI

For comparison, original NSF WQI is calculated with nine WQ parameters using online software (WU 2008) and the same is shown in table 5.2. Comparison lines are shown in figure 5.2. It is observed from the chart that two WQI profile lines are almost parallel at the middle that proves the correctness of the analysis. As the modified NSF WQI lies below the original one, it indicates that modified NSF WQI gives a little conservative value than the original one. It is obvious as the modified method deals with only four WQ parameters.

Table 5.5: NSF WQI for Tejab nullah

ID	DO (mg/L)	Temp (^{o}C)	100% sat DO	% DO	I(do)	WiIi	BOD (mg/L)	I(bod)	WiIi	FC (CFU/100ml)	I(fc)	WiIi	pH	I(pH)	WiIi	WQI = Σ WiIi	CLASS
D6	0.0	19	9.4	0.00	0.2	0.06	88	2	0.38	50000	5.91	1.66	7.4	96.07	21.14	23	E
D7	1.6	21	9.0	17.78	11.9	3.69	142	2	0.38	73000	4.64	1.30	7.6	90.10	19.82	25	E

Table 5.6: NSF WQI for the Nunia nullah

ID	DO (mg/L)	Temp (^{o}C)	100% sat DO	% DO	I(do)	WiIi	BOD (mg/L)	I(bod)	WiIi	FC (CFU/100ml)	I(fc)	WiIi	pH	I(pH)	WiIi	WQI = Σ WiIi	CLASS
D8	7.9	16	9.94	79.48	79.4	24.63	2	82.67	15.71	470	26.12	7.31	8.2	72.19	15.88	64	A
D9	0.0	17	9.74	0.00	0.2	0.06	190	2	0.38	2000	9.39	2.63	7.8	84.13	18.51	22	D/E
D10	0.7	18	9.54	7.34	5.0	1.55	100	2	0.38	1500	12.72	3.56	7.5	93.09	20.48	26	D/E
D11	6.4	19	9.35	68.45	66.5	20.63	5	61.67	11.72	480	25.88	7.25	7.9	81.15	17.85	57	B

Table 5.7: NSF WQI for Singaran nullah

ID	DO (mg/L)	Temp (^{o}C)	100% sat DO	% DO	I(do)	WiIi	BOD (mg/L)	I(bod)	WiIi	FC (CFU/100ml)	I(fc)	WiIi	pH	I(pH)	WiIi	WQI = Σ WiIi	CLASS
D14	10.7	19	9.35	114.44	92.39	28.64	16	19.22	3.65	2100	17.58	4.92	8.50	63.24	13.91	51	B
D15	7.9	18	9.54	82.81	83.34	25.83	26	6.92	1.31	870	19.01	5.32	8.20	72.19	15.88	48	C

Table 5.8: NSF WQI for Tamla nullah

ID	DO (mg/L)	Temp (^{o}C)	100% sat DO	% DO	I(do)	WiIi	BOD (mg/L)	I(bod)	WiIi	FC (CFU/100ml)	I(fc)	WiIi	pH	I(pH)	WiIi	WQI = Σ WiIi	CLASS
D19	3.6	19	9.35	38.50	25.59	7.93	38	2	0.38	2300	16.28	4.56	7.8	84.13	18.51	31	D/E
D20	3.8	20	9.17	41.44	34.93	10.83	26	6.92	1.31	8900	11.72	3.28	7.5	93.09	20.48	36	D/E
D21	5.2	17	9.74	53.39	48.91	15.16	48	2	0.38	11200	10.95	3.07	8.5	63.24	13.91	33	D/E

Table 5.9: NSF WQI for other drains/nullah points

ID	DO (mg/L)	Temp (^{o}C)	100% sat DO	% DO	I(do)	WiIi	BOD (mg/L)	I(bod)	WiIi	FC (CFU/100ml)	I(fc)	WiIi	pH	I(pH)	WiIi	WQI = Σ WiIi	CLASS
D1	9.2	22	8.83	104.19	98.74	30.61	14	21.68	4.12	16000	9.75	2.73	8.4	66.22	14.57	52	B
D2	7.8	20	9.17	85.06	85.97	26.65	23	10.61	2.02	1100	18.76	5.25	8.1	75.18	16.54	50	C
D3	4.4	22	8.83	49.83	44.75	13.87	26	6.92	1.31	3700	14.68	4.11	7.8	84.13	18.51	38	D/E
D4	4.3	24	8.51	50.53	45.57	14.13	28	4.46	0.85	10000	11.33	3.17	7.7	87.12	19.17	37	D/E
D5	8.2	19	9.35	87.70	89.06	27.61	2	82.67	15.71	220	34.89	9.77	8.1	75.18	16.54	70	A
D12	9.6	18	9.54	100.63	100.95	31.29	5	61.67	11.72	8700	11.80	3.30	8.2	72.19	15.88	62	B
D13	8.4	19	9.35	89.84	91.56	28.38	3	75.67	14.38	15300	9.90	2.77	8	78.16	17.20	63	B
D16	6.8	22	8.83	77.01	76.55	23.73	3	75.67	14.38	200	35.99	10.08	7.7	87.12	19.17	67	A
D17	7.1	28	7.93	89.53	91.20	28.27	4	68.67	13.05	300	31.31	8.77	8	78.16	17.20	67	A
D18	6.4	27	8.07	79.31	79.24	24.56	3	75.67	14.38	100	44.00	12.32	8	78.16	17.20	68	A

Table 5.10: NSF WQI for municipal discharges

ID	DO (mg/L)	Temp (^{o}C)	100% sat DO	% DO	I(do)	WiIi	BOD (mg/L)	I(bod)	WiIi	FC (CFU/100ml)	I(fc)	WiIi	pH	I(pH)	WiIi	WQI = Σ WiIi	CLASS
M1	0.0	17	9.74	0.00	0.2	0.06	80	2	0.38	10100	11.30	3.16	7.4	96.07	21.14	24.7	D/E
M2	1.0	20	9.17	10.91	7.4	2.29	35	2	0.38	7600	12.25	3.43	7.6	90.10	19.82	25.9	D/E

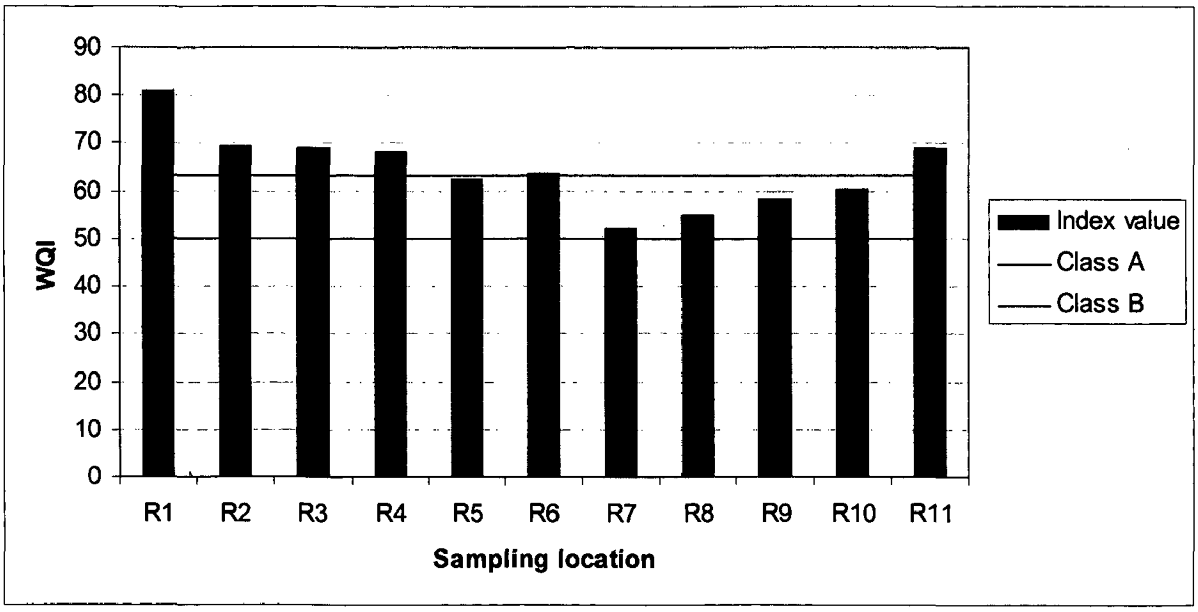


Figure 5.1: NSF WQI chart for Damodar river points

The chart clearly indicates class 'A' category water in the upper stretch of the river, then WQ deteriorate to class 'B' category due to pollution addition but the river recovers its quality at the end sampling point due to huge water storage.

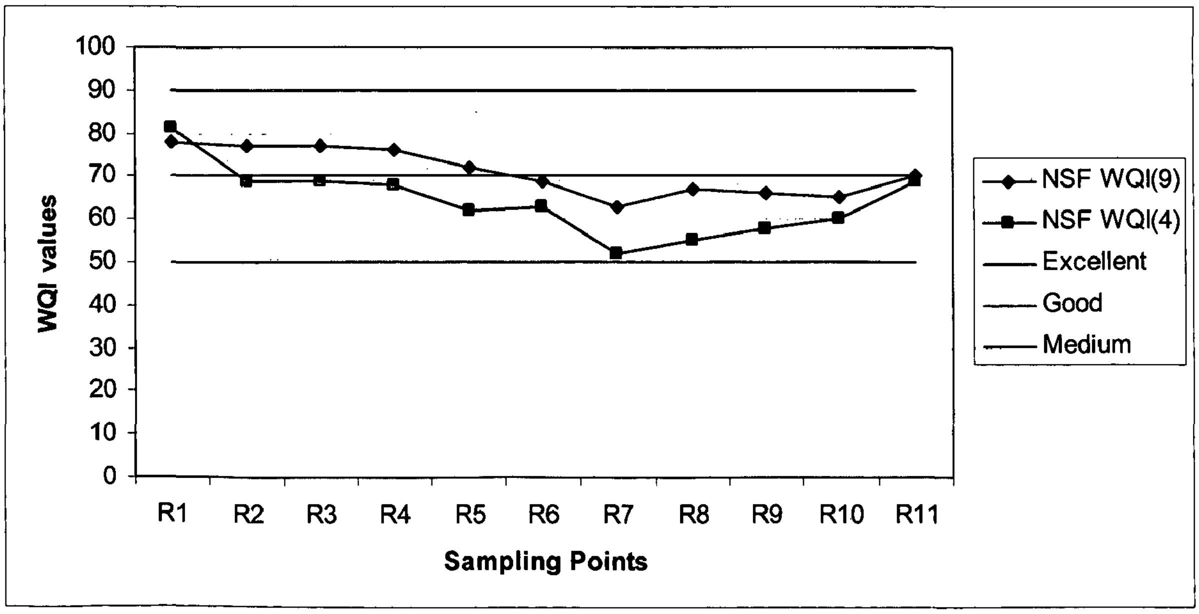


Figure 5.2: Comparison of original and modified NSF WQI for the river points

Top line shows the WQ for ideal condition while the bottom line, as already shown in the form of bar chart in figure 5.1, is for actual situation. Both of them show an excellent to good WQ in Damodar river for the selected stretch. Bottom line also depicts the longitudinal profile of the river.

5.3 COMPARISON WITH CPCB'S DATA

5.3.1 MINARS Monitoring Station in the Study Area

There are four river water quality monitoring stations and three ground water quality monitoring stations falls in the study area and being monitored under the National Water Quality Monitoring Programme. The locations of these stations are shown in Figure 4.2 in chapter 4. Table 5.11 and 5.12 shows the distribution of the total monitoring stations under Monitoring of Indian National Aquatic Resources Series (MINARS) in West Bengal and there locations in the study area respectively.

Table 5.11: Distribution of MINARS monitoring stations in West Bengal

No. of MINARS Monitoring Stations	Water body-wise distribution			
	River	Ground Water	Lakes	Total
West Bengal	18	15	1	34

Table 5.12: Location of the MINARS monitoring stations in the study area

Sl	MINARS for River WQ		MINARS for Ground WQ	
	ID	Locations	ID	Locations
1	C1	Dishergarh village (near Bihar-West Bengal Border)	G1	Mine pit water, Asansol
2	C2	D/S OF IISCO after 3rd outfall at Dhenna village	G2	Near IISCO, Burnpur
3	C3	Narainpur after confluence of Nunia Nullah	G3	At Durgapur
4	C4	Near Mujher Mana village after confluence of Tamla Nullah (After Barrage)		

5.3.2 Results of MINARS Monitoring Stations in the Study Area

Modified NSF WQI for the CPCB's data available on its website has also been calculated for the years between 2003 and 2006 and the results are presented in table 5.13 to 5.16 sequentially. Groundwater data is available for the year 2005 and the same shown in table 5.17. Whereas the standard values for them are given in Appendix – III.

Table 5.13: Damodar WQ data (mean value) 2003 (after CPCB 2003)

Stn	Temp	DO	BOD	COD	TC	FC	pH	EC	WQI	Class
C1	30	8.2	0.9	10	6275	1750	7.5	216	73	A
C2	30	8.5	0.9	13	6043	943	7.8	215	70	A
C3	30	8.2	0.9	11	8288	3738	7.9	300	69	A
C4	32	6.4	1.3	14	28625	12763	7.7	353	66	A

Table 5.14: Damodar WQ data (mean value) 2004 (after CPCB 2004)

Stn	Temp	DO	BOD	COD	TC	FC	pH	EC	WQI	Class
C1	30	8.0	0.6	4.5	21625	6108	7.8	172	70	A
C2	30	7.9	0.6	6.8	12525	3633	7.8	203	71	A
C3	30	7.9	0.6	5.5	13692	3025	7.9	266	70	A
C4	30	4.6	1.2	24.8	78500	31558	7.8	403	55	B

Table 5.15: Damodar WQ data (mean value) 2005 (after CPCB 2005)

Stn	Temp	DO	BOD	COD	TC	FC	pH	EC	WQI	Class
C1	30	7.2	0.7	5	15283	2833	7.53	199	72	A
C2	30	8.1	1.0	5	4675	658	7.64	212	73	A
C3	31	8.0	1.1	5	20467	1992	7.72	263	71	A
C4	31	6.1	2.6	11	63583	20035	7.98	478	60	B

Table 5.16: Damodar WQ data (mean value) 2006 (after CPCB 2006)

Stn	Temp	DO	BOD	COD	TC	FC	pH	EC	WQI	Class
C1	30	8.2	0.9	6.0	26486	12843	7.64	409	70	A
C2	29	8.2	0.9	4.3	5717	1117	7.59	204	73	A
C3	30	8.1	0.9	9.8	19386	6257	7.71	267	71	A
C4	28	6.7	1.3	25.6	68750	36825	8.00	506	62	B

Table 5.17: Ground WQ data (mean value) 2005 (CPCB 2005)

Stn	Temp	DO	BOD	COD	TDS	TSS	TS	TC	FC	pH	EC
G1	27	0.2	0.2	5.0	430	9	439	139	42	8.0	692
G2	28	0.5	0.5	5.0	462	5	467	350	14	7.8	614
G3	29	1.1	0.2	-	-	-		-	-	7.1	1376

Contd...

Stn	TUR	Hard	Alkalinity	Chloride	SO_4	PO_4	NH_4^+-N	NO_3	TKN	B	F
G1	3.6	252	403.0	33.0	27.0	0.1	0.16	0.28	1.0	0.33	0.29
G2	1.1	298	324.0	41.5	2.9	0.0	0.14	0.10	0.6	0.01	0.01
G3	-	-	-	-	-	-	-	1.13	-	-	-

These results indicate that the coliform numbers are much higher than the limits for class 'C' category water but over all river water quality is very good in the study area. After Tamla nullah confluence the WQ further deteriorates due to obstruction of flow by Durgapur barrage. Ground water of the stretch is not suitable for drinking water source due to high coliform and low DO though the other parameters conform to IS: 10500-1991.

5.4 WATER QUALITY MAPPING OF SELECTED RIVER STRETCH

The NSF WQI values in the each river sampling stations have been finally used to prepare river map on Google map using standard colour code. Microsoft paint has been used for river stretch mapping.

5.4.1 Previous Approach

In 1994, CPCB in collaboration with Survey of India prepared a water quality map of Ganga river basin based on DBU classification. In this map, the Damodar river quality was shown as class 'C' category. The selected map portion is shown in figure 5.3.

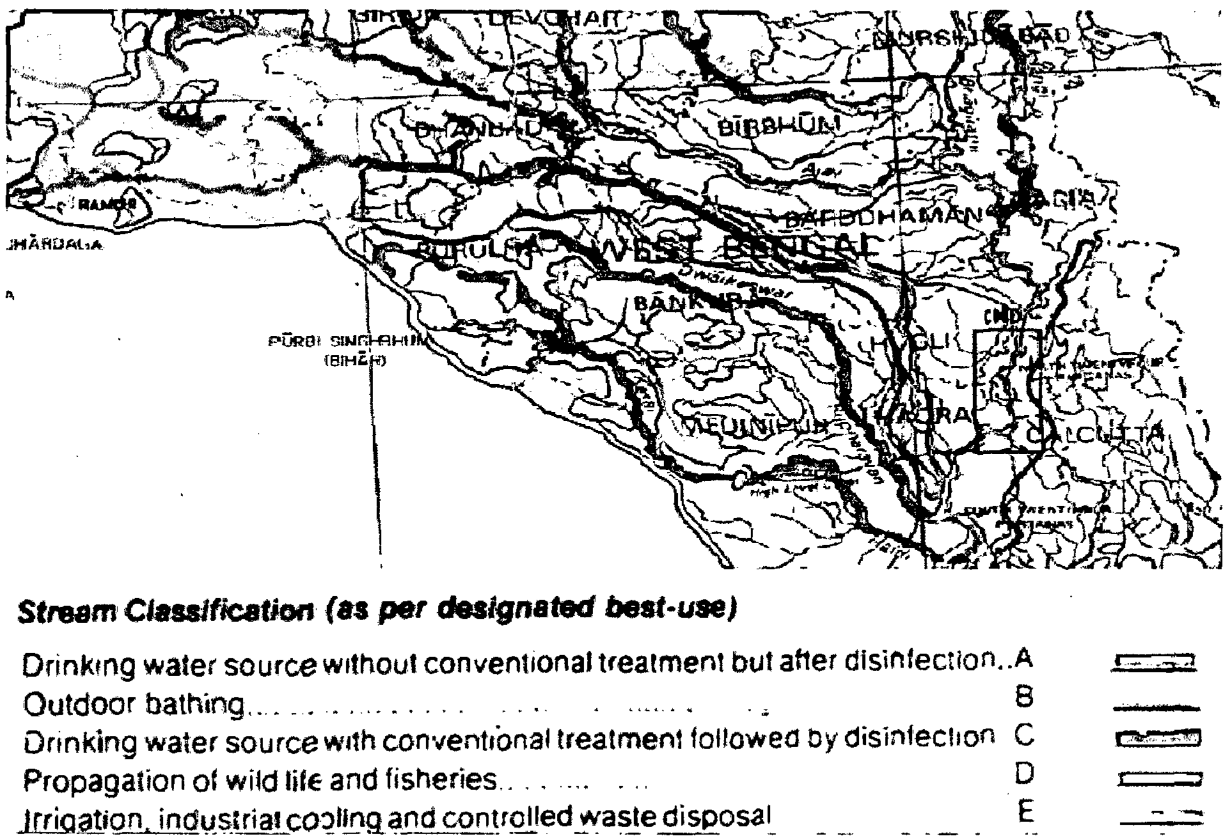


Figure 5.3: Water quality map of whole Damodar river in 1994

5.4.2 Present Study

In the present study, a similar map has been prepared but colour code used are as per NSF WQI. Therefore, different appearance of WQ map has been found which shows that WQ of Damodar river is maintained above the Class 'A' from the d/s of Panchet dam to common confluence point of South drains III and IV. After Singaran nullah discharge, WQ deteriorate a little bit and falls to Class 'B' upto the u/s of barrage water due to the addition of industrial effluents into the river without proper treatment. The river stretch again gained its quality near the barrage due to reservoir formation. About 32 km u/s and

2.5 km d/s of the stretch fall under 'A' class and in between 33.5 km stretch falls under 'C' class category. It is also observed that the overall WQ of river is really improved over the decades. Figure 5.4 shows the water quality for the present study.

5.5 PERMISSIBLE LIMITS FOR INDIVIDUAL WQ PARAMETERS

5.5.1 For Damodar River

As per CPCB's classification of inland surface water, it can be seen that the river water quality is very good with respect to DO, pH, TDS, conductivity, nitrate, sulphate and chloride. However, in term of BOD and coliform count, the river condition is poor and falls under or below class 'C' category. Individual WQ parameters of the river is compared with permissible limits set by the CPCB standards and IS: 2296-1982 and the river is classified accordingly. That type of classification is shown in table 5.18.

5.5.2 For Industrial Effluent Discharges

Water quality of the industrial effluents is compared with IS: 2296-1982. It is found that some industries in Durgapur are discharging heavy alkaline wastewater directly to the Tamla nullah. The discharge of Durgapur Steel Plant's major drain is worst in WQ, because it is further polluted by the local labour slum. Status of industrial discharges is assessed after comparing the maximum permissible limits for individual WQ parameters as set by the IS: 2490-1974. This is shown in table 5.19. The maximum permissible limit of industrial effluents discharged into inland surface waters is given in Appendix III.

5.5.3 Permissible Limits for River as a Drinking Water Source and Irrigation

River Barakar is the main source of drinking water in Kulti and Asansol town and River Damodar is tapped at various points for drinking water supply purpose for the entire stretch. Durgapur barrage is the main source of irrigation and drinking in the large area of Burdwan and Bankura districts. As the coliform count is quite high in the entire river stretch, conventional treatment and disinfection is necessary. Limit for phenolic compound is excessive at few points and these should be avoided for drinking water source. Other parameters conform to the permissible limits as per Indian standards (IS: 10500-1991). Further, since the conductivity is much below the CPCB's permissible limits, river water may be suitable for irrigation purposes.

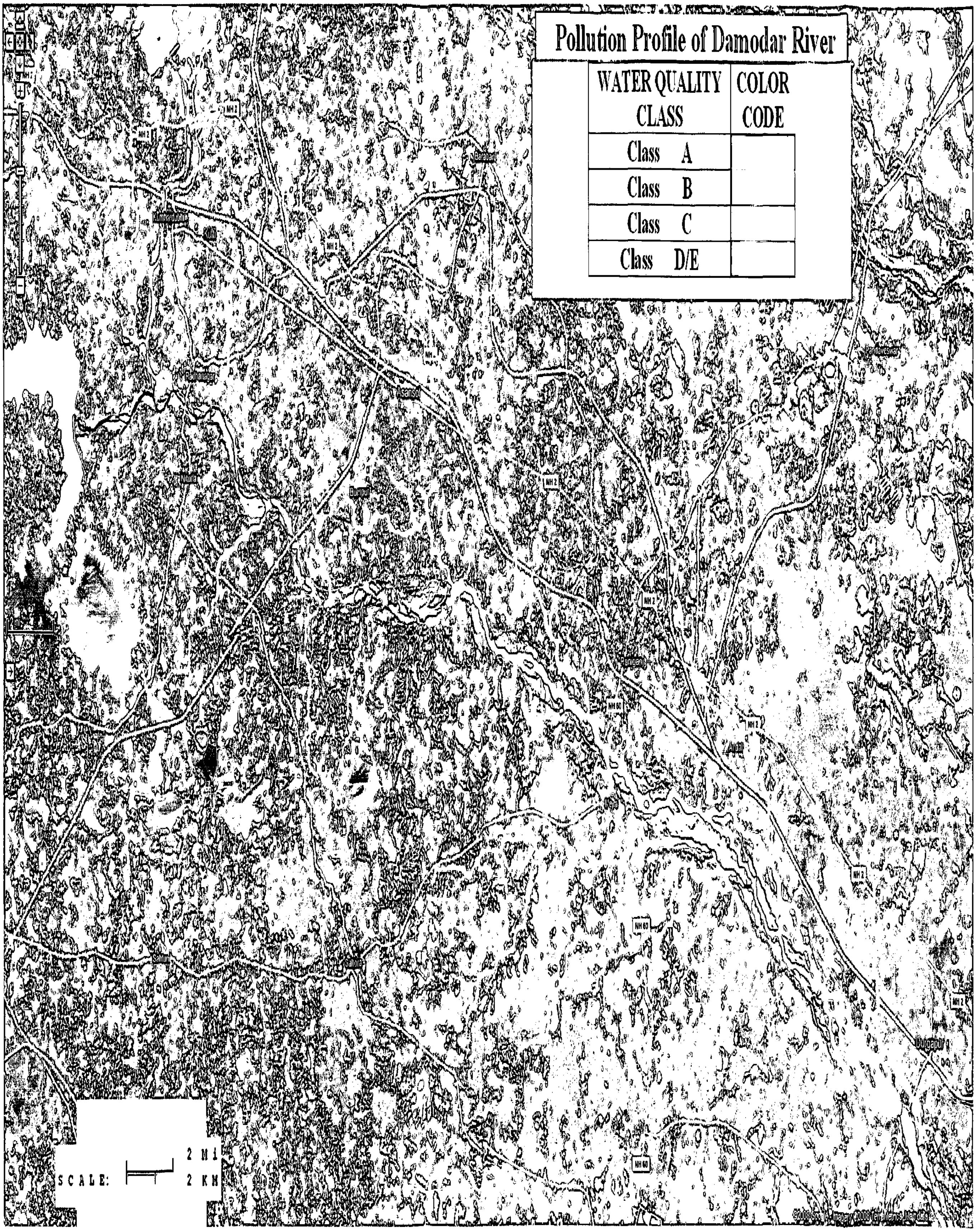


Figure 5.4: Water quality map of Damodar river stretch in 2008

Table 5.18: Classification of Damodar river for individual WQ parameters

ID	DO	Class	BOD	Class	TDS	Class	Chloride	Class	TC	Class	pH	Class	EC	Class	Free NH_3 as N	Class	Sulfate	Class	Nitrate	Class
	mg/L	A,B, C,D	mg/L	A,B, C	mg/L	A,C, E	mg/L	A,C, E	MPN/ 100ml	A,B, C		All	µ-mho /cm	D & E	mg/L	D	mg/L	A,C, E	mg/L	A&D
R1	8.5	A	2.6	B	180	A	18	A	1150	C	7.5	A	300	OK	0	OK	51.2	A	18	A
R2	8.8	A	2	A	120	A	12	A	5300	< C	8.2	A	200	OK	0.2	OK	38.2	A	BDL	A
R3	8.8	A	2	A	121	A	13	A	5350	< C	8.2	A	300	OK	0.8	OK	ND	-	BDL	A
R4	8.7	A	2.2	B	128	A	15	A	5610	< C	8.2	A	500	OK	1.2	OK	ND	-	0.3	A
R5	8.6	A	5.5	< C	135	A	16	A	8190	< C	8.1	A	300	OK	0.2	OK	ND	-	2.5	A
R6	8.4	A	3	B	120	A	16	A	11000	< C	8.0	A	200	OK	0.5	OK	35.8	A	18	A
R7	8.8	A	20	< C	120	A	22	A	9600	< C	8.1	A	200	OK	0	OK	ND	-	18	A
R8	8.6	A	5	< C	130	A	24	A	9370	< C	8.1	A	300	OK	0	OK	ND	-	18	A
R9	8.8	A	5	C	120	A	22	A	27500	< C	8.5	C	200	OK	0	OK	ND	-	20	A
R10	7.9	A	4	< C	180	A	22	A	28900	< C	8.1	A	300	OK	0.5	OK	ND	-	20	A
R11	8.6	A	2	A	120	A	16	A	580	C	8.3	A	200	OK	2	X	42.6	A	36	D

Table 5.19: Status of industrial discharges as per IS: 2490-1974

ID	pH	Remark	TSS (mg/L)	Remark	TDS (mg/L)	Remark	BOD (mg/L)	Remark	COD (mg/L)	Remark	Phenol (mg/L)	Remark	Cyanide (mg/L)	Remark	O&G (mg/L)	Remark
I1	9.6	X	ND	-	ND	OK	ND	-	ND	-	0.011	OK	BDL	OK	0.01	OK
I2	9.5	X	3405	X	360	OK	15	OK	108	OK	0.001	OK	BDL	OK	ND	-
I3	7.8	OK	37	OK	900	OK	22	OK	90	OK	0.048	OK	BDL	OK	ND	-
I4	8.9	OK	23	OK	1020	X	105	X	512	X	0.001	OK	0.04	OK	35	X
I5	7.8	OK	9	OK	780	OK	3	OK	20	OK	ND	-	BDL	OK	ND	-

ND=Not Done, BDL=Below Detection Limit, X=Exceeding the permissible limits

5.6 TREND ANALYSIS

The water quality trends from 2003 to 2008 with respect to DO, BOD, feacal coliform and pH are shown in figure 5.5 while the overall WQI trend is shown in figure 5.6. It is clear from these figures that there is an increasing trend of BOD, though it is below 3 mg/l. Increasing trend of DO and decreasing trend of coliform indicates that there is a gradual improvement in water quality with respect to organic pollution.

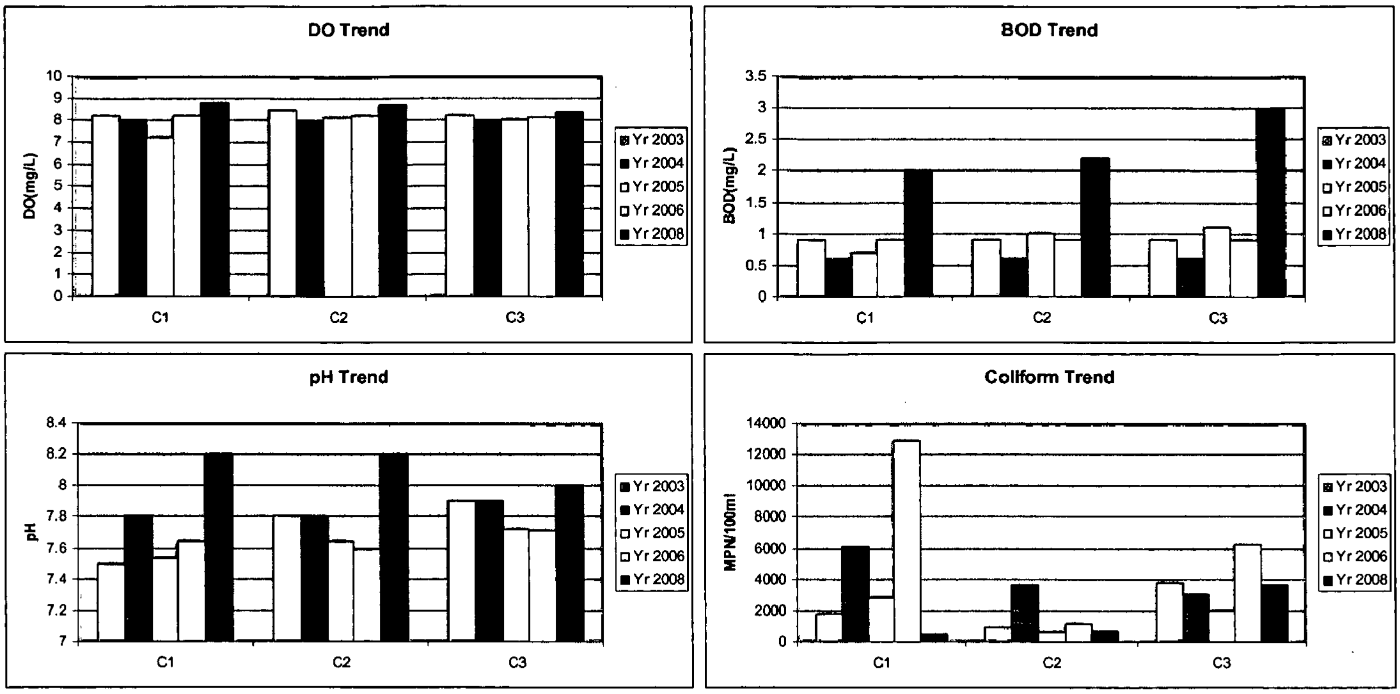


Figure 5.5: Trend of individual WQ parameters

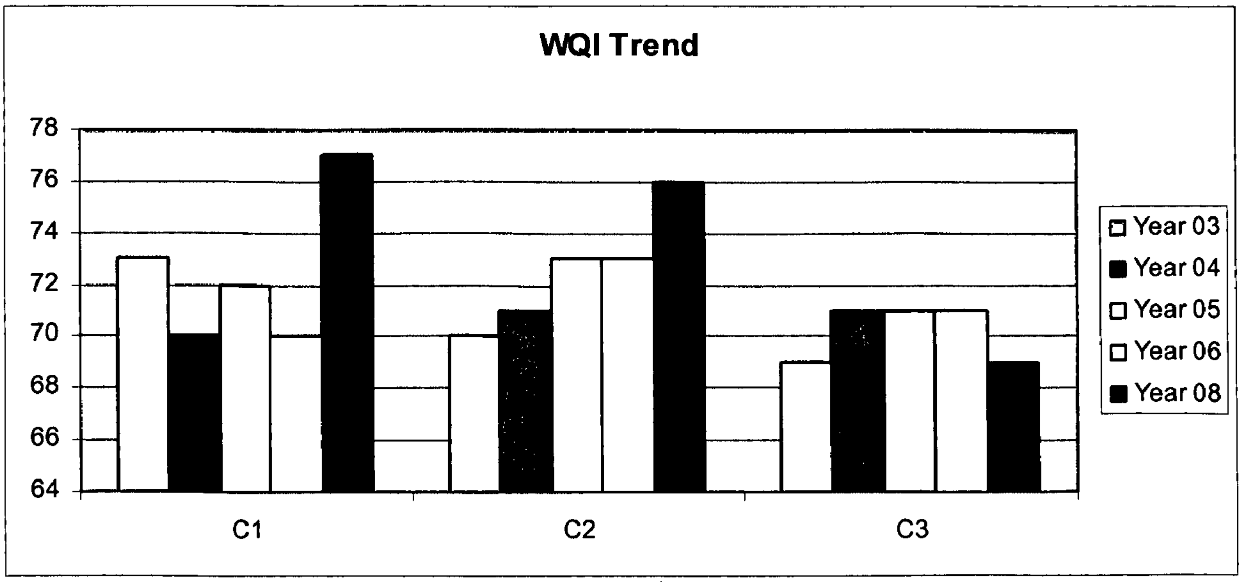


Figure 5.6: WQI trend

5.7 DISCUSSIONS

5.7.1 General Discussions

As pH value of the entire stretch lies above seven, the river water is alkaline in nature. With regard to total hardness, the water is soft to moderately hard. BOD and COD values increase after south drain - IV confluence indicating to poor water quality. Coliform counts are considerably higher in the entire stretch. BOD coupled with coliform indicates heavy sewage discharge as one of the main stress of pollution.

Severe polluted Tamla nullah meets the Damodar river after the Durgapur barrage with approximately four cumec discharge in lean season. To maintain the healthy WQ through self-purification of the river, d/s discharge of the barrage should be around 40 cumec. But the average discharge of the river is found around 50 cumec. To maintain u/s reservoir full condition, it is difficult to meet the required discharge at d/s of the barrage. Therefore, the river after Tamla nullah confluence remains polluted due to less flow and more pollution input.

5.7.2 Identification of Polluted Stretches

WQ map shows that in the upper part, drains from IISCO Burnpur and Chinakuri plants pollute the stretch. Because of low discharges, they have low impact on the river. In the lower stretch, entire Tejab nullah, middle portion of Nunia nullah and entire Tamla nullah is severely polluted which are responsible for the deterioration of the river quality from class 'A' to class 'B'. Asansol municipality and surrounding medium and small industries pollute the Tejab and Nunua nullah while Durgapur industrial area pollutes the Tamla nullah. So, proper treatment facilities are required in these cities for domestic and industrial effluents before discharging to those nullahs.

5.7.3 Existing Conservation Measures in the Study Area

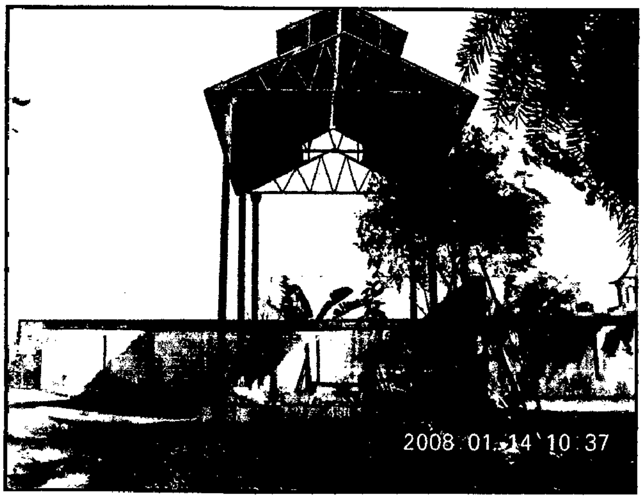
5.7.3.1 Sewage treatment plant (STP): Trickling filter-based treatment plants are observed in the industrial colonies but their capacities are small. In Durgapur, a bio-filter STP of 0.35 MGD capacity is found non-functioning (Plate 5.1). Industrial colonies have their own treatment facilities but these are old, inadequate in capacity and often non-functioning. Hence, raw disposal of sewage is an environmental threat in this area.

5.7.3.2 Industrial effluent treatment plant (ETP): Existing ETPs of the major industries are shown in Table 3.2 in Chapter 3. Their adequacy of treatment, method of functioning could not be assessed due to inaccessibility.

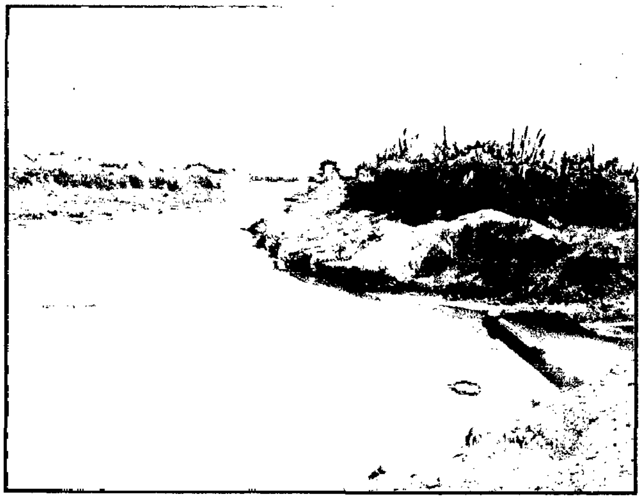
5.7.3.3 Crematoria: Though a few coal-based crematoria are found in the area (Plate 5.1), unorganized haphazard burning of the dead bodies on the riverbank is a common practice. Coal/wood based crematoria should be replaced with more number of improved electric crematoria.

5.7.3.4 Ash pond: The wastewater from power plant of DPL is treated in ash pond for sedimentation of pollutants. DTPS has six large ash ponds in series situated at the fallow land beside the Damodar river near Durgapur (Plate 5.1) and these are maintained periodically. No overflow was observed in the lean period.

Apart from that, around 10 nos. public toilets (*Sulabh Souchalaya*) and 500 nos. cattle sheds exist in this region (Data as per Asansol and Durgapur Municipal Corporation). Plantation programme is also initiated. Plate below shows the existing pollution abatement schemes in the study area.



Coal based crematoria



Ash pond of DTPS

STP of Durgapur Project Ltd.

STP at Durgapur industrial colony

Plate 5.1: Existing pollution abatement schemes

5.7.4 CPCB's Initiative to Pollution Abatement in Industries

CPCB regularly reviews the status of major industries under the delegation of the powers under Section 5 of the Environment (Protection) Act, 1986. Three industries in this stretch had been identified as defaulter due to not having adequate facilities to comply with standards and have been closed. Following table shows the status (As on December 31, 2001) of the pollution control program for industries.

Table 5.20: Status of pollution control program in the study stretch (CPCB 2008)

Sl	Industries identified for not having adequate facilities to comply with the standards		Industries closed as defaulter	
1	M/s Indian Iron and Steel Company, Burnpur	Iron and steel	M/s Hindusthan Fertilizer Corporation,	Fertilizer
2	M/s Durgapur Steel Plant, Durgapur	Iron and steel	M/s Everest Paper Mill, Burdwan	Paper and pulp
3	M/s Durgapur Thermal Power Station Durgapur,	Thermal power	M/s Bengal Paper Mill, Burdwan	Paper and pulp

5.8 CONSERVATION AND MANAGEMENT PLAN FOR THE STRETCH

From the above discussions, it is clear that existing pollution control measures are not very sound. STPs and ETPs are inadequate in capacity and often non functioning. The main pollutants in the stretch are faecal coliform and BOD that are coming into the river from a numerous drains and nullahs as well as in-stream use of river water. The lack of proper management of municipal solid wastes and mining wastes is also a problem. Therefore, proper conservation measures should be planned to tackle these sources of pollution. The plan for river conservation and environmental management in this stretch should consist following aspects:

5.8.1 Technical Aspects

5.8.1.1 Sewage treatment plants: Targeting to future population and wastewater generation in this industrial belt, two STPs of 100 MLD capacity should be installed one at Asansol and other at Durgapur. One additional STP of 60 MLD capacity may be constructed in between Kulti and Chinakuri towns. Pond system is an ideal solution for coliform reduction from wastewater and is techno economically viable as plenty of land is available in suburbs. Based on the field monitoring data, oxidation ponds with a detention time of 5 days is proposed in Durgapur and Asansol suburbs as BOD > 30 mg/L and TSS > 50 mg/L. Treatment through settling pond with detention time of 8 hrs and a maximum depth of 3m may be provided near Chinakuri town as coliform counts are very high. Land requirement for these ponds systems may be taken as 2.5 acres per MLD capacity (Pande *et al* 2000). Otherwise, no treatment is required.

Modern and efficient sewage treatment technologies that are efficient in coliform reduction viz. Fluidized Aerobic Bed (FAB), Cyclic Activated Sludge Technology (C-TECH) or Membrane Bioreactor (MBR) system may be adopted replacing the conventional systems if their O&M cost is afforded. Locations of the proposed STPs are shown in figure 5.7 and 5.8.

5.8.1.2 Industrial effluent treatment plants: Big industries should have sound ETPs with proper waste disposal system. Medium and small-scaled industries must use common effluent treatment plants (CETP). No direct discharge is allowed either to nullahs or to river. For air pollution control, electrostatic precipitators (ESP) should be installed or upgraded in each and every facroty. Stack hight and smoke emission should conform to the standard norms.

5.8.1.3 Solid waste management: The average quantity of solid waste generated is about 0.45 kg per capita per day (NEERI 1994). Heaps of solid waste is dumped at many places beside the highways and the periodic burning is a common practice. This should be prevented by taking proper solid waste management programme. Adequate number of vats/bins should be provided in each town for segregation of biodegradable and non-biodegradable waste. The biodegradable waste can be subjected to composting through vermiculture, may be converted through bio-methanation/ incineration for the production of biogas/boiler operation that can be finally converted into electricity.

5.8.1.4 Low cost sanitation: Effective sanitation facilities are lacking in the towns and open defecation is a common practice. In order to contain the pollution from these non-point sources, low cost and decentralized sanitation systems are proposed for coalieries and densely slum areas (e.g. *Munda basti* in Durgapur).

5.8.1.5 Bathing *ghats:* Unorganized bathing is another problem in this area. A few bathing *ghats* are found in Durgapur region but there should be at least two *ghats* in each town. *Mela* locations must be provided with bathing *ghats* for atleast 50 m of length.

5.8.1.6 Conservation buffers: Conservation buffers are small areas or strips of land in permanent vegetation, designed to slow water runoff, provide shelter and stabilize riparian areas. Strategically placed buffer strips in the agricultural field can effectively mitigate the movement of sediment, nutrients and pesticides. Buffers may include contour bunds, filter strips, grassed waterways, shelterbelts/windbreaks and wetlands. Development of river fronts may also be included in this category.

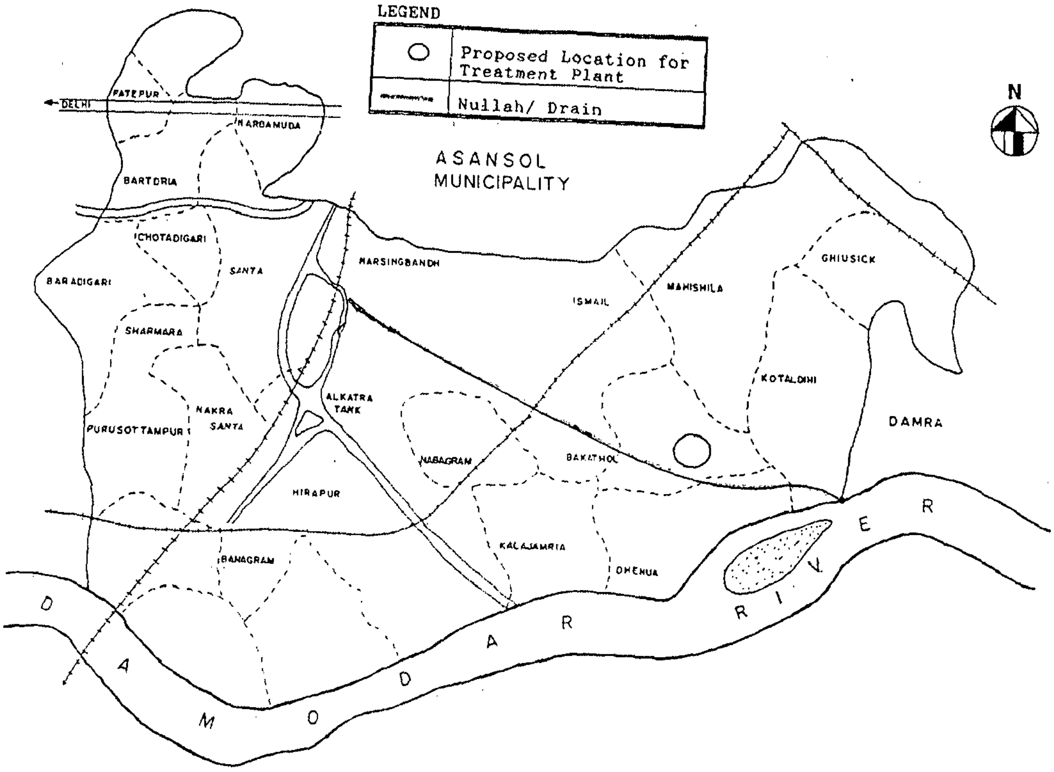


Figure 5.7: Location of proposed STP in Asansol

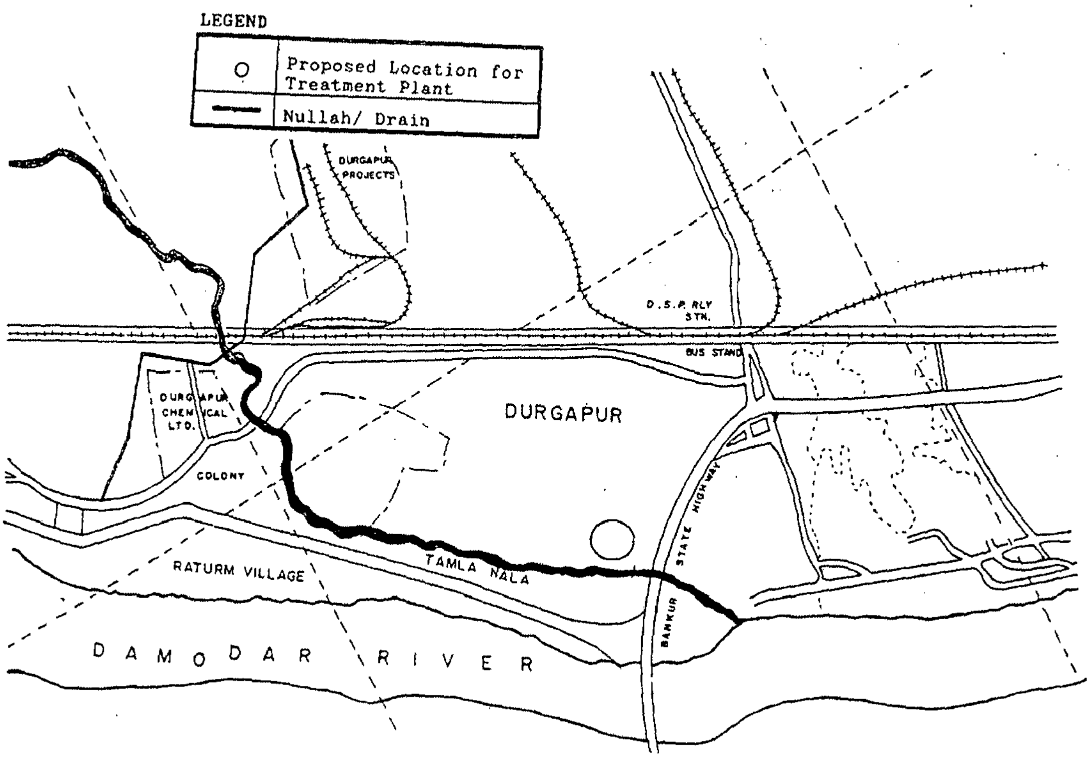


Figure 5.8: Location of proposed STP in Durgapur

5.8.2 Non-technical Aspects

5.8.2.1 Afforestation: Forest cover of the area is only 20.19 % but as per forest policy, it should be 33 % (MoEF 2008). Plantation is proposed for the towns covering at least 10 to 20 acres for controlling soil erosion especially in the mining areas. It is also proposed to make green belt of tall trees surrounding every industry.

5.8.2.2 Public participation and awareness program: To create awareness in the mass, water quality problems through public media (e.g. radio, television, posters, hoardings, public meetings etc.) should be regularly highlighted. This must be done in Bengali and Hindi languages.

5.8.2.3 Enforcement of laws and acts: Water (Prevention and Control of Pollution) Act, 1974 and other relevant rules and acts like Air (Prevention and Control of Pollution) Act, 1981, Environmental (Protection) Act, 1986, Hazardous Wastes (Management and Handling) Rules, 1989, Municipal Solid Wastes (Management and Handling) Rules, 2000 etc. should be applied more stringently.

5.8.3 New Dimensions to WQ Management

5.8.3.1 Application of Geographic Information System: The use of geospatial tools, like GIS and GPS with digital databases, could help to manage water resources effectively through reliable characterization of Damodar river system. GIS can be used to modeling of WQ parameters and their impacts over a large area with a minimam amount of time and effort. Carrying capacity based study of Damodar river basin could easily be done with the help of GIS.

5.8.3.2 Nutrient management: Anthropogenic activities have changed the balance of nitrogen and phosphate on the planet. Burning of coal for energy, disposal of organic wastes, use of fertilizer in agricultural field have an effect on the N and P cycles. Positive consequences include improved crop yields, while negative consequences include water resource deterioration. All consequences need to be considered when attempting to manage N and P.

5.8.3.3 Carbon trading: It is an administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. The Government should set a limit on the amount of a pollutant that can be emitted. Industries are to be issued emission permits and are required to hold an equivalent number of allowances called *credits*, which represent the right to emit a specific amount of pollutants. The total amount of credits should not exceed that limit. Companies that need to increase their emissions must buy credits from those who pollute less. The transfer of allowances is referred to as a trade. In effect, the buyer is paying a charge for polluting, while the seller is being rewarded for having reduced emissions. Thus, it will be easy to reduce pollution at the lowest possible cost to the society.

Carbon trading is a better approach than a direct production tax or direct regulation system. Companies most of the effort will be spent on environmental activities and the investment will be directed at sustainable projects that can earn credits. This is an active trading program for greenhouse gas reduction in the European Union and United States and it may be implemented in India in similar fashion for reduction of overall pollution in industrial belts like our study stretch.

5.8.3.4 Air pollution control for WQ management: Emission of oxides from thermal power plants, factories, automobiles and other sources reach the river through a number of pathways and affect the water quality. So air pollution control is equally important as water problems. As the environmental processes are linked with different environmental media i.e. land, water, and air; a multimedia perspective rules and regulations should be developed in a holistic framework for water quality management.

5.8.3.5 Environmental Impact Assessment (EIA): EIA is mandatory for those water resource developmental projects that potentially impairing the water quality and aquatic ecosystems of the river. New industrial installations, solid waste landfills and infrastructure development projects should comply with strengthened control systems against pollution and delineation of appropriate remedial measures.

Finally, these will be followed by continuous monitoring of the quality of river water to study the output of the conservation measures.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The Damodar river water in the stretch selected for study is alkaline in nature and soft to moderately hard with respect to hardness. Based on the results of water quality assessment of the river stretch in terms of water quality index, it is concluded that the water quality of the river is "good" and this fact has been reflected by the selected index system. As the river has sufficient discharge during lean period with respect to the waste drains/nullahs, its overall water quality is quite good. River water is safe as a drinking water source prior to conventional treatment and disinfection, as well as for irrigation, industrial cooling and propagation of wild life and fisheries.

Coliform is the most critical parameter in the stretch. High coliform counts coupled with BOD indicate heavy sewage discharge as one of the main causes of organic pollution. The whole stretch of the river and its tributaries, nullahs, has been affected by anthropogenic activities, especially, by the direct discharge of sewage. The river bed sediment may also be affected by inorganic, toxic metals and chemicals by the heavy industrial and mining discharges. But sediment profile study was out of scope.

Modified NSF WQI, used in this thesis, gives a little conservative value than the original one so it is better to work with all the parameters. The indexing system shows the river is of good quality though the coliform levels are quite high. Hence, there should be higher weightage value for coliform sub-index.

The Damodar Action Plan, an end-of-the-pipe pollution treatment scheme, seeks to tackle municipal effluents while industries are more prone to continue pollution in the region. The targeted capacity for the sewage treatment is very low compared to actual sewage generation.

6.2 LIMITATIONS

There are some limitations in the present study, which can not be overcome due to time constraint. For detailed WQ assessment of any river, it is necessary to analyze pre-monsoon, monsoon and post-monsoon sampling data. Though lean period data i.e. winter season data provides critical values, the present work is unable to foresee the true profile of the river as it requires more time and cost compared to the time frame available for the thesis work.

Only grab samples could be collected which may not represent average conditions. The time lag in between the sample collected and analyzed in laboratory for distant sampling points may produce some erroneous results. Another drawback is that efficiency of the existing treatment facilities for the sewage and industrial effluents could not be assessed due to inaccessibility of the plant sites.

6.3 RECOMMENDATIONS FOR POLLUTION ABATEMENT

1. Damodar Action Plan must be initiated to conserve the life line of the region i.e. Damodar River. Environmental Master Plan of major and minor towns of the basin should be prepared. Implementation of the conservation plans in major cities like Asansol and Durgapur should be given high priority.
2. Additional ash ponds should be constructed to control fly ash generated by the thermal power plants. Attempt should be made to dispose off fly ash for backfilling underground mines and manufacturing of fly ash based bricks and cement.
3. Coalfields are generating huge amount of overburden dump, thereby damaging the landscape as well as creating environment pollution. Land reclamation followed by afforestation should be done on a large scale.
4. Coal and wood burning in domestic sector must be supplemented by liquefied petroleum gas (LPG) and improved ovens, both in mining and tribal areas.
5. Tribal should be provided with alternative source of livelihood apart from collection of forest wood and unauthorized coal mining.
6. Desiltation of Maithon, Panchet and Durgapur barrage reservoirs need to be taken in order to increase the reservoir capacity. Minimum flow of water should be maintained from these dams and barrage to increase assimilative capacity of the river, especially, during the lean period.
7. Environmental awareness programme should be conducted in rural areas for the protection of forest, consuming good quality of drinking water and health and primary hygiene.
8. The working status of effluent treatment plant (ETP) of large industries like IISCO of Burnpur, ASP, DSP, DPL, and DCL of Durgapur need to be regularly monitored. Augmentation and/or modification of the existing system are necessary to make it foolproof.
9. Industries like coal washeries and coke oven plants should have combined effluent treatment plant (CETP).

10. For medium size and large-size industries, it should be made mandatory to obtain ISO: 14000 certification because these environmental management standards exist to help organizations to minimize their operations that negatively affect the environmental.

11. The industrial solid waste generated by steel plants should be properly disposed off for protecting the ground water from being contaminated.

12. Minimize adverse effects from nitrogenous fertilizers and other agro-chemicals (pesticides, herbicides etc) in agricultural practices through their rational and planned use.

13. Development of bio-sinks for pollutant assimilation like green belt around the industries especially in most polluted zones at Durgapur regions may be done.

6.4 FUTURE SCOPE OF WORK

The study can be continued in many dimensions. The assessment of heavy metals and toxic elements in water as well as in river bed sediments should be studied properly with suitable instrumental facilities. The measurement of pesticide, surfactant and persistent organic pollutants (POP) may also be studied. Their impact on phyto and zooplankton of the river water and the bio-monitoring of invertebrate and micro invertebrates may be studied and consequently bio-mapping of the stretch could be done.

The impact of pollution on the surrounding inundated agricultural land during and after the flood season, on the ground water in the neighboring area could be assessed and water quality modeling with respect to critical parameters could be formulated for Damodar river pollution.

Lastly, it is clear that something needs to be done in order to restore the water quality of the Damodar river towards a pristine state. As water is our most precious natural resource, we must conserve its totality in a sustainable way. According to word of Mikhail Gorbachev, President of Green Cross International, "We must treat water as if it were the most precious thing in the world, the most valuable natural resource. Be economical with water! Don't waste it! We still have time to do something about this problem before it is too late."

Abbasi S.A., *Water Quality Indices State – of – the – art*, Centre for Pollution Control & Energy Technology, Pondicherry University, Pondicherry, 2002.

American Public Health Association (APHA), *Standard methods for the examination of water and wastewater,* 20th Edition, Washington.1998.

Bansil, P.C., *Water Management in India*, Concept Publishing Company, New Delhi, 2004.

Bhardwaj R.M., "Status of Wastewater Generation and Treatment in India" *International Work Session on Water Statistics*, Vienna, June 20-22, 2005.

Bhargava, D.S., "Expression for Drinking Water Supply Standards", American Society of Civil Engineers (ASCE), Vol 111, No. 3, 304-317, 1985.

Bordalo A. A., Teixeira R. and Wiebe W. J., "A Water Quality Index Applied to an International Shared River Basin: The Case of the Douro River", *Environmental Management*, Springer, Netherlands Vol 38, 910–920, 2006.

Brown, Robert M., Nina I. McClelland, Rolf A, Deininger and Ronald G.T., "A Water Quality Index – Do we Dare?", *Water Sewage Works*, 339-349, October 1970.

Central Pollution Control Board (CPCB) and Survey of India (SI), *Water Quality Atlas of India*, New Delhi, June 1994.

Central Pollution Control Board (CPCB), *Environmental Atlas of India*, New Delhi, June 2001.

Central Pollution Control Board (CPCB), *Water Quality in India – status and trends (1990-2001),* New Delhi, March, 2003.

Chapman, Deborah, *Water quality Assessment: A guide to the use of biota, sediment & water in environmental monitoring,* E&F N Spon Publisher, Madras, 1996.

De A.K., Sen A.K. and Modak D.P.,"Some industrial effluents in Durgapur and their impact on the Damodar river", *Environment International*, USA, Vol. 4, 1980.

De A.K., Sen A.K. and Md. Karim R.,"Pollution profile of Damodar river sediment in Raniganj – Durgapur industrial belt, West Bengal.", *Environment International*, USA, Vol. 11, 1985.

De A.K.,"Growth of water pollution in Asansol -Durgapur industrial belt and its impact on the water quality of the Damodar River"; *Environmental Research*, MoEF, India, 1993.

Garg S.K., *Water Supply Engineering*, Khanna Publishers, Delhi, 1999.

Gronewold A.D. and Wolpert R.L,"Modeling the Relationship Between Most Probable Number (MPN) and Colony-Forming Unit (CFU) Estimates of Fecal Coliform Concentration", Duke University, Durham, USA, February 2008.

Gupta R.K. and Singh G.,"Damodar River Pollution Due to Coal Washeries", *Pollution and Biomonitoring of Indian Rivers*, ABD Publishers, Jaipur, 2000.

Gupta V.K. and Singh G.,"Damodar River Water Quality Status along Dugda – Sindri Industrial Belt of Jharia Coalfield", *Pollution and Biomonitoring of Indian Rivers*, ABD Publishers, Jaipur, 2000.

Jha R, Ojha, C. S. P. and Bhatia K. K. S., "Development of Refined BOD and DO Models for Highly Polluted Kali River in India", *Journal of Environmental Engineering*, ASCE, August, 2007.

Kumar V, "Water pollution of Yamuna", *Nistads News*, Vol.4, No.2, October 2002.

Indian Standard 2296:1974, *Tolerance Limits for Inland Surface Waters Subject to Pollution*, Bureau of Indian Standard, New Delhi, 1974.

Indian Standard 10500: 1991, *Indian Standard Drinking Water Specification*, Bureau of Indian Standard, New Delhi, 1993.

Indian Standard: 2488 (Part I to V) – 1966, *Indian Standard Methods of Sampling and Test for Industrial Effluents*, Bureau of Indian Standard, New Delhi, 1999.

Indian Standard 3025 (Part 1): 1987, *Indian Standard Method of Sampling and Test (Physical and Chemical) for Water and Wastewater,* Bureau of Indian Standard, New Delhi, 2005.

Johnson R., Redding K. and Holmquist D.,*"Water Quality with Calculators",* Vernier Software & Technology, 2007.

National Environmental Engineering Research Institute (NEERI), *A laboratory manual,* Nagpur, 1986.

National Environmental Engineering Research Institute (NEERI), *Feasibility Report on Pollution Abatement of Damodar River*, Nagpur, Vol 1 & 2, December, 1994.

Ott W. R., *Environmental Indices – Theory and Practice*, ANN Arbor Science Publishers Inc, USA, 1978.

Pande S.P., Kelkar P.S. and Hasan M.Z., "Pollution Abetment Schemes for River Damodar at Ramgarh Town – a case study", *Environmental Pollution Control Journal,* Vol. 4, No. 1, Nov.-Dec. 2000.

Paria T. and Konar S.K., "Ecological Degradation of some rivers in West Bengal", *River Pollution in India and its Management*, APH Publishing Corporation, N Delhi, 2003.

Paul. A.C. and Pillai K.C.,"Pollution Profile of a River", *Journal of Water, Air, & Soil Pollution*, Vol 10, No 2, Springer, Netherlands, 1978.

Planning Commission (PC), Govt. of India, "Report of the Working Group on Rivers, Lakes and Aquifers in Environment & Forests for the Eleventh Five Year Plan (2007-2012)". New Delhi, April, 2007.

Sahu B.K., Rao R.J., Behera S.K. and Pandit R.K.,"Effect of pollutants on the dissolved oxygen concentration of the river Ganga at Kanpur", *Pollution and Biomonitoring of Indian Rivers*, ABD Publishers, Jaipur, 2000.

Sargoankat A. and Deshpande V.,"Development of an overall index of pollution for surface water based on a general classification scheme in Indian context", *Journal of Environmental Monitoring and Assessment*, Vol 83, Netherlands, 2003.

Singh G. and Gupta V.K, "A Pollution profile of Damodar river", *Pollution and Biomonitoring of Indian Rivers*, ABD Publishers, Jaipur,2000.

Singh A.K., Mondal G.C., Singh P.K., Singh S., Singh T.B., and Tewary B.K., "Hydrochemistry of reservoirs of Damodar River basin, India: weathering processes and water quality assessment", *Journal of Environmental Geology*, Vol 48, 1014–1028, 2005.

Singh A.K., Hasnain S. I., "Environmental geochemistry of Damodar River basin, east coast of India", *Journal of Environmental Geology*, Vol 37, No. 1-2, January,1999.

Singh A.K., Hasnain S.I. and Banerjee D.K. "Grain size and geochemical partitioning of heavy metals in sediments of the Damodar River – a tributary of the lower Ganga, India", *Journal of Environmental Geology*, Vol 39, No. 1, November, 1999.

Sinha A.K., Singh V.P. and Srivastava K.,"Physico-chemical studies on River Ganga and its tributaries in Uttar Pradesh – the present status", *Pollution and Biomonitoring of Indian Rivers*, ABD Publishers, Jaipur, 2000.

Sharma K. D., "Studies on the Water Pollution of Yamuna River and Its Influence on Drinking Water Supply of Agra City", *Environmental Research*, MoEF, 1993.

Subramanya K., *Engineering Hydrology*, 2nd Edition, Tata McGraw-Hill Publishing Co. Ltd, New Delhi, 2006.

Tiwary R.K. and Dhar B.B.,"Environmental Pollution from Coal Mining Activities in Damodar River Basin, India", *Journal of Mine Water and the Environment*, Vol 13, Jun-Dec, 1994.

Important web address

Bankura, West Bengal - the official website, visited in April 2008.
URL:http://bankura.gov.in

Bardhaman District, West Bengal, India, the official website, visited in April 2008.
URL: http://bardhaman.gov.in

Census of India 2001, visited in April 2008.
URL: http://www.censusindia.net

CPCB, Implementation Status of Pollution Control Programme in the 17 Categories of industries (As on December 31, 2001), visited on April 2008.
URL: http://www.cpcb.nic.in/oldwebsite/wbcat.htm

Central Pollution Control Board (CPCB), Highlights (Assessment of Pollution / Case Studies), 2005.
URL: http://www.cpcb.nic.in/oldwebsite/Highlights05/ch-6.htm

CPCB, water data 2003.
URL: http://www.cpcb.nic.in/Water/GANGA.html

CPCB, water data 2004.
URL: http://www.cpcb.nic.in/Water/Ganga-2004.html

CPCB, water data 2005.
URL: http://www.cpcb.nic.in/Water/Ganga-2005.html

CPCB, water data 2006.
URL: http://www.cpcb.nic.in/Water/NWMP%20 WEBSITE06.HTML

CPCB, water, Global Environmental Monitoring Stations/ Monitoring of Indian National Aquatic Resource, visited on April 2008.
URL: http://www.cpcb.nic.in/Water/Water.html

CPCB, News letter, Archives, Coal reserves, visited on April 2008.

URL:http://www.cpcb.nic.in/News%20Letters/Archives/Clean%20Coal%20Initiatives/ch2-CLEANCOAL.html

Centre for Science and Environment (CSE) Damodar. Visited on April 2008.
URL: http://www.rainwaterharvesting.org/Crisis/Damodar.htm

Damodar Valley Corporation (DVC) - Other Activity - Environment Management & Pollution Control visited on April 2008.
URL: http://www.dvcindia.org/ communityenvironmentmanagement.htm

DVC, Infrastructure, visited on April 2008.
URL: http://www.dvcindia.org /dvcinfraustructure.htm

Environmental Information System (ENVIS), Centre of Environmental Problems of Mining, visited on April 2008.
URL: http://www.geocities.com/envis_ism/standard9.html

Ministry of Environment and forest (MoEF), Clean Technology Division, Damodar River Basin, visited on April 2008.
URL: http://envfor.nic.in/divisions/cltech/Damodar/1.1.htm

Ministry of Environment and Forest (MoEF), Annual Reports 1998-99, visited on April 2008.
URL: http://envfor.nic.in/nrcd/rdap.html

Press Information Bureau (PIB), Government of India, MoEF, Tuesday, August 07, 2007.
URL: http://www.pib.nic.in/release/rel_print_page1.asp?relid=29666

Purulia district's official website, visited on April 2008.
URL: http://purulia.gov.in

Singh L.B., Pandey P.N., Mahto B. and Singh R.K., *River Pollution*, A.P.H. Publishing Corporation, New Delhi, 2007.
URL: http://www.biblio.com/books/125349914.html

Tikoo V., "Water Supply – The Indian Scenario", Friends of the Earth [NOAH], Denmark, visited on April 2008.

URL: http://www.noah.dk/miljosk/vidya.pdf

United Nations Environment Programme (UNEP)-*Environmental knowledge for change*, visited on June 2008.
URL: http://maps.grida.no/go/graphic/freshwater_stress

Wilkes University (WU), 2008, *Calculating NSF Water Quality Index,* Center for Environmental Quality Environmental Engineering and Earth Sciences,
URL: http://www.water-research.net/watrqualindex/index.htm

Wikipedia, the free encyclopedia, Damodar River, visited on April 2008.
URL: http://en.wikipedia.org/wiki/World_population

Wikipedia, the free encyclopedia, World Population, visited on June 2008.
URL: http://en.wikipedia.org/wiki/Damodar_River

APPENDIX I

A) NATIONAL SANITATION FOUNDATION WATER QUALITY INDEX

In 1970, Brown, McClelland, Deininger and Tozer presented a water quality index structure supported by the National Sanitation Foundation (NSF), USA and the resulting index is known as NSF WQI. It is calculated after aggregating the sub-indices for nine parameters as weighted sum, using the following equation.

$$NSF\ WQI = \sum_{i=1}^{n} W_i I_i$$

Where Wi = Weights for nine parameters are listed below.

Ii = Sub index value of i^{th} parameter determined graphically.

Parameters and their weights for NSF WQI

Sl. No.	Parameters	*Weights (Wi)*
1.	Dissolved Oxygen	0.17
2.	Feacal coliform	0.15
3.	PH	0.12
4.	5 day BOD	0.10
5.	Nitrates	0.10
6.	Phosphates	0.10
7.	Temperature	0.10
8.	Turbidity	0.08
9.	Total solids	0.08

Finally a 100 point index divided into five ranges corresponding to the general descriptive terms gives the water quality of the water body.

Descriptor words and colors suggested for reporting NSF WQI

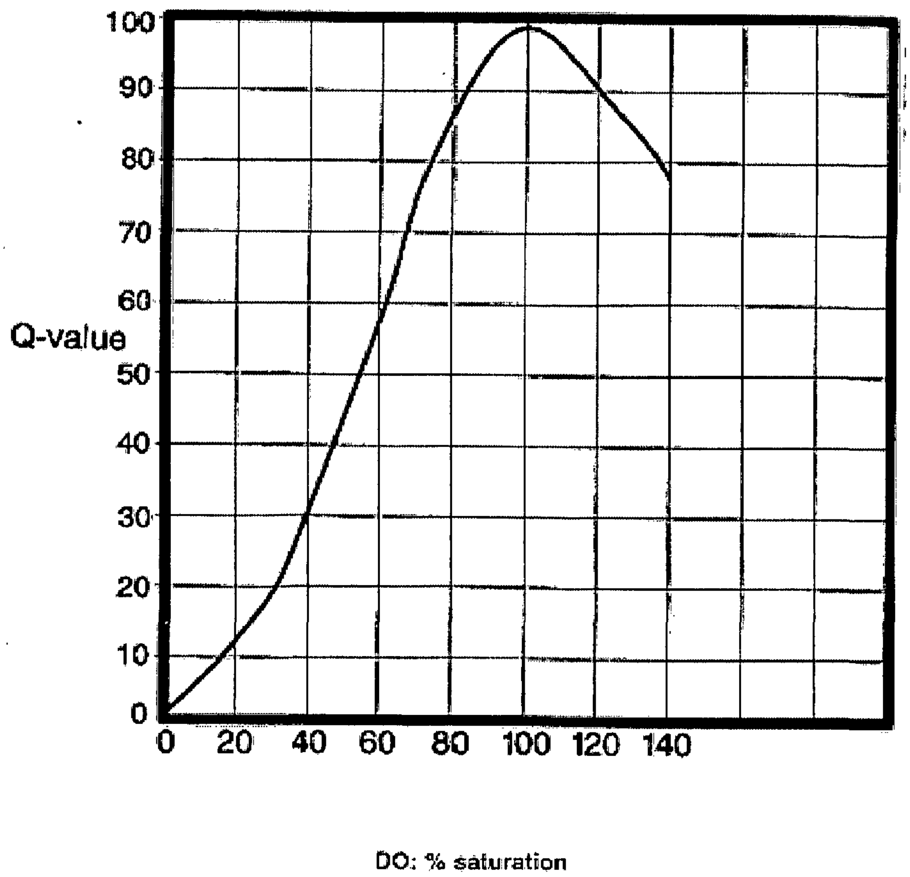
Descriptor words	Numerical range	Color
Very bad	0-25	Red
Bad	26-50	Orange
Medium	51-70	Yellow
Good	71-90	Green
Excellent	91-100	Blue

B) CALCULATION OF NSF WQI USING ONLINE SOFTWARE
[Ref: http://www.water-research.net/watrqualindex/index.htm]

Water quality index is a 100 point scale that summarizes results from nine different parameter measurements. According to the book *Field Manual for Water Quality Monitoring*, the National Sanitation Foundation surveyed 142 people representing a wide range of positions at the local, state, and national level about 35 water quality tests for possible inclusion in an index. Nine factors were chosen and some were judged more important than others, so a weighted mean is used to combine the values. The field measurements could be converted to sub indices (Q-values), respondents were asked by questionnaire to graph the level of water quality (0 through 100) corresponding to the field measurements. When test results from fewer than all nine measurements are available, relative weights for each factor were scaled to the total so that the range remains 0 to 100.

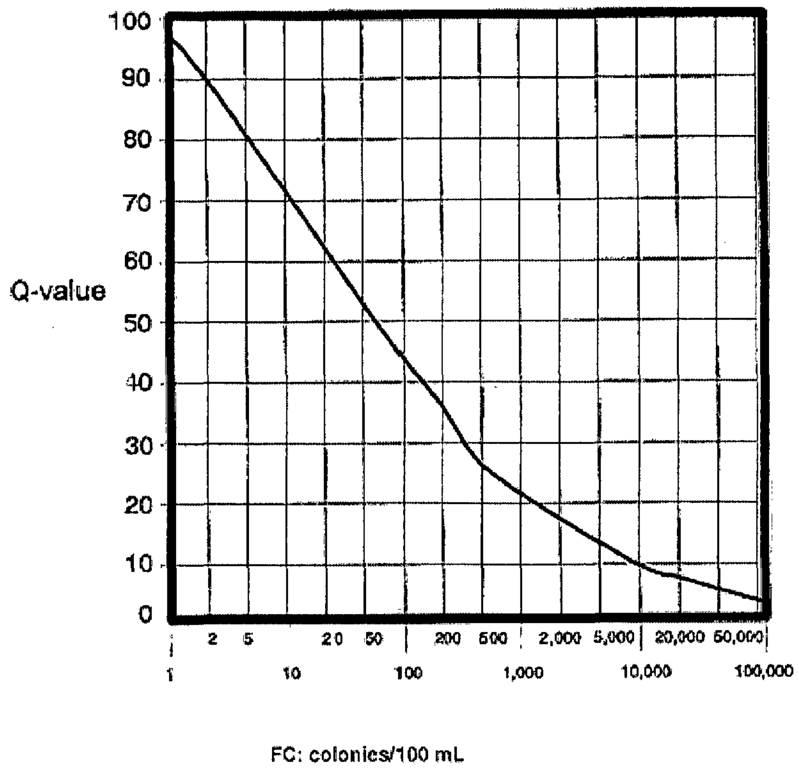
Charts corresponding to nine field measurements are given below for Q-value conversion.

1. Water Quality Sub Index: DO saturation (%)



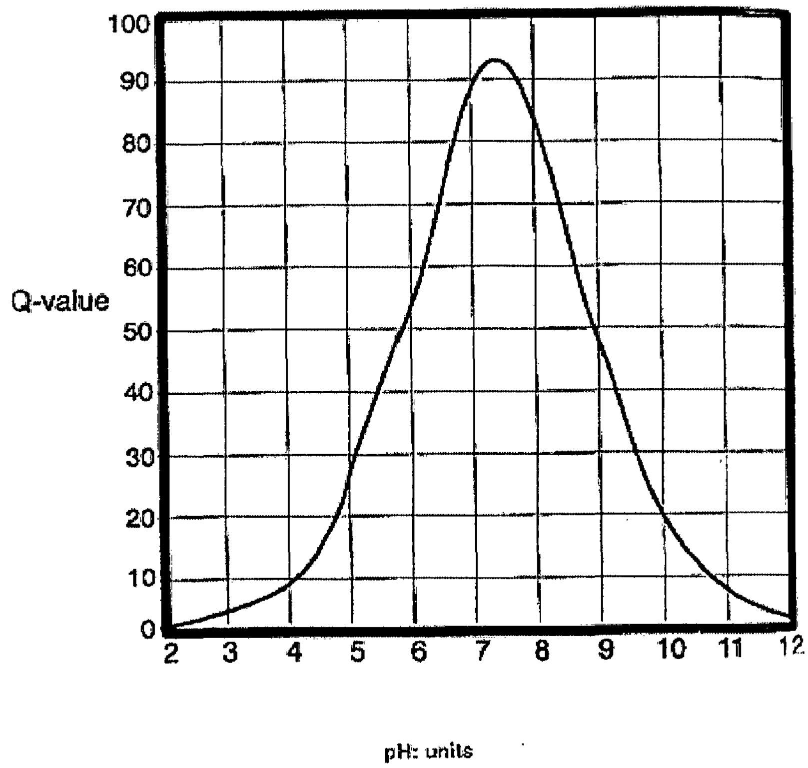
Note: If dissolved oxygen is greater than 140%, the quality index equals 50.

2. Water Quality Sub Index: Fecal Coli



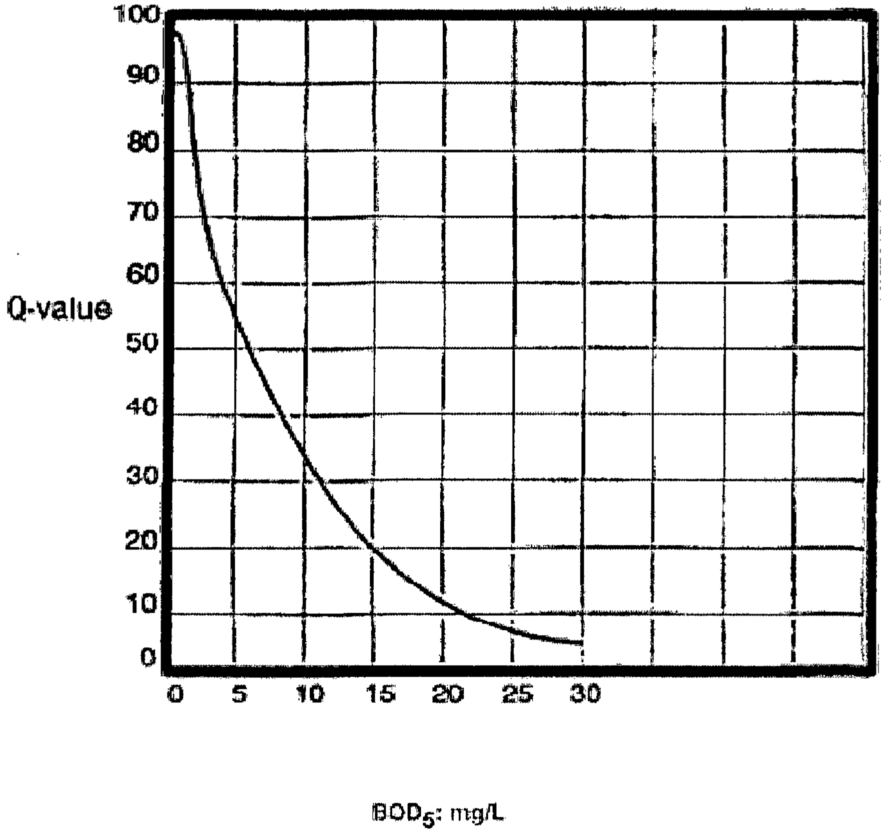
Note: If the number of fecal coliform colonies is greater than 100,000, the quality index equals 2.

3. Water Quality Sub Index: pH



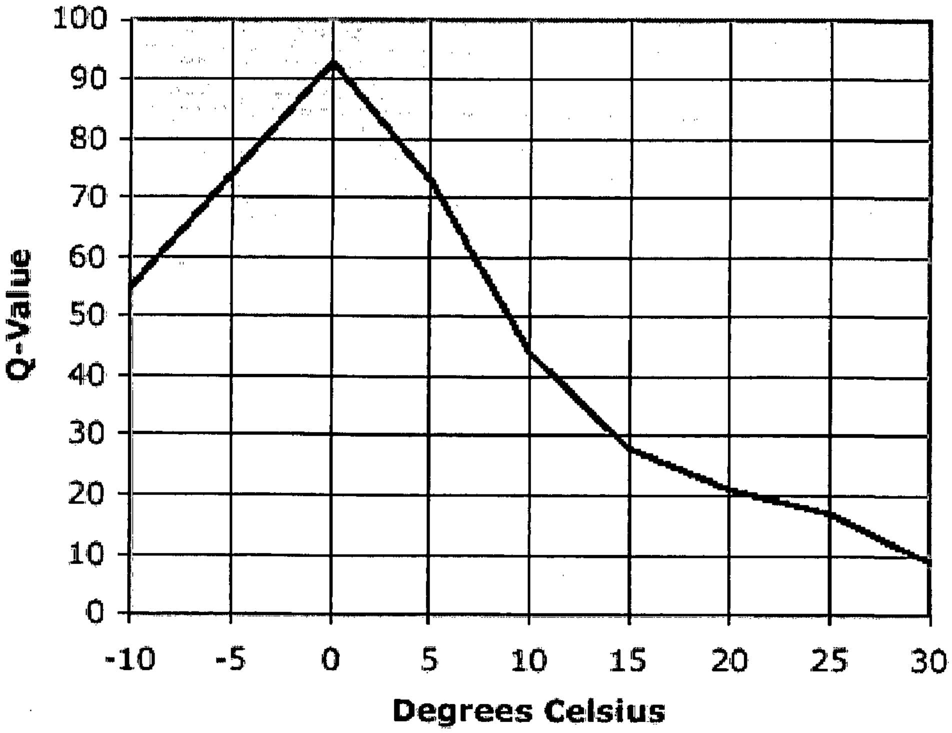
Note: If pH is less than 2.0 or greater than 12.0, the quality index equals 0.

4. Water Quality Sub Index: BOD

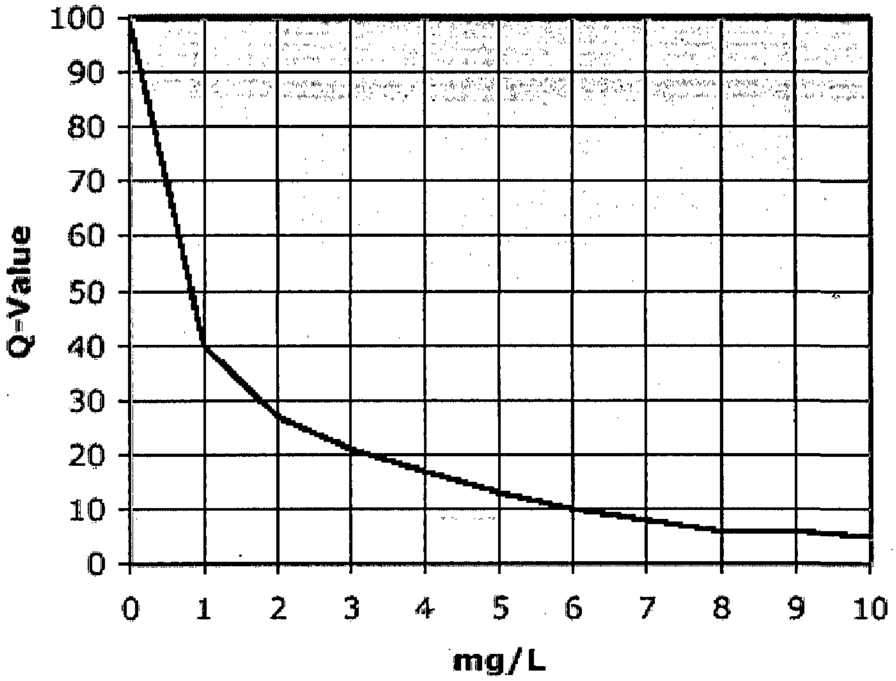


Note: If biochemical oxygen demand is greater than 30 ppm, the quality index equals 2.

5. Water Quality Sub Index: Temperature

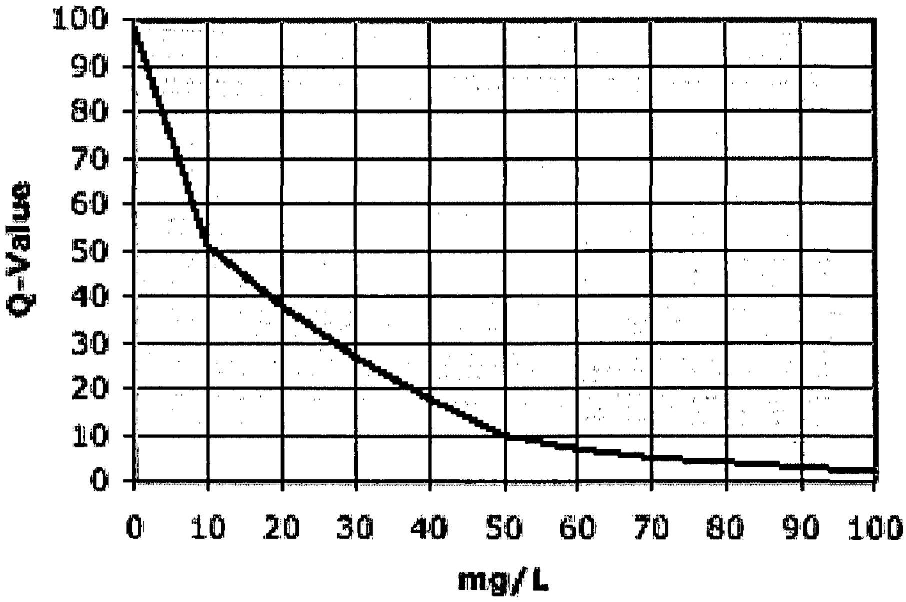


6. Water Quality Sub Index: Total Phosphate



Note: If total phosphate is greater than 10 ppm, the quality index equals 2.

7. Water Quality Sub Index: Nitrate



Note: If nitrate nitrogen is greater than 100 ppm, the quality index equals 1.

Water Quality Factors and Weights

Factor	Weight
Dissolved oxygen	0.17
Fecal coliform	0.16
pH	0.11
Biochemical oxygen demand	0.11
Temperature change	0.10
Total phosphate	0.10
Nitrates	0.10
Turbidity	0.08
Total solids	0.07
Total	1.00

Finally, NSF WQI = Σ_P WiIi

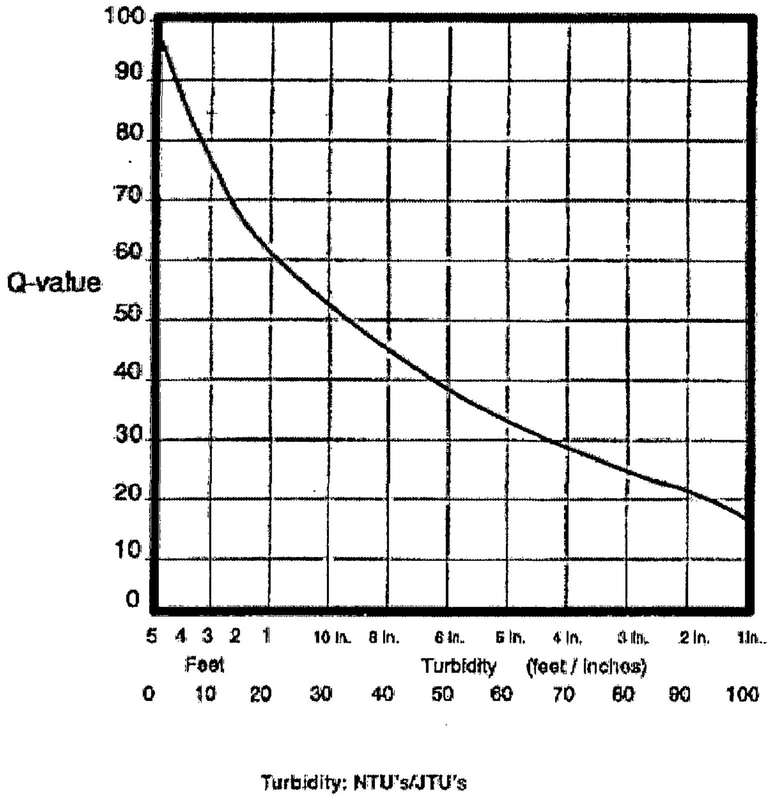
Where Ii = Sub index for i^{th} water quality parameter (Q-value)

Wi = Weight (in terms of importance) associated with water quality parameter

and P = Number of water quality parameters (≤ 9).

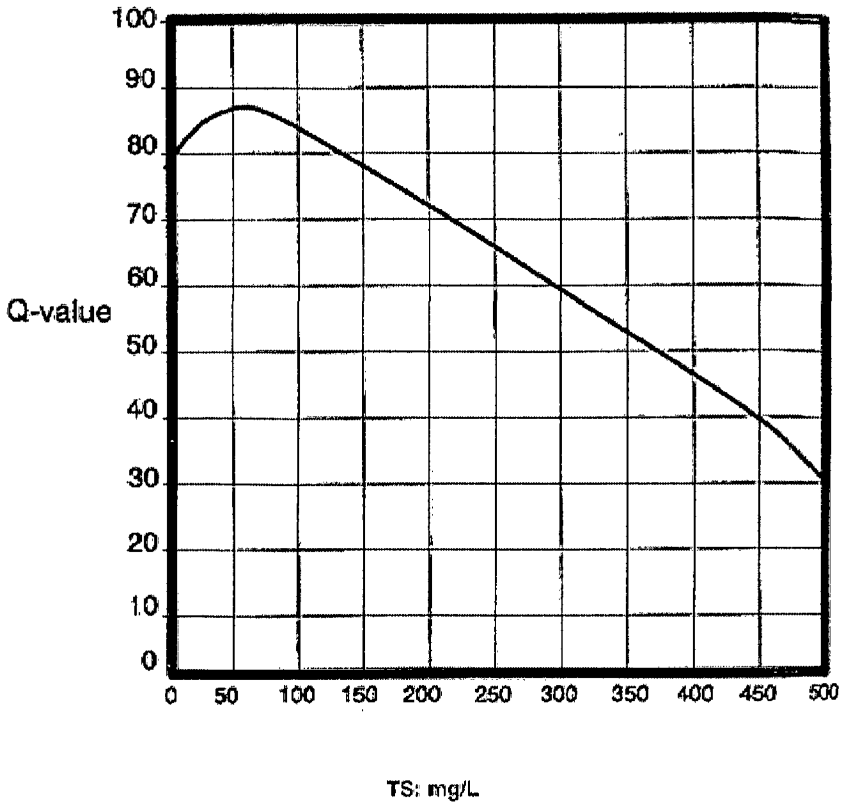
Then 100 point index is compared with ranges corresponding to the general descriptive terms to state the water quality status.

8. Water Quality Sub Index: Turbidity



Note: If turbidity is greater than 100 NTU, the quality index equals 5.

9. Water Quality Sub Index: Total Solids



Note: If total solids is greater than 500 ppm, the quality index equals 20.

Water Quality Factors and Weights

Factor	Weight
Dissolved oxygen	0.17
Fecal coliform	0.16
pH	0.11
Biochemical oxygen demand	0.11
Temperature change	0.10
Total phosphate	0.10
Nitrates	0.10
Turbidity	0.08
Total solids	0.07
Total	1.00

Finally, NSF WQI = Σ_P WiIi

Where Ii = Sub index for i^{th} water quality parameter (Q-value)

Wi = Weight (in terms of importance) associated with water quality parameter

and P = Number of water quality parameters (≤ 9).

Then 100 point index is compared with ranges corresponding to the general descriptive terms to state the water quality status.

APPENDIX II

A. FIELD SAMPLING PROFORMA

1. Date: Time:
2. Sampling ID:
3. Locational details:
4. Latitude: Longitude:
5. Air temperature (°C): Water temperature (°C):
6. pH:
7. Conductivity:
8. NH_4^+:
9. DO bottle no: BOD bottle no:
10. Cyanide bottle no:
11. Heavy metal bottle no:
12. Pesticide bottle no:
13. Oil & Grease bottle no:
14. Bacteriology bottle no:
15. Physico-chemical:
16. Sediment:
17. Phyto plankton: Zoo plankton:
18. Visual observation: Color: clear/grayish/brownish/greenish/blackish/other

    Odor: odorless/fishy/pungent/other
19. Flow: Depth (m):

    Width (m):

    Length of stretch (m): Time of travel (s):

    Velocity (m/s):

    Discharge (cumec):
20. Activities observed:
21. Photo ID:

APPENDIX III

WATER QUALITY CRITERIA AND STANDARDS

CPCB's Primary Water Quality Criteria for DBU classes

Designated-Best-Use	Class of water	Criteria
Drinking Water Source without conventional treatment but after disinfection	A	1. Total Coliforms Organism MPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 6mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 2mg/l or less
Outdoor bathing (Organized)	B	1. Total Coliforms Organism MPN/100ml shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 5mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms Organism MPN/100ml shall be 5000 or less 2. pH between 6 to 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Propagation of Wild life and Fisheries	D	1. pH between 6.5 to 8.5 2. Dissolved Oxygen 4mg/l or more 3. Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	1. pH betwwn 6.0 to 8.5 2. Electrical Conductivity at 25°C micro mhos/cm Max.2250 3. Sodium absorption Ratio Max. 26 4. Boron Max. 2mg/l
	Below-E	Not Meeting A, B, C, D & E Criteria

Source: Water Quality Criteria; CPCB
URL: http://www.cpcb.nic.in/Water/waterqualitycriteria.html

B. FORMAT FOR DATA COLLECTION

1. **Name of the town**: ________________________________
2. **Data source** with name, address & phone no.:
   i) ____
   ii) ____
3. **Administrative map**: **Drainage map**:
4. **General description** on
   4.1 Type (Mostly rural / Mostly urban / Industrial / Mixed)
   4.2 Population growth (Growing / Stable / Declining : Fast / Normal / Slow)
   4.3 Occupation (Mostly farming / Mostly Industrial / Commercial / Mixed)
   4.4 Agriculture (Crop__________________,Vegetables__________________)
   4.5 Industrial types:____
   4.6 Health: Diseases____
   4.7 Any Plan of Town development:
5. **Raw water**
   5.1 Surface water sources – availability in MLD_________________________
   5.2 Distribution system – lay out map:
   5.3 Treatment system details and capacities: ________________________
   5.4 No of Household Connections _______________
   5.5 No of ponds ______________________________
   5.6 No of dug wells __________________ No of deep tube wells___________
   5.7 Ground water quality & withdrawal in MLD __________________________
6. **Sanitation**
   6.1 Unorganized system
      6.1.1 Existing no of Septic tanks _______________
      6.1.2 Existing no of Public Toilets _______________
      6.1.3 Future proposal for low cost community toilets
   6.2 Sewerage
      6.2.1 % coverage
      6.2.2 Existing length of sewer in km _______________
      6.2.3 Existing no of pumping stations _______________
      6.2.4 Existing Treatment Plants details:
      6.2.5 Treated water quality:
      6.2.6 Future Proposal for sewage collection & treatment : location, capacity, type, lay out map & cost:
      6.2.7 Disposal / Receiving water body, flow in MLD _______________
7. **Pollution Abetment Schemes**
   7.1 No of Crematoria ____________
   7.2 No of bathing ghats ___________
   7.3 Solid waste management system (quantity, vehicles, staff):
   7.4 Cattle sheds _______________
8. **Afforestation Programme**:

Data collected by ____

APPENDIX III

WATER QUALITY CRITERIA AND STANDARDS

CPCB's Primary Water Quality Criteria for DBU classes

Designated-Best-Use	**Class of water**	**Criteria**
Drinking Water Source without conventional treatment but after disinfection	A	1. Total Coliforms Organism MPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 6mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 2mg/l or less
Outdoor bathing (Organized)	B	1. Total Coliforms Organism MPN/100ml shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 5mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms Organism MPN/100ml shall be 5000 or less 2. pH between 6 to 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Propagation of Wild life and Fisheries	D	1. pH between 6.5 to 8.5 2. Dissolved Oxygen 4mg/l or more 3. Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	1. pH betwwn 6.0 to 8.5 2. Electrical Conductivity at 25°C micro mhos/cm Max.2250 3. Sodium absorption Ratio Max. 26 4. Boron Max. 2mg/l
	Below-E	Not Meeting A, B, C, D & E Criteria

Source: Water Quality Criteria; CPCB
URL: http://www.cpcb.nic.in/Water/waterqualitycriteria.html

Maximum Permissible Limits for Industrial Effluent Discharges (in mg/L)

Parameter	Into inland surface waters Indian standards: 2490(1974)	Into public sewers Indian Standards: 3306(1974)	On land for irrigation Indian Standards: 3307 (1974)
pH	5.50-9.00	5.50-9.00	5.50-9.00
Biological oxygen demand (for 5 days at 20°C)	30.00	350.00	100.00
Chemicals oxygen demand	250.00	--	--
Suspended solids	100.00	600.00	200.00
Total dissolved solids (inorganic)	2100.00	2100.00	2100.00
Temperature (°C)	40.00	45.00	--
Oil and grease	10.00	20.00	10.00
Phenolic compounds	1.00	5.00	--
Cyanides	0.20	2.00	0.20
Sulphides	2.00	--	--
Fluorides	2.00	15.00	--
Total residual chlorine	1.00	--	--
Arsenic	0.20	0.20	0.20
Cadmium	2.00	1.00	--
Chromium (hexavalent)	0.10	2.00	--
Copper	3.00	3.00	--
Lead	0.10	1.00	--
Mercury	0.01	0.01	--
Nickel	3.00	3.00	--
Zinc	5.00	15.00	--
Chlorides	1000.00	1000.00	600.00
Boron	2.00	2.00	2.00
Sulphates	1000.00	1000.00	1000.00
Sodium(%)	--	60.00	60.00
Ammonical nitrogen	50.00	50.00	--
Alpha emitters (milli curie/ml)	10^{-7}	10^{-7}	10^{-8}
Beta emitters (as curie/ml)	10^{-6}	10^{-6}	10^{-7}

Source: Pollution Control Acts, Rules, and Notification, CPCB, New Delhi, 1998.
URL: http://www.geocities.com/envis_ism/standard9.html

APPENDIX IV

CONVERSION OF UNITS FOR WQ PARAMETERS

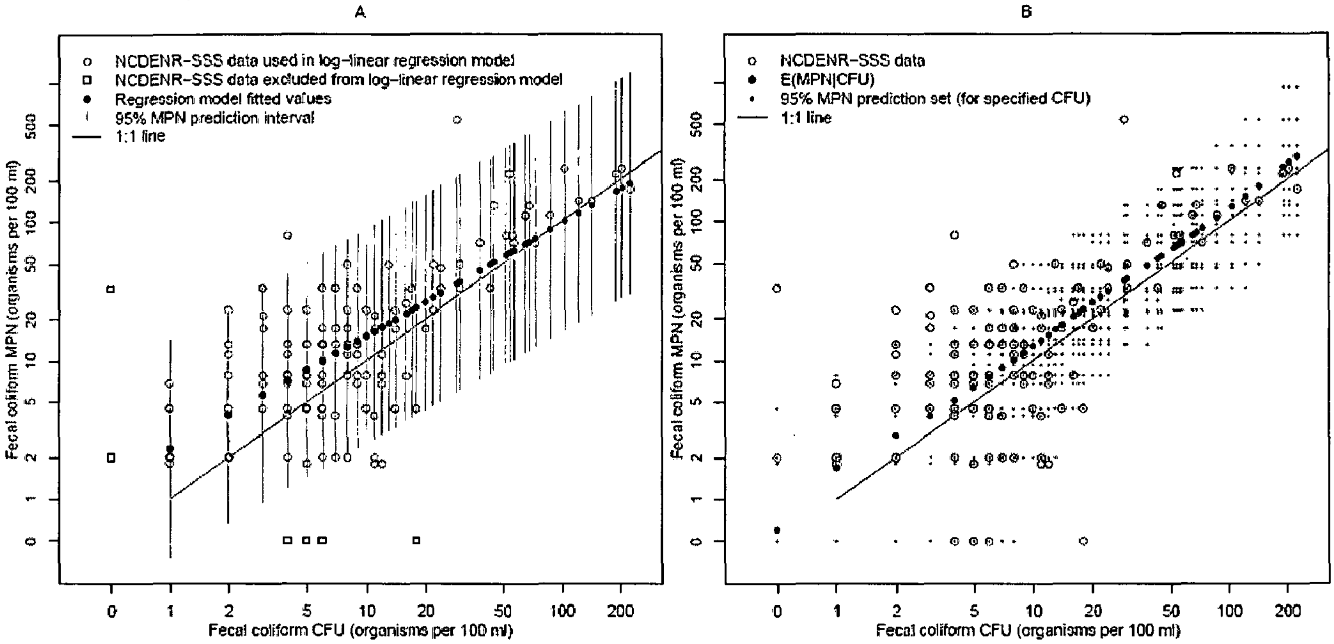
Approximate Barometric Pressure at Different Elevation (Johnson 2007)

Elevation in feet	Elvation in metre	Pressure (mm Hg)	Elevation in feet	Elvation in metre	Pressure (mm Hg)	Elevation in feet	Elvation in metre	Pressure (mm Hg)
0	0	760	1500	457.2	720	3000	914.4	683
250	76.2	753	1750	533.4	714	3250	990.6	677
500	152.4	746	2000	609.6	708	3500	1066.8	671
750	228.6	739	2250	685.8	702	3750	1143	665
1000	304.8	733	2500	762	695	4000	1219.2	659
1250	381	727	2750	838.2	689	4250	1295.4	653

100% Dissolved Oxygen Capacity (mg/L) (Johnson 2007)

Temperature (°C)	100% DO Capacity (mg/L)										
	760 mm	750 mm	740 mm	730 mm	720 mm	710 mm	700 mm	690 mm	680 mm	670 mm	660 mm
0	14.57	14.38	14.19	13.99	13.80	13.61	13.42	13.23	13.04	12.84	12.65
1	14.19	14.00	13.82	13.63	13.44	13.26	13.07	12.88	12.70	12.51	12.32
2	13.82	13.64	13.46	13.28	13.10	13.92	12.73	12.55	12.37	12.19	12.01
3	13.47	13.29	13.12	12.94	12.76	12.59	12.41	12.23	12.05	11.88	11.70
4	13.13	12.96	12.79	12.61	12.44	12.27	12.10	11.92	11.75	11.58	11.40
5	12.81	12.64	12.47	12.30	12.13	11.96	11.80	11.63	11.46	11.29	11.12
6	12.49	12.33	12.16	12.00	11.83	11.67	11.51	11.34	11.18	11.01	10.85
7	12.19	12.03	11.87	11.71	11.55	11.39	11.23	11.07	10.91	10.75	10.59
8	11.90	11.74	11.56	11.43	11.27	11.11	10.96	10.08	10.65	10.49	10.33
9	11.62	11.46	11.31	11.16	11.01	10.85	10.70	10.55	10.39	10.24	10.09
10	11.35	11.20	11.05	10.90	10.75	10.60	10.45	10.30	10.15	10.00	9.86
11	11.09	10.94	10.80	10.65	10.51	10.36	10.21	10.07	9.92	9.78	9.63
12	10.84	10.70	10.56	10.41	10.27	10.13	9.99	9.84	9.70	9.56	9.41
13	10.60	10.46	10.32	10.18	10.04	9.90	9.77	9.63	9.49	9.35	9.21
14	10.37	10.24	10.10	9.96	9.83	9.69	9.55	9.42	9.28	9.14	9.01
15	10.15	10.02	9.88	9.75	9.62	9.48	9.35	9.22	9.08	8.95	8.82
16	9.94	9.81	9.68	9.55	9.42	9.29	9.15	9.02	8.89	8.76	8.63
17	9.74	9.61	9.48	9.35	9.22	9.10	8.97	8.84	8.71	8.58	8.45
18	9.54	9.41	9.29	9.16	9.04	8.91	8.79	8.66	8.54	8.41	8.28
19	9.35	9.23	9.11	8.98	8.86	8.74	8.61	8.49	8.37	8.24	8.12
20	9.17	9.05	8.93	8.81	8.69	8.57	8.45	8.33	8.20	8.08	7.96
21	9.00	8.88	8.76	8.64	8.52	8.40	8.28	8.17	8.05	7.93	7.81
22	8.83	8.71	8.59	8.48	8.36	8.25	8.13	8.01	7.90	7.78	7.67
23	8.66	8.55	8.44	8.32	8.21	8.09	7.98	7.87	7.75	7.64	7.52
24	8.51	8.40	8.28	8.17	8.06	7.95	7.84	7.72	7.61	7.50	7.39
25	8.36	8.25	8.14	8.03	7.92	7.81	7.70	7.59	7.48	7.37	7.26
26	8.21	8.10	7.99	7.89	7.78	7.67	7.56	7.45	7.35	7.24	7.13
27	8.07	7.96	7.86	7.75	7.64	7.54	7.43	7.33	7.22	7.11	7.01
28	7.93	7.83	7.72	7.62	7.51	7.41	7.30	7.20	7.10	6.99	6.89
29	7.80	7.69	7.59	7.49	7.39	7.28	7.18	7.08	6.98	6.87	6.77
30	7.67	7.57	7.47	7.36	7.26	7.16	7.06	6.96	6.86	6.76	6.66
31	7.54	7.44	7.34	7.24	7.14	7.04	6.94	6.85	6.75	6.65	6.55

Relasionship between MPN and CFU for Coliform Count



Graph for empirical linear regression model (panel A) and theoretical probability model (panel B) of the relationship between feacal coliform MPN and CFU estimates from the same water quality sample. (Gronewold and Wolpert, 2008)

LIST OF PUBLICATIONS

- Sharma M.P., Singal S.K. and Patra S., "Water Quality Profile of Yamuna River", *Journal of Hydro Nepal* (Communicated)

- Sharma M.P., Singal S.K. and Patra S., "Water Quality Management of Damodar River" (Under process)