# EFFECT OF WATER QUALITY PARAMETERS ON BIOTA

A THESIS

submitted in fulfilment of the
requirements for the award of the degree
of
DOCTOR OF PHILOSOPHY



By

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Sincerely

dedicated

to

Dr. R.N. Goyal

and

my parents

# CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled, **'EFFECT OF WATER QUALITY PARAMETERS ON BIOTA'** in fulfilment of the requirement for the award of the degree of **Doctor of Philosophy**, submitted in the **Department of Biosciences and Biotechnology** of the University is an authentic record of my own work carried out during the period from February 1989 to November 1991 under the supervision of **Dr. R.N. Goyal, Dr. G.S. Randhawa and Dr. V.P. Agarwal.**

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

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# ABSTRACT

# ABSTRACT



The study of pollution in an ecosystem is an area of global interest particularly as it directly or indirectly affects living beings. One of the major sources of pollution in river ecosystem is water which is polluted by mixing of sub-water stream containing industrial or sewage waste. As the water of river and streams are extensively used for many purposes such as water supply, irrigation and general amenities, it is highly desirable that the sources of water should be kept free from undesirable pollutants so that the interests of the community can be safe guarded.

Saharanpur is an important major industrial city of Western Uttar Pradesh. The waste from numerous industries is mixed in the river Dhamola, which passes through the city. The water of this river is used for agriculture purposes including bathing and drinking by domestic mammals. The water of the river Dhamola just before entering in Saharanpur (North side of city) is colourless and visually looks pure, whereas, after about twelve kms south of entering in Saharanpur, the grey colour of the water can be easily seen. Essential micro and macro nutrients in the river are very much influenced by the mixing of waste discharge. Hence the contamination by sewage and other waste products causes pollution by disturbing the water quality. Apart from this, the sewage has high population of certain pathogenic micro and macro organism which in a rainy season, further affects the

aquatic life and water quality. As the visual changes indicated pollution in the river Dhamola within Saharanpur City, it was considered interesting to study the extent of pollution in this river and is the subject matter of this thesis. The studies include an in-depth analysis of various physico-chemical and biological factors at selected points of the river Dhamola. It has been concluded that the water of this river is not sufficiently pure and hence should not be used for bathing or drinking by human beings and domesticated animals. Attempts have also been made to minimise the pollution load by using certain vascular hydrophytes.

The first chapter of the thesis is General Introduction and highlights the importance of pollution study in present days. The second chapter of the thesis has been devoted to the Literature Review. It reveals the important relevant references reported in the literature relating to the present studies on water pollution. The different methods of water analysis and techniques for reduction of pollutants have been discussed. Biological treatment processes by different species of algae, cyanobacteria and higher vascular hydrophytes and significant results relevant to the present study have also been incorporated at proper places.

The next chapter is devoted to the Materials and Methods. The different methods of analysis of physico-chemical and biological parameters of river water, industrial and domestic effluents according to the methods specified in ''Standard Methods for the Examination of Water and Waste Water'' [American Public Health Association, 1987] has been discussed. The details of the experiments for minimising the pollution load of all the samples by using certain vascular hydrophytes (biological treatment), are also presented in this chapter. Three distinct aquatic plant species, viz., Eichhornia crassipes, Lemna minor and Ceratophyllum demorsum were used in stages I to III, whereas in stages IV and V a combination of E. crassipes, L. minor and L. minor, C. demorsum were used. The treatment of the industrial effluent as well as domestic sewage was allowed upto four weeks and the physico-chemical and biological parameters were determined at an interval of one week.

The results obtained on the above studies form the fourth chapter of the thesis. Various parameters determined for the water samples collected at different places of river Dhamola are presented. The samples were collected for a period of two years, i.e., from July 1988 to June 1990 and the results of physico-chemical analysis are presented. The various parameters of the waste water samples collected from sampling stations 4 (domestic sewage) and 5 (industrial effluent) mixing in the river Dhamola clearly indicated that the values of BOD, COD, $CO_2$ MPN and SPC are much higher than the tolerance limit of

Indian Standard for the discharge of waste water into the inland surface water. Also the samples had a very low value of DO during the entire course of investigation. The water samples obtained from sampling station 5 did not indicate the presence of any planktonic population whereas, in domestic sewage only protozoans were found in all the seasons. Algae was also detected during the rainy season in domestic sewage.

The analysis of Dhamola river water at sampling station 1 indicated the qualityof water with the parameters (mg/l) DO [min. 7.2 ], BOD [max. 20.5], COD [max. 49.0], $CO_2$ [max. 1.1 ], chloride [max. 22.0], total solids [max. 489 ] and total hardness [max. 151 ]. Thus, the water at sampling station 1 was found sufficiently pure for the bathing and agricultural purposes. Due to the discharge of waste water into the river Dhamola, after the entering into the Saharanpur city, the quality of river water changes and the analysis at sampling station 2 (two kms. downstream of the merging point of waste water) indicated it to be polluted. It was found that the values of BOD, COD, $CO_2$, total hardness, MPN, SPC, diatoms and protozoans increase tremendously whereas, the values of DO and algae (primary producer) decrease. The values observed for physico-chemical and biological parameters indicated that the water at sampling station 2 was not suitable for bathing purposes due to high value of BOD and coliform bacteria. It's use in bathing may lead to several chronic diseases.

Analysis of water samples obtained from sampling station 3 also indicated the high values for BOD and coliform bacteria. Therefore, it was concluded that the water of the river Dhamola is not suitable for domestic purposes even after seven kms of the mixing of waste water. Other physico-chemical and biological parameters of the water at sampling station 3 are slightly better due to the self purification of river water. The content of the dissolved oxygen in river water reduced significantly at sampling station 2 in comparison to sampling station 1 due to the mixing of organic matter of the waste water. But at station 3 it was found that the concentration of dissolved oxygen increased due to the self purification. The values of different physico-chemical and biological parameters of river water have also been correlated with each other using a package of LOTUS program. An excellent statistical correlation was observed among the following parameters: turbidity - total solids, DO with BOD, COD and algae, BOD with CCD, SPC and algae, COD with SPC and algae and diatoms - protozoans.

Attempts have also been made to use various vasuclar hydrophytes and their combination for the treatment of industrial and domestic effluents to reduce the pollution load of the waste products. Eichhornia crassipes was found most effective in the reduction of pollution load in all the seasons of the year. The values of DO was found to increase in four weeks treatment whereas BOD, $CO_2$, COD, MPN and SPC decreased. The decrease in the value of chloride ions was about 40-50% in ccmparison to control. As E. crassipes has large leaf area, well developed arenchyma and root systems, more transpiration occurs during photosynthesis and possibly causes an increase in DO value. L. minor used in stage II was found particularly useful for the removal of chloride ($Cl^-$), $CO_2$, turbidity, total solids and SPC. Hence the combination of E. crassipes and L. minor used in stage IV was found most effective in reducing the pollution load of domestic sewage as well as industrial effluent.

It was observed that before entering in Saharanpur city the water of river Dhamola is pure as indicated by normal values of physico-chemical parameters, but the value of these parameters was found to increase significantly at the mixing point and after mixing point of industrial/domestic discharge into the river. This indicated that a high pollution load has been added in the river in Saharanpur city due to which there is increase in the turbidity, total hardness, total solids, BOD, COD, chloride, $CO_2$, MPN, SPC, protozoans etc.

Thus, the present studies clearly indicate that the river Dhamola becomes polluted after entering into Saharanpur city. The use of plant species, viz., E. crassipes and L. minor can reduce the pollution created by domestic sewage and industrial effluent to some extent and then water of the river Dhamola will be suitable for bathing purposes. A more vigrous treatment, however, is needed for making it suitable for drinking purposes. It is worth mentioning at this stage that the aquatic plant species used in the present investigation are not only useful for pollution removal but their biomass can also be successfully used for the production of methane gas.

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# LIST OF ABBREVIATIONS USED IN THE THESIS

| | |
|---|---|
| DO | Dissolved oxygen |
| BOD | Biochemical oxygen demand |
| COD | Chemical oxygen demand |
| MPN | Most probable number |
| SPC | Standard plate count |
| ppm | Part per million |
| Max. | Maximum |
| Min. | Minimum |
| S-R | Sedgwick refter |
| E.crassipes | Eichhornia crassipes |
| L. minor | Lemna minor |
| C.demorsum | Ceratophyllum demorsum |
| U.P. | Uttar Pradesh (state of India) |

# CHAPTER - I

# INTRODUCTION

The turn of the last two decades has witnessed the development and expansion of research in various fields of pollution study in the entire globe. This period has seen a continued growth in the large scale pollution of air, water and soil due to heavy industrialization and urbanization. The alarming information provided by Union Minister for Environment in the Lok Sabha on August 12,1991 that Delhi (India) is one of the most polluted cities in the world indicates the importance of monitoring pollution in metropolitan cities. The continuous and rapid increase in population has increased the water requirements for agriculture, industry and for domestic use. Hence water is becoming one of the major constraints for further socio-economic development. As the increase in population presses the need of more food in the world, an efficient planning of water resources for irrigation is a high priority item on the economic development agenda in most countries.

It is well known that, higher productivity and better living standards of a modern society depend on the creation of an infrastructure capable of guaranteeing an adequate supply of water of acceptable quality. Human developments, which were developed in the vicinity of water several decades ago, due to multiple conveniences provided: water supply, hygeine, water power, transportation, protection, pleasure and scenic beauty has resulted in the large scale pollution of not only water but also of air and soil. The multifaced dependence on water demands strong measures to keep the water free from undesirable pollutants and adaptation of extensive water conservation measures. In this context, it is well known that the rivers and streams are extensively used for many purposes such as water supply, disposal of sewage and trade of effluents, irrigation and land drainage needs, navigation, commercial and recreational fisheries, other forms of recreations and general amenities. Some of these uses create conditions which reduce the capacity of streams to cope with the pollution and strict control measure are necessary, if the interests of the community are to be safeguarded. Conditions in different parts of the country vary widely and the factual information about these conditions is required at regular intervals to asses the current position and the long time effects of the control methods adopted.

## 1.1 POLLUTION AND ITS KINDS

Pollution is an undesirable change in the physical, chemical and biological characteristics of air, water and soil that harmfully affect the animal as well as plant life. The undesirable constituents that pollute the environment must be controlled for the ecological balance of nature.

In relation to the industrial and domestic waste water, pollution can be divided in four categories:

a. Physical
b. Chemical
c. Physiological
d. Biological

a. Physical pollution :

Physical pollution consists the changes in the physical characteristics of water bodies after the mixing of industrial as well as domestic waste discharge. These waste discharges may change either of the properties of water bodies, viz., temperature, colour, turbidity, foams, suspended solids and radioactivity etc.

b. Chemical pollution :

Chemical pollution in water is observed when any of the following parameters of water changes, viz., pH, acidity, alkalinity, chlorides, sulphates, sulphides etc. The presence of toxic compounds, heavy metals (biodegradable and non-biodegradable) and organic chemicals in the water bodies also produce chemical pollution. When the pH of water is less than 5.0, it causes corrosion of metals and irritates the skin of living beings. Both acids and alkalies are toxic to aquatic life and are generally discharged from various industries.

c. Physiological pollution :

Physiological pollution in water is observed due to the unpleasant taste and odour. For example, sulphide, phenols and chloride give bad odour. Iron and manganese salts destroy the taste of water which may harm the aquatic life. Sulphides containing water gives $H_2S$ and thus smell like rotten eggs.

d. Biological pollution :

The pollution in water caused by some pathogenic micro-organisms, like fungi, algae, protozoans, viruses, bacteria and helminthic parasites which are normally found in domestic waste water is named as biological pollution. It is usually observed where sewage is discharged. These micro-organisms are responsible for many enteric disease like, typhoid, cholera, amoebiasis, tuberculosis, lep-speric, hepatitis, poliomyelitis etc.

## 1.2 WATER POLLUTION PROBLEMS IN INDIA

Since long, the water pollution problems in India have been observed due to the mixing of waste water from various industries as well as domestic waste discharges into the rivers/streams without proper treatment. The pollution in the holy river Ganga is well known as approximately 270 million litres per day of untreated sullage including 30 million litres per day of industrial effluent was found to be mixed into the river Ganga from Kanpur city alone. In 1987, Maharashtra Pollution Control Board has filed a case against the High Explosive Factory at Khadki near Pune for discharging untreated effluent into the river Mula. Similarly, Central Pollution Control Board, Delhi, has recently reported the increase of pollution load in Yamuna river in Delhi region due to the mixing of various industrial and domestic wastes.

The mixing of this type of wastes discharge into the rivers/streams cause the death of aquatic population like fish and other useful macro-organisms. The discharge of waste water in rivers, e.g. in Kullu river, Chambal, Mahi and Ganga river has seen the tragic loss of fishes.

The various conventional methods used for the disposal of such pollutants as the activated sludge, trinkling filters, anaerobic digestions methods etc. are extremly costly from the point of view of the capital financial capacities of local Government authorities. In certain cases raw sewage has been used for the irrigation of crops in sewage farms. Oxidation stabilization ponds (lagoons) which are generally known as low cost alternatives for the treatment of effluents require more operation and maintenance cost as compared to aquatic macrophyte treatment systems.

The use of aquatic hydrophytes for reducing pollution level of industrial effluents and domestic wastes as well as pollution in river water is relatively a new area of research. In recent years, experiments have been conducted in the different laboratories to evaluate the role of hydrophytes in reducing the pollution [1-4]. The plants used in these studies include, Eichhornia crassipes, Lemna minor, Pistia stratiotes, Hydrocotyle umbellata, Azolla caroliniana, Salvinia rotudifolia, Egeria densa etc.

Thus it is clear from the preceeding paragraphs that the effluents from industries and municipal waste water affects the water quality, fish population and bottom fauna characteristics of a river [5-10].

The aquatic macrophytic system can be effectively used to reduce the pollution level in the water bodies and the industrial effluents [4]. Physico-chemical and biological studies/surveys of Nagase river in Japan [11], Neva river in USSR [12], Menotre river in Italy [13], Stream of China [14], Big-blue and Sagavonirtok river in USA [15] and Tama river in Japan [16] indicated that the water of these rivers is highly polluted due to mixing of effluents.

## 1.3 SUBJECT MATTER OF THE THESIS

Dhamola is an important river of Western Uttar Pradesh in Saharanpur district, which passes through the city and runs from North to South. The water of this river is used for agricultural purposes as also for bathing and drinking by domestic animals. The principal source of water in Dhamola is natural water which comes from the hilly region of Northern India (Dehradun hilly region, basin of Himalayas).

The water of this river, just before entering in Saharanpur city (North side of city), is odourless and visually looks pure, whereas after about seven miles (11Kms) south of entering in Saharanpur, the grey colour of the water can be easily seen due to mixing of waste from numerous industries. Essential micro and macro nutrients in the river are very much influenced by the mixing of waste discharge (industrial as well as domestic waste). Hence, the contamination by sewage (domestic waste) and other waste products causes pollution by disturbing the water quality. Apart from this, the sewage, has high population of certain pathogenic micro and macro organisms which in a rainy season further affects the aquatic life and water quality.

Such visual changes indicated pollution in the river Dhamola within Saharanpur city, hence it was considered interesting to study and determine the extent of pollution in this river by industrialization and urbanization of Saharanpur city. Attempts have also been made to cut ways and means to minimize the pollution load of the river Dhamola by using certain vascular hydrophytes (biological treatment). These studies include an analysis of various physico-chemical and biological factors at selected points of the river Dhamola. It has been found that the water of this river is not sufficiently pure and hence should not be used for bathing, or drinking by human beings and domestic animals.

The present study has been divided into two main parts:

(A) Analysis of the various physico-chemical and microbiological parameters of the water samples obtained at selected points of the river Dhamola from July 1988 to June 1990. The industrial effluents as well as adjoining city sewage were also analysed before they mix in the river. Statistical analysis of the results is also deduced.

(B) The role of three hydrophytes viz., Eichhornia crassipes, Lemna minor and Ceratophyllumdemorsum in the reduction of pollution load of effluents/waste discharge has also been studied. It has been observed that the use of the combination of two or more plant species in reducing pollution is more efficient in comparison to a single plant.

The thesis has been divided into five chapters and the material presented is as follows:

# CHAPTER - II

# LITERATURE REVIEW

The study of pollution in an ecosystem is an area of recent global interest, particularly as it directly or indirectly affects living beings. The increase of population, urbanization and industrialization leads to the generation of large volumes of waste water from domestic, commercial, industrial and other sources [17]. According to Shende and Sunderson [18] about 13,163 million gallons of waste water is released every day from various urban and rural centres of India.

The effluent from chemical industries is one of the most potent source of water pollution. The wastes from industries that are known to cause serious pollution problems, have been attributed by Basu [19] to distillary effluents and pulp and paper mill effluents. The deterioration of water quality of natural water and canal water has been reported due to the mixing of industrial effluents [20].

The disposal of sewage and industrial wastes in land is an age old practice in India. According to Central Board's reports, CUPS/4/1978-79 and CUPS/6/1979-80 [21], out of 142 class-I cities and 190 towns, 52 cities and 43 towns respectively, are disposing their waste water on land [22].

The presence of heavy metals in effluents from the industries create the phytotoxicity as well as toxicity to human food chain. A comparison of plants irrigated with industrial waste water and domestic sewage indicated that plants irrigated with industrial waste water had high accumulation of heavy metals in comparison to plants irrigated with domestic sewage [23]. The field survey of these areas indicated that the growth of plants in both the cases was suppressed and was not as expected from unpolluted water. The quality of ground water collected from raw sewage irrigated areas was a matter of concern with respect to copper and zinc. The degree of heavy metal contamination was comparatively high in the case of raw sewage irrigated areas whereas copper, lead and cadmium contents were found as 0.6, 0.1 and 0.24 ppm respectively and were more than the permissible range of Central Public Health and Environmental Engineering Organization [24].

In recent years, UNESCO initiated the first multidisciplinary study on the major rivers of the world, which led to interesting and alarming information about the extent of pollution in these rivers. Besides, the well known hydrological features, hydrobiological aspects and primary geochemical cycle operating in different sectors of the rivers were studied in some of the major river of temperate zones in the European continent and North America [25].

Excellent reviews dealing with the ecological aspects of the algae in streams and rivers have been appeared in the literature [26,27]. The phyto plankton and zooplankton studies on number of rivers from Europe and North America have been studied by various workers. These rivers include Thames, Essex, Stour, Lee of England, James, Sacrament of USA, Danube (USSR) for phytoplankton studies and Rhine (Germany), Yamuna (India), Nile (Africa), Lower Missouri, Ohio (North America) for zooplankton studies [27].

In contrast to some developed countries, very little attention has been paid to the pollution in Indian rivers. Few scanty references available in literature deal only with ecological point of view in limited zones. Yamuna [28] Cauvery [29], Pawana, Mutha and Mula [30], Jhellum [31], and Khan [32] are some of the rivers in which pollution has been studied in very limited zones.

The dynamics of the river ecosystem for Ganga (India) was determined by Saxena et al. [33] at Kanpur and Ray et al. [28] at Allahabad on the basis of hydrological data collected at these points.

In general, the concentration of coliform bacteria is used as an index of civic pollution. The impact of bacterial population on water quality in various rivers of the world has also been studied. Some pertinent references are for Hull, Aires and Welsh in England [34-36], Ogiline, Swift Meduxnepeag [37], Dunbar [38] and Athabasca [39] of Canada, Nile of Egypt [40], Nida of Poland [41], Tisza of Hungary [42], Tigris of Iraq [43] and Sagami of Japan [44].

The studies on bacterial survey of Indian rivers are relatively less. Mathur [45] has investigated the seasonal distribution pattern of coliform bacteria in Yamuna river in Delhi. Bilgrami and Datta Munshi [46] have studied the concentration of coliform bacteria in Ganga river from Patna to Farraka.

Central Pollution Control Board in 1977 initiated a programme on regular water quality monitoring in the Ganga basin under basinwise pollution control task. In the first phase, the water of the river Yamuna was monitored at fifteen sampling stations for the analysis of physico-chemical and bacteriological parameters during the period 1977-1979 [47]. In the second phase, the Central Pollution Board decided to take the cooperation of State Pollution Boards of Uttar Pradesh, Bihar and West Bengal in surveying the water quality of river Ganga with the network of about forty monitoring stations from Hardwar to Diamond Harbour, Calcutta, during early 80's [48]. Nevertheless, this agency did not undertake the mountaneous stretch of the holy river Ganga for monitoring the biological parameters.

The self purification of the river is one of the natural phenomena which controls the microbiol imbalances. Wurhmann [49] summarized the death rate of coliform bacteria in various rivers of the world (Ohio, Missouri, Tennessee and Cumberland) and found that the time required for about 90% decay is close to 10 hrs. The effect of conventional microfauna for the control of bacterial population and rate of the extent of decline of the Escherchia coli bacteria has been studied on marine water by various workers [50-52]. However, the studies to provide precise information on the bacteriological quality in Indian rivers is still lacking in the literature.

Katz [5] has documented some of the effects of municipal waste water effluents on the water quality, fish population and bottom fauna characteristics of a receiving streams and rivers. It was found that the addition of effluents into river influenced the water quality parameters such as dissolved oxygen (low), BOD (high), $CO_2$-content (high), fish population (low), bottom fauna (low) and composed primarity of worms (low).

The effect of domestic sewage in the water quality of the Yagyu river in Japan was studied by Ushami et al.[6] and he found that the water pollution is caused by the accumulation of COD, nitrogen, phosphorus, bacteria and protozoa in a stagnant areas formed by dams in the middle stream. The impact of industrial effluents on the water quality of Welland river, Ontorio, which was receiving large quantity of N and C containing inorganic compounds was the subject of interest in 1980's. It was found by Dickman et al. [7], that the areas receiving the waste water discharges were completely devoid of all life except bacteria. Studies on the properties of water in river Isar between Muench and Moosburg, Germany [8] indicated that the discharge of waste water from the Muench sewage plant-II requires immediate attention with respect to complete denitrification and very extensive retention of settable solid before mixing in the river. Biological studies of fishing in the Upper Weser River in Germany [9] indicated that the effluent of industrial waste water causes sickness in and ultimate death of the fishes. Sickness of the fish is intensified at the chloride concentration of 3000 mg/l. The effect of municipal and industrial waste water in river Bosna (Yugoslavia) in the region from Doboj to Modria was studied by Bendic and Stojanta [10] and it was found that the pollution load was 63.678 pollutant units/inhabitate. An intensive survey on the effect of sewage effluent discharge in San Gabriel and Bushy rivers in Texas, USA indicated that such mixing caused a very low levels of dissolved oxygen below the discharge points. The extensive nutrient levels stimulated the growth of benthic algae.

Similar studies on various rivers like, Leba [53], Lupawa [54], Slupia [55], Wiep-rza river basin [56] of poland, Nagase [57] and Yoda [58] of Japan, River of Southern Missouri, USA [59] and Halifax of flourida, USA [60] have also been carried out. The studies on pollution in the last decade attracted world wide attention and not only the above mentioned rivers but several others important rivers were also studied for the physico-chemical and biological characteristics [11-16,61].

The long term study on the effect of seasonal variations on water quality in the river Rhine has been appeared in the literature recently [62]. The analysis of 240 water samples and of 79 suspended matter samples collected during a 10 year period indicated a complicated pattern of the major dissolved ions due to pollution. A simple steady state model is used to estimate the contribution of aluminosilicate rock and of lime stones to the total denudation. The bacteriological water quality of a multiuse catchment basin on Avalon Peninsula (New Foundland) and in potable water have also been analysed [63,64]. Seasonal fluctuations in population numbers were observed in all samples.

The effect of body size, depth and sampling site on spatial heterogenity were examined in the zooplankton community of a small lake by Bernadette et al. [65]. Analyses were performed by regression analysis of 27 sets and results were presented. A carbamate insecticide, 'Carbaryl' was applied in spring to concrete ponds and it was found that at 1.0 ppm, all Zooplankton species were killed [66]. Similarly an organophosphorous insecticide, 'Temphos' was found effective in eliminating almost all zooplankton at a concentration of 500 mg/l [67].

Effect of industrial disharges on the ecology of phytoplankton in the rivers also attracted attention in the last few years. Joy et al. [68] studied the ecology of phytoplankton production in the river Periyar (India), which receives the effluent discharge from a dozen industrial units. Spatial variation of phytoplankton composition, chlorophyll pigments and physico-chemical features of water were observed. The water of river Ganga (India) was also found quite good before entering in Balia city (Uttar Pradesh) while it was found polluted due to the mixing of sewage and industrial effluents at down stream [69].

Shankar et al. [4] made a comparative study on BHEL, Jwalapur drain, Naisota and Lalta Rao sewer drains at Hardwar and found that the colour of sewage was black with pungent smell. The physico-chemical characteristics of water at various selected points were determined. The

Rishikesh sewage was analysed by Chaudhuri [70] and it was found that it carried a high BOD (average 233.1 mg/l) and low dissolved oxygen (0.8 mg/l). The values of COD, MPN, SPC and turbidity were also found to be quite high (average values : 275.5 ppm, $236.7 \times 10^4$ per ml, $151.6 \times 10^5$ per ml. and 252.2 NTU respectively).

It is, therefore, clear that pollution in water by mixing the effluents from the industries as well as sewage causes severe pollution problems and requires an immediate attention. Out of the several treatments explored for the treatment of effluents/sewages, use of the hydrophytes has been suggested several decades ago inspite of the fact that it requires several days treatment. Hydrophytes have been found to possess the potential to lower down the pollution load in the polluted water. Mostly these hydrophytes are aquatic weeds and are generally considered as troublesome plants to humans. Fresh-water macrophytes grow naturally in water bodies polluted by nutrients. Many aquatic plants utilize these nutrients and produce large amount of biomass which can be used for some beneficial purposes. The concept of using aquatic plants for treating waste water is gaining attention of local and state agencies these days in various parts of USA (California, Florida, Mississippi, Lousiana and Texas). Aquatic macrophyte system can be effectively used for reducing pollutant levels in water bodies [1,4,71-73] and the biomass of aquatic macrophytes are used for production of gaseous fuel [74,75] and feed and fibers [76]. Aquatic plants which possess capability of reducing pollution on one hand also suffers from the disadvantages, particularly by Eichhornia crassipes that it grows wildly and the magnitude of the area under its cover can be judged by the remote sensing techniques [77]. Eichhornia crassipes has also been named as Bengal Terror [78], curse of Bengal [78], Blue devil [79] Million Dollor Weed [80] and Cinderella of the plant world [81].

Sioli [82] has observed that water hyacinth roots eliminate some amino acids and carbohydrates in the surrounding water and that the excretion of organic substances may be one of the possible reasons for rich community of aquatic animal life.

Despite several efforts with different control measures and heavy expenditure, the scientists have hardly received any success in controlling the aquatic weeds specially E. crassipes, which provides food to animals and also provides fibre, fuel and fertilizers. Thus, scientist these days are willing to accept aquatic plants specially E. crassipes as their trusted partner in solving the problems of water pollution. Eichhornia crassipes has also been claimed as a future scavanger for various organic and inorganic pollutants from waste waters. There is an ever growing interest in this plant around the world for reducing pollution in water. Among all the aquatic weeds, E. crassipes is well known for its ability to lose water rapidly through its leaves during transpiration. Due to this property, the plant also derived its name in Hindi as 'Samudra Sokh' (one which is capable of absorbing the ocean). A number of experimental studies have shown that the water loss through evapotranspiration from water hyacinth does not exceed the loss from open water surface. The value reported for the ratio of evapotranspiration (Et)/evaporation (E) and rates [Et/E] are very divergent. Dass [83] reported the water loss by water hyacinth to be 5.78 to 9.84 (average 7.76 ± 1.35) times higher in different seasons as compared to open surface of water bodes.

The growth rate of water hyacinth in India is different at different places. The total annual average net growth of water hyacinth is $1039/m^2$ and max. rate is $3.89/m^2/day$ [84]. In Assam, the maximum growth rate was determined as $9.79/m^2/day$ [83], while in areas near Jaipur, still higher growth rate has been observed in a sewage receiving entrophic water bodies [85,86].

Several experimental studies in laboratories as well as in fields have shown that water hyacinth reduces the quantity of suspended particles, algae, dissolved impurities, nitrogen, phosphorous and other nutrients, redox potential, BOD, COD, turbidity, faecal coliform bacteria and organic carbon content in water bodies [87-94].

Since the first report published by Pirie in 1960 [95], a large number of reports have appeared in the literature on the possibility of extraction of proteins from water hyacinth and its use for combating protein deficiency in human beings [96]. The value of protein content determined from nitrogen estimations, however, varies widely from 8% of dry weight (0.85% fresh wt) to 5.3 - 5.7% dry weight [97]. Various essential and non-essential amino acids content determined in water hyacinth are summarized in Table 2.1.

**Table 2.1** Essential and Non-essential Amino acids Content (%) in Crude protein of Water hyacinth

| | | | |
|---|---|---|---|
| Methionine | 0.73 | Arginine | 2.98 |
| Cystine | 11.60 | Histidine | 1.90 |
| Phenylalanine | 4.72 | Glycine | 5.14 |
| Tyrosine | 2.98 | Alanine | 5.59 |
| Threonine | 4.32 | Serine | 5.59 |
| Lysine | 5.34 | Aspartic Acid | 17.37 |
| Isoleucine | 4.32 | Glutamic acid | 9.29 |
| Valine | 0.27 | Proline | 4.33 |
| Leucine | 7.20 | | |

A number of workers have shown that aquatic plants also absorb and accumulate a large number of heavy metals (Cu, Cd, Ni, Ag, Cr, Fe, Zn, Mg, Mn, As etc.) and organic pollutants, i.e. phenolic dyes, diphoenamide dyes and photographic pollutants etc [92,94,98-101]. Hence, water hyacinth can be used as sensitive biological indicator for continuous monitoring of trace quantities of toxic heavy metals in an aquatic system [98-100].

Biological methods for purification of water and waste water are generally more energy efficient and cost effective than physico-chemical methods. Vascular aquatic plants employing solar energy as a principal energy source have shown the capability of absorption, translocation and/or metabolic breakdown of heavy molecules present in water and waste water [102].

Saksit [102] conducted the field experimental study, batch screening study and continuous study to determine the trace heavy metal ions removal capacity of various plants in effluents and sewage waste. The objective of the field study was to observe the trace contaminant accumulation under natural condition in an effort to determine plant species for screening study. Plant species efficiency potential as determined by preliminary literature evaluation and experience. The plants were divided into three categories, viz., floating, submerged and rooted once as shown in table 2.2.

**Table 2.2** Details of aquatic plant species selected by Saksit [102]

| Sl.No. | Common Name | Scientific Name | Classification |
|---|---|---|---|
| 1. | Bulrush | Seirpus Sp. | Rooted |
| 2. | Rush | Juncus Sp. | Rooted |
| 3. | Arrohead | Sagittaria graminea | Rooted |
| 4. | Water hyacinth | Eichhornia crassipes | Floating |
| 5. | Duck Weed | Lemna minor | Floating |
| 6. | Water bonnet | Pistia stratiotes | Floating |
| 7. | Elodia | Elodia canadensis | Submerged |
| 8. | Contail | Ceratophyllum demorsum | Submerged |
| 9. | Alligater weed | Alternathera philexeroides | Submerged |

The batch screening study was conducted to determine the removal capacity of heavy metal ions by various plant species. Bulrush [Seirpus sp.] was observed as the efficient rooted system. This plant exhibited a very high capacity of removing cadmium (Cd) from aquatic system. Water hyacinth appeared to be the most effective floating species, for trace contaminant reduction and it showed the highest removal capacity of cadmium. Among the submerged plants contail (Ceratophyllum demorsum) showed the highest capability for reducing cadmium.

Plants play more dominent role than aquatic animals in the aquatic system because they have great effect on the aquatic environment and are more adaptable to either harsh or fluctuating environmental conditions. Floating plants have their photosynthetic part at or just above the water surface with roots extending down into the water column. This extensive root system acts as an excellent medium for filtration/absorption and bacterial support potential. Root development has been shown as the function of nutrients available in the water and the nutrient demand of plants [103].

Aquatic system treatment occurs at a comparatively slow rate in essentially unmanaged natural environment, while the aquatic plants, viz., E. crassipes in particular remove the trace heavy metal ions rapidly from an aquatic system. Heavy metal ions are removed from the water and waste water [103] during aquatic treatment by plant uptake (plant adsorption), chemical precipitation (formation of precipitates with insoluble compounds), ion exchange with settled clay and organic compounds and adsorption (on substrate and plant surface). Metal uptake by plants depend upon several factors including pH, concentration of metal ions, depth of root system of plant and growth rate of plant in the aquatic system. Higher initial concentration of the trace heavy metal ions, extensive root system and growth rate of water hyacinth plant increases the total uptake capacity of the plant.

The water hyacinth plants completely saturated with heavy metal ions are periodically removed and disposed of in the adjacent pit. The useful products like protein, biogas, compost, fiber etc. can also be obtained from the disposed hyacinth [73-76].

Biomass is defined as a quantitative estimate of the total mass of living organisms within a given area or volume. It may include the mass of a population or of a community but provides no information on community structure. As water hyacinth plants are living organisms of plant kingdom, they exhibits characteristics like very fast growth rate, unlimited annual productivity owing to hydrous factors, considerable power of absorbing matters (dissolved or suspended) in liquid media and as a result it has tremendous capability for water purification.

Haller et al. [104] using radioisotope of phosphorus ($P^{52}$), reported that larger amounts of phosphorus were absorbed by water hyacinth from solutions containing phosphorus. Further, upto 50% of the absorbed phosphorus backed out from the stem and root tissues within six days.

The use of water hyacinth for nutrients removal was first demonstrated in 1967 by Sheffield [91]. He reported 80% reduction in $NH_3$-N when the aerated effluent passed through water hyacinth pond with retention time of 10 days. Reduction in the nitrate nitrogen occured upto 81% but only after anaerobiosis was established in 42 days. Phosphates were reduced initially upto 51% but decreased to only 20% after one month due to the release of phosphorus from decaying plants. Clock [105] observed that in a pond with five days detention time, 39-94% of total nitrogen and 61% phosphates were removed by water hyacinth and still greater amounts were removed during the period of vigorous growth.

Miner et al. [106] reported removal of 23 lb/acre ammonia nitrogen and 17 lb/ac phosphate from a sewage lagoon. Bagnall et al. [107] found that water hyacinth removed only 9% nitrogen and 8% phosphorous from secondary treated effluent from a pond with a detention time of 10 hrs. However, the percentage removal increased to 60% with five days detention period. They also observed that crowding, lower temperature and greater water depth resulted in low removal of nutrients. Further, they recommended regular harvesting of plants at the rate of 25 to 35% per week. Similar observations on depth of water and retention time were made by Cornwell et al. [108] and Minshall et al. [109].

Other factors affecting the removal of nitrogen and phosphorus include release of nitrogen as gas, concentration of nutrients due to evaporation, formation of complex precipitates involving phosphates and growth rate of plants, temperature etc. It has been pointed out that in temperate region, the plants would have to be introduced every year and large populations would be required to remove nutrients within a short time [110].

The capability of pollutant removal by water hyacinth have been found during different studies. The data obtained for the removal of some of the pollutants is quite impressive, viz., 100 mg phenol in 72 hrs. by 2.72 gms dry wt. of water hyacinth [101], 75 mg fluoride [89] and also 80.8% cadmium in seven days [111]. The water hyacinth have also been shown to accumulate abnormally high quantities of cobalt and Iron [111]. In another study, hyacinth plants have also claimed to absorb sulphates and sodium from textile factory wastes [112]. Based on these studies, the use of water hyacinth in sewage treatment has been suggested by many workers [98,99,113-114] particularly for advanced water treatment [115].

Shankar et al. [4] found that Eichhornia plant grown by using effluents of Indian Drugs and Pharmaceutricals Ltd. Rishikesh, Uttar Pradesh, India, were healthy and the number of leaves increased four times within 30 days and was better than that of plant grown using tap water. Besides, there was increase in dissolved oxygen level and decrease in BOD value of effluent. Hardners, alkalinity, turbidity and Chloride on the other hand showed a declining trend.

The use of Chlorella pyrenoidesa and Scenedesmus species in the removal of nutrients from the waste water has also been reported by Tam and Wong [116]. It was found that these plants were capable of reducing more than 80% of total phosphorus and inorganic nitrogen present in settled sewage. Jain et al. [117] used recently Azolla pinnata and Lemna minor for the removal of lead and zinc from polluted water.

Thus, it is clear that plant species have long been used for removal of toxic metal ions from the effluents and waste water and thus are the cheap source for pollution reduction. In the present studies, attempts have been made to use Eichhornia crassipes, Lemna minor and Ceratophyllum demorsum for the removal of pollution load. The physico-chemical characteristics of waste water have also been determined before and after the treatment. It was observed that species of Eichhornia is particularly useful for reducing the pollution load of sewage and effluent under investigation.

# CHAPTER - III

# MATERIALS AND METHODS

## 3.1 DETAILS OF RIVER DHAMOLA

Dhamola river is an important river of Saharanpur city of Western Uttar Pradesh. It originates from Dehradun hilly region (basin of Himalaya) as a natural water source. It flows through the Saharanpur city from North to South. The quality of water of this river, about 5 to 6 Kms before entering into Saharanpur city, is very good and is used for drinking, bathing and agricultural purposes by animals as well as human beings. The altitude of the river Dhamola near Saharanpur is about meters. The flow of this river ranges from 2-3 km/hr during entire year. The length of this river in Saharanpur city is about 12 kilometers and breadth almost 10-30 meters which depends on the mode of flow. The total flow of water is about 500-800 million liter per day. The average depth of the river is about 0.9-1.5 meters. But the depth and breadth of this river is different at different sampling stations. The water of the river Dhamola just before entering the North of Saharanpur city (upstream) is colourless and visually looks pure, whereas, after about 12 kilometers of entering the Saharanpur (down stream), the grey colour of the water can be easily seen. Essential micro and macro nutrients of the water in the river are very much influenced by the mixing of waste discharge. Hence, the contamination by sewage and other waste products causes pollution by disturbing the water quality of river Dhamola. Since, Saharanpur is an important city, it was considered interesting to explore the cause of pollution in Dhamola river so that the role of industrial effluents and sewage on pollution can be evaluated.

The quality of Dhamola river water before entering the Saharanpur city is very good and the flora and fauna (aquatic) survive magnificiently. But, after the mixing of industrial effluents and sewage water, the aquatic life was found to be disturbed. The origin of river Dhamola and map of Saharanpur city, position of industries and points of mixing effluents and sewage discharge into the river Dhamola are presented in figures 3.1 and 3.2.

## 3.2 SAMPLING STATIONS

Sampling stations were selected after an extensive survey of the area on the basis:

- that the site represents the state of aquatic system including inputs, withdrawls and other related features.

- that it should be accessible in all seasons.

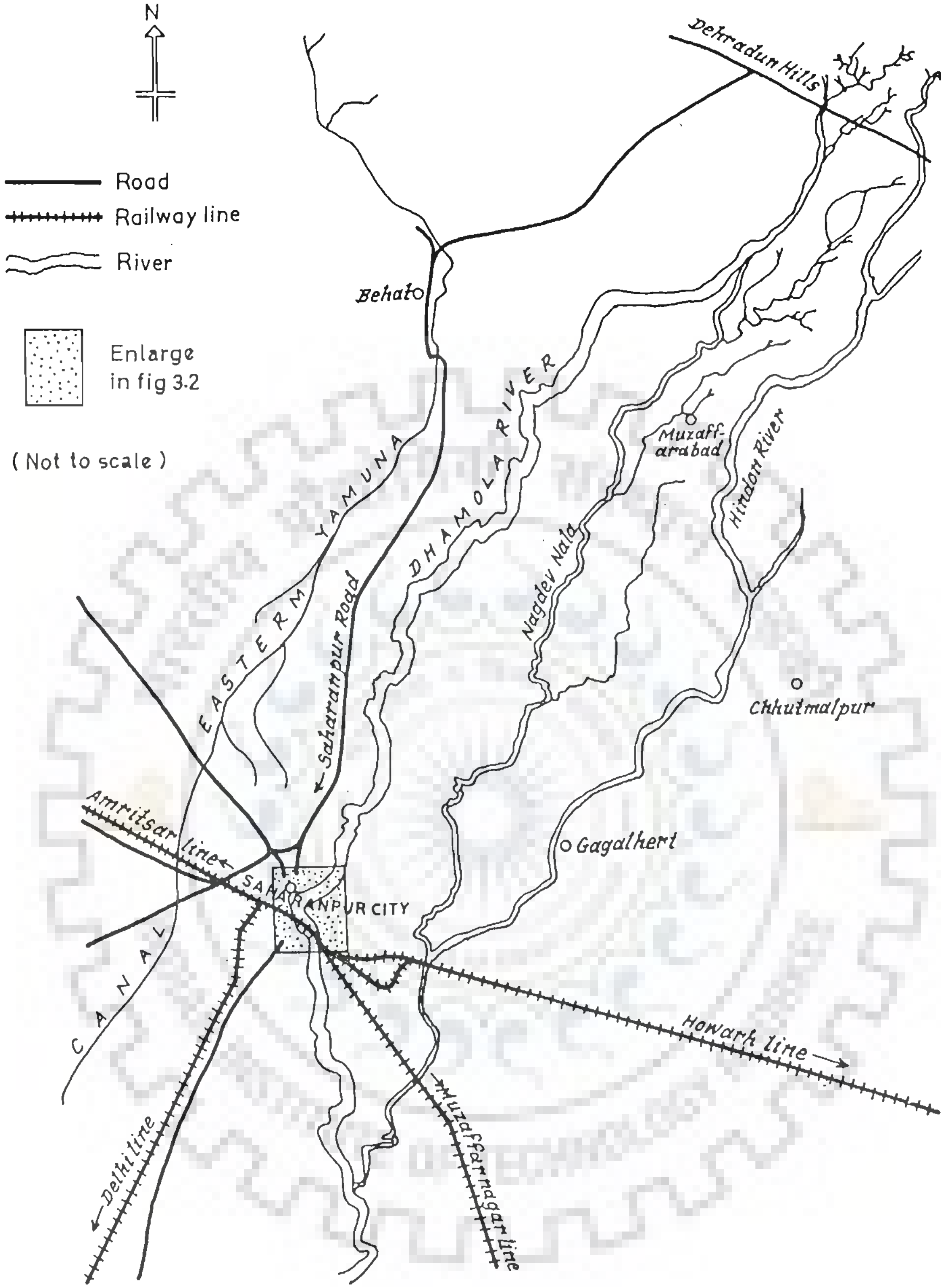


Fig. 3.1 Area map for the origin of River Dhamola

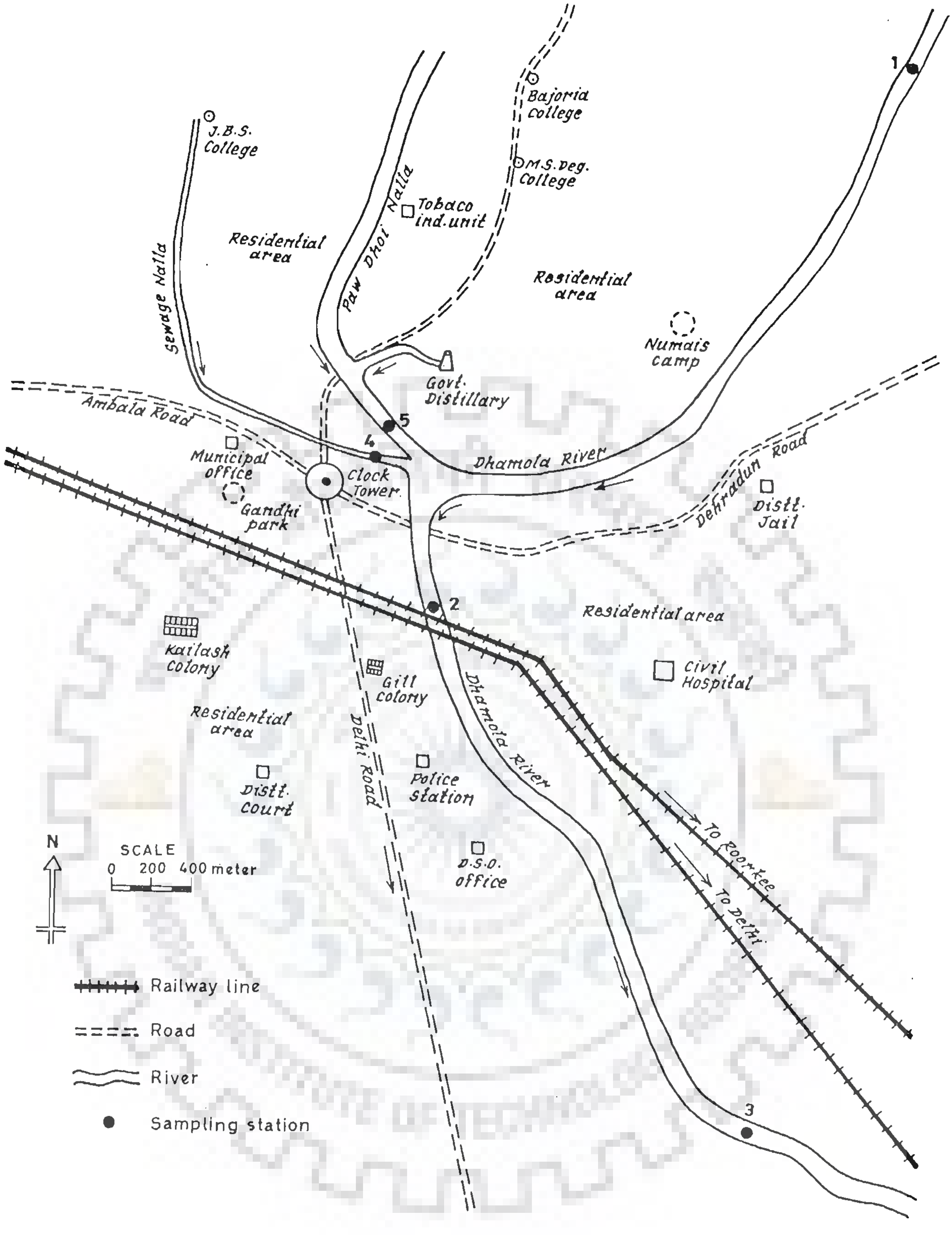


Fig. 3.2 Area map of river Dhamola in Saharanpur city

- that it should have uniformity of concentrations of pollutants across the river section implying well mixed conditions, and

- that it should be concerned with the population of that place.

Five sampling stations covering the stretch of about 12 Kms of Dhamola river at different areas of Saharanpur were selected as shown in Fig. 3.2. Points 1,2 and 3 provided water of the river Dhamola whereas 4 and 5 are the sampling stations of sewage water and industrial effluent respectively. The details of the selected sampling station are as follows:-

### 3.2.1 Sampling Station - 1

The first sampling station was selected before the entering of Dhamola in Saharanpur city. This sampling station is represented by no.1 in fig. 3.2. At this point the depth of the river is about 1.2 meters and breadth about 20-25 meters. The flow of water at this point is about 2 kms/hr. The water looks visually pure. A photograph of this sampling station is presented in plate - 1.

### 3.2.2 Sampling Station - 2

The second sampling station was selected after 2 km of the mixing of effluent waste discharge (industrial as

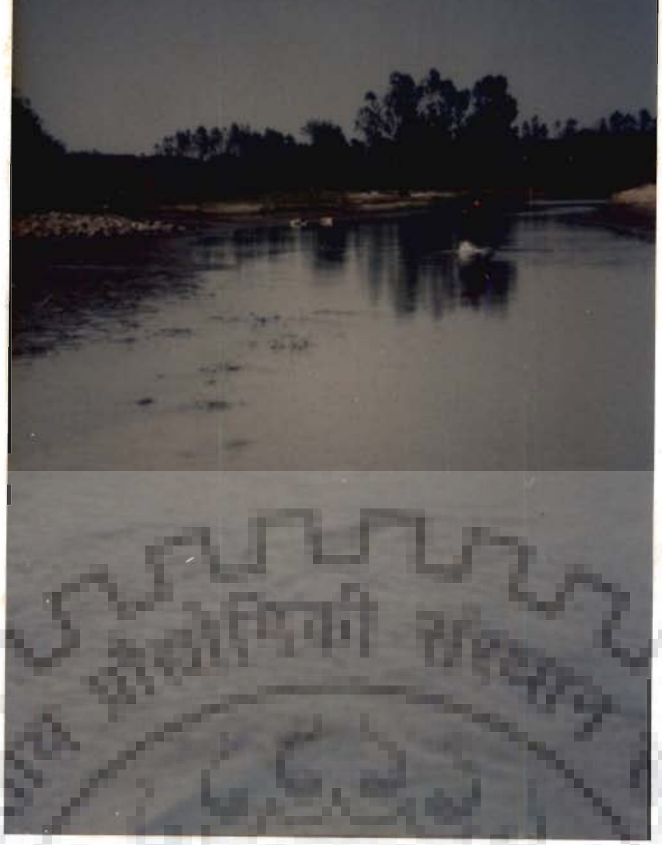

Plate 1 Dhamola river before entering into Saharanpur City (sampling Station 1)

Plate 2 Mixing of waste water into the river Dhamola

well as domestic) at about 7 kilometers from sampling station 1. The water at this point is dark grey in colour with pungent smell. The depth of the river at this point is about 1.35-1.5 meters and breadth 20-30 meters. The usual flow at this point is also about 2-3 km/hr. The altitude at point - 2 is 266.67 meters. Photographs of Dhamola at sampling point - 2 are presented in plates 2 and 3.

### 3.2.3 Sampling Station - 3

The third sampling station further down stream was selected outside the city about 5 kms apart from sampling point - 2. The depth and breadth at this sampling station is practically similar to point - 2. The flow rate of water was also found to be same as that of points - 1 and 2. The elevation of this point is 265.37 meters. Photographs showing details of this sampling station are presented in plates 4 and 5.

### 3.2.4 Sampling Stations 4 and 5

The fourth and fifth sampling stations selected were the places where the sewage water and the effluent of the industries respectively as shown in Fig. 3.2. Though the waste water of industry and sewage merge in Dhamola at the same point, however, the samples of both were collected separately about half a kilometers before the mixing in Dhamola. The exact discharge from the industries and sewage could not be determined. However,

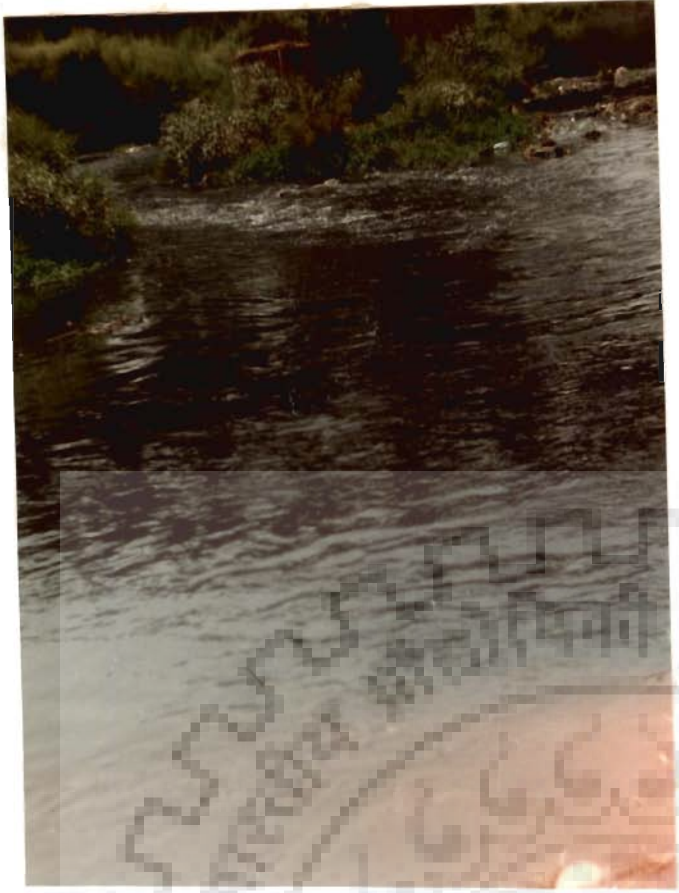

Plate 3  Sampling station 2

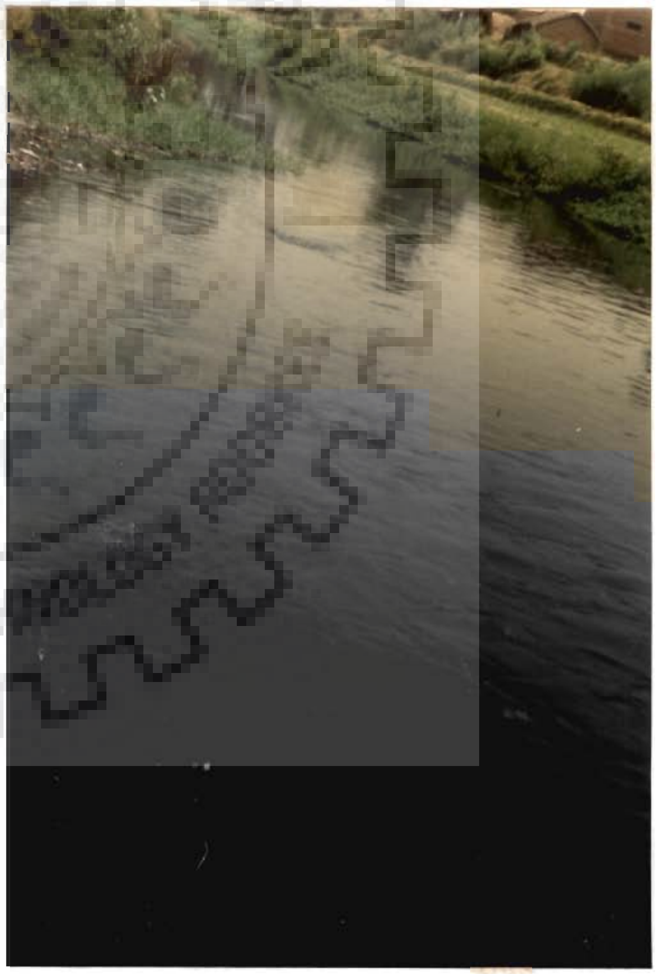

Plate 4  Sampling station 3, seven kms downstream of the waste water mixing

Plate 5 Sampling station 3 (close up)

Plate 6 Domestic sewage (sampling station 4)

the approximate values mentioned by the related authorities were 80-100 million liters per day for sewage waste and 50-60 million liters per day for industrial effluent. Some selected photographs taken at various points are presented in plates 6 and 7.

### 3.3 Sampling Program

Samples from points 1 to 5 were obtained on 15th/16th of every month from July, 1988 to June, 1989. From July 1989 onwards, the frequency was reduced to once in three months.

### 3.4 Sample Collection

For physico-chemical analysis , the samples were collected in large polyethylene containers. These containers were cleaned with dilute NaOH before sampling and again washed several times with water for sample collections. Samples were collected at the depth of approximately 0.5 meter below the surface of running water. Handling of samples was done very carefully to minimize the occurrence of any change during storage and transportation. Samples for the determination of dissolved oxygen were collected in 300 ml BOD bottles with the help of a sampler. The bottles were filled completely upto the brim. These samples were preserved by adding 1.0 ml each of alkaline potassium iodide solution and mangnous sulphate solution at the sampling sites.

Plate 7 Industrial effluent (sampling station 5)

As the water at the top of the fast flowing river has low plankton density, the samples for plankton studies were concentrated in order to get count in an appropriate range. 100 litres of water collected by a bucket of 10 litres, was filtered through a plankton net (bolting silk No. 25, mesh size 55 micron) to collect the plankton samples. The total community obtained was transferred to a clean 250 ml glass bottle and the final volume was made upto 100 ml with the filtered water. Generally the preservation was avoided as it may result in the transformation of shape and size of some of the individual organisms, making the identification difficult. Wherever it was necessary, two parallel samples were taken, one without preservative and the other with preservative (4.0 percent neutralized formalin).

Water samples for bacteriological examination were usually taken from a depth of 0.3-0.5 meter below the surface. Bacteriological water samples were collected in sterile narrow mouthed glass bottles of 250 ml capacity with ground stoppers. The details of various containers used for collection of samples, their optimum storage time and the method for the preservation related to various water characteristics are summarised in Table 3.1.

**Table 3.1** Summary of special sampling or handling used

| Parameters | Container | Optimum storage time | Method of Preservation |
|---|---|---|---|
| Turbidity | P | With in a week | Refrigeration |
| Total solids | P | With in a week | Refrigeration |
| pH | P,G | Analysed at site | - |
| Total hardness | P | Analysed same day | Refrigeration |
| Chloride | P | Analysed with in a week | Refrigeration |
| Dissolved oxygen | G | Fixed at sampling site, analysed same day | Refrigeration |
| BOD | P,G | Analysed and incubated same day | Refrigeration incubated in BOD incubator |
| COD | P.G. | Analysed same day | Acidified with concentrated $H_2SO_4$ |
| MPN (Coliform bacteria) | G | Analysed same day | Refrigeration |
| SPC(Coliform bacteria) | G | Analysed same day | Refrigeration |
| Algae | G | Analysed same day | Refrigeration |
| Diatoms | G | Analysed same day | Refrigeration |
| Protozoan | G | Analysed same day | Refrigeration |

P = polyethylene container, G = glass bottle.

## 3.5 SIGNIFICANCE OF PHYSICO-CHEMICAL PARAMETERS

### 3.5.1 pH

pH is an important parameter of both natural and waste water as it is a measure of acidity or alkalinity. The pH range for the existence of most biological life is quite narrow. The industrial waste, due to the presence of acids and alkalies in it, alter the pH of the water at mixing point. It is thus very important that the excessively acidic or alkaline waste should not be discharged without neutralizing the acidity or alkalinity of the waste water. The determination of pH value also helps in the chemical and biological treatment of the waste water.

### 3.5.2 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. In water, turbidity is caused due to the presence of suspended matter like, silt, clay, finesand, inorganic and organic matter, soluble coloured organic compounds, plankton and other micro organisms. It is useful in describing the clearity of water. The turbidity is measured in Nephlo Turbid Unit or Jackson Turbid Unit.

### 3.5.3 Total Solids

Total solids value for a water sample is defined as the amount of residue left after the evaporation of a known volume of sample and its subsequent drying in an oven at a fixed known temperature. The total solids determined in a water sample include the dissolved material, e.g., soluble organic/inorganic compounds, and suspended matter (plankton, clay, and other micro and macro organisms). Water with high total solids generally affect water quality adversely as it has inferior palatability. A limit of 500 mg dissolved solids/lire is generally acceptable for drinking water.

### 3.5.4 Dissolved Oxygen

Dissolved oxygen is an important test for determining pollution in water. The level of dissolved oxygen in natural and waste water depends upon the physico-chemical and biochemical activities in the water body. It directly affects the aquatic life in water because it is necessary for all the aerobic micro as well as macro organisms. It is measured in mg/l. and calculated using the expression :

DO (mg/l) = volume in ml of 0.025 N $Na_2S_2O_3$ used in titration

### 3.5.5 Biochemical Oxygen Demand

BOD is the amount of oxygen required by micro-organisms for the degradation of organic matter under aerobic conditions. The waste water usually does not contain sufficient amount of oxygen to maintain aerobic condition during degradation. For complete stabilization of organic matter, required amount of oxygen is taken as a measure of its organic content. It is measured in mg/l unit. The relation used for calculation of BOD is :

$$BOD\ (mg/l) = \frac{[D_1 - D_2] - [B_1 - B_2]\ f}{P}$$

where

$D_1$ = DO of diluted sample immediately after preparation (mg/l).

$D_2$ = DO of diluted sample after 5 days incubation at 20°C (mg/l).

$B_1$ = DO of seed control before incubation (mg/l).

$B_2$ = DO of seed control after incubation (mg/l).

P = decimal volumetric fraction of sample used.

f = ratio of seed in diluted sample to seed in seed control (% seed in diluted sample)/(% seed in seed control).

### 3.5.6 Chemical Oxygen Demand

Chemical oxygen demand is the required amount of oxygen in water for the complete oxidation of organic matter. It is directly related to the chemical changes in natural water bodies due to the mixing of certain waste products (industrial as well as domestic). It is measured in mg/l units. It is determined using the expression :

$$COD\ (mg/l) = \frac{[a - b]\ N \times 8000}{ml\ of\ sample}$$

where

a = ml of $FeSO_4(NH_4)_2SO_4$ for blank.

b = ml of $FeSO_4(NH_4)_2SO_4$ for sample.

N = Normality of $FeSO_4(NH_4)_2SO_4$ solution.

### 3.5.7 Carbon Dioxide (Free)

Pure water usually contains less than 10 mg free carbon dioxide per litre. The $CO_2$ content of water is an important parameter as it contributes significantly to corrosion. Free carbon dioxide occurs in water due to the combustion of carbonic matter present in water bodies. It can be determined by potentiometric titration or with phenolphthalein indicator. In the present studies phenolphthalein indicator method was employed. The calculation used is as follows :

$$CO_2\ (mg/l) = \frac{A \times N \times 44000}{ml\ of\ sample}$$

where

A = ml used of the titrant

N = Normality of titrant

### 3.5.8 Chloride

Chloride is another important water quality parameter which gives an idea of the hardness and taste of water. It is present in the form of chloride ($Cl^-$) ions which are the major inorganic anions in water and waste water. The amount of chloride present in water varies from 10 mg/l to 500 mg/l in natural water bodies depending upon the source. The high value of chloride in water indicates pollution. The municipal sewage is the primary cause of increase in chloride concentration as NaCl is a common constituent of diet and passes unchanged through the digestive system. It is represented as mg/l and can be calculated using the formula :

$$Cl^- \text{ (mg/l)} = \frac{(\text{ml of } AgNO_3 \text{ used for sample} - \text{ml of } AgNO_3 \text{ used for blank}) \times 1000}{\text{ml of sample}}$$

### 3.5.9 Total Hardness

Hardness in the water is due to the presence of salt of calcium and magnesium. Hence, the total hardness is defined as the sum of calcium and magnesium concentrations. It poses problem of scale formation in boilers. The hardness of water may vary from zero to about few hundred mg/l depending on the source of water. It is expressed as calcium carbonate in mg/l. It is determined by volumetric method using EDTA. The hardness is calculated using expression :

$$\text{Hardness (mg } CaCO_3/l) = \frac{A \times B \times 1000}{\text{ml of sample}}$$

where

A = ml of titrant for sample

B = mg $CaCO_3$ equilent to 1.0 ml EDTA.

## 3.6 METHODS USED

A brief summary of the techniques used and its principle for physico-chemical and biological parameters is presented in Table 3.2.

## 3.7 CHEMICALS AND APPARATUS USED

The chemicals used for determining physico-chemical and biological parameters of water were obtained from the following sources : E.Merck (India) Limited, Bombay, (Ammonia buffer, Potassium chromate indicator, Silver nitrate, Mangnous sulphate, Potassium iodide, Sodium thiosulphate, Starch, Phosphate buffer, Magnesium sulphate, Ferroin indicator, phenolphthalein, Potassium hydrogen phthalate and Sodium hydroxide), HiMedia, Bombay (Lactose, Peptone, Sodium chloride, Eriochrome black T-indicator) and BDH chemical Division, Bombay) (Sulphuric acid, Ferric chloride, Calcium chloride, Potassium dichromate and Ferrous ammonium sulphate).

**Table - 3.2 Summary of Analytical Methods**

| Parameters | Technique | Principle/Apparatus |
|---|---|---|
| Turbidity | Nephelometry | Nephelometry [118] |
| Total solids | Gravimetric | Evaporation at 103°C - 105°C |
| $CO_2$(free) | Volumetric | Phenolphthalein titration, titrant 0.1 N NaOH [118] |
| Hardness | Volumetric | Complexometric titration [118] titrant 0.01 EDTA, indicator-Erichrome black-T indicator, using ammonia buffer. |
| Chlorides | Volumetric | Argentometric titration[119] titrant M/35.5 $AgNO_3$, indicator potassium chromate ($K_2CrO_4$). |
| Dissolved Oxygen | Volumetric | Wrinkler's Method [119], titrant N/80 Sodiums thiosulphate indicator starch (fresh). |
| BOD | Volumetric | Wrinkler's method [118] 5 day incubation at 20°C. |
| COD | Volumetric | Reflux method followed by redox titration, titrant -0.1 N Ferrous ammonium sulphate [$FeSO_4(NH_4)_2SO_4$], indicator Ferroin [118]. |
| MPN | McConkey | Three tubes of McConkey broth (purple) incubated for 24 hrs and 48 hrs. |
| SPC | dilution | Standard agar plate (1.5%) incubated for 24 hrs [118]. |
| Phytoplankton | Microscopic | Sedgwick-Rafter Counting Cell, 1/100 dilution [118]. |
| Zooplankton | Microscopic | Sedgwick-Rafter Counting Cell, 1/100 dilution [118]. |

The glass apparatus used for physico-chemical and biological parameters were sterilized in an autoclave (SEW India, Delhi). The pH was determined using Global, DPH-500 pH meter. HACH Nephelometer (turbidity meter model - 2100 A) was employed for determination of trubidity. The oven (model-USW 143), BOD incubator (Narang Scientific Works, New Delhi), Sedgwick-Rafter Counting Cell, Plankton net (No.25), S-J Sampler, colony counter and microscope (model - 47, Beck, London were used.

## 3.8 BIOLOGICAL PARAMETERS

### 3.8.1 Plankton

The counting of different phytoplankton and zooplankton, e.g. algae, diatoms and protozoan was achieved from the 100 ml sample in which total community was suspended after filtering the water through plankton net. The device employed for counting was based on the Sedgwick Rafter (S-R) counting cell at area 50 x 20 x 1 mm with a total capacity of 1.0 ml sample. The sample was mixed throughly using a shaker at the speed of 25 r.p.m. 1.0 ml of the sample was then transferred by using a large bore pipette to Sedgwick Rafter cell cavity. All the plankton population (algae, diatoms and protozoan) were counted in 100 random fields (chambers) simultaneously under 40 times magnification with a Metzer compact inverted microscope [120]. The average number of plankton count per chamber was multiplied by the total countable factor to obtain the total number of individuals per species in the concentrated samples. The counting of one sample was made atleast three times to get a reliable information. For the identification of plankton species, high magnification (450 times) was used. The planktons were identified with the help of following Edmondson [121], Smith [122], Desikachary [123] for phytoplankton and Pennak [124], Calaway and Lackey [125] and Needham and Needham [126] for zooplankton.

### 3.8.2 Bacterial Population

The water samples collected in 100 ml glass bottles were immediately tested for coliform and total heterotrophic bacterial, e.g. for the incubation in the field, a portable, battery operated incubator was used. The temperature of incubation was 35 $\pm$ 0.5$^{o}$C and the time was 24 hrs. In some cases a multiple of 24 hrs as required for the different test was used.

#### 3.8.2.1 Coliform Bacteria (MPN)

Population of total coliform was enumerated by MPN techniques as per Standard Methods [118]. The tubes of $M_c$Conkey broth (purple) were used for each dilution. The unit to determine the MPN count is number of bacteria per 100 ml.

#### 3.8.2.2 Standard Plate Count of Heterotrophic Coliform Bacteria

The total heterotrophic coliform bacteria were enumerated in terms of standard plate count (SPC) bacteria using nutrient agar (1.5%) as culture media. The water samples collected were diluted in saline (0.9% NaCl) and checked on agar-agar plates for the bacterial colony measurement by the innoculation method. If the number of colonies were more than 300, the samples were further diluted and left for 24 hrs and the colonies were counted again. The counting of SPC is generally number of bacteria present per ml.

## 3.9 STATISTICAL ANALYSIS

### 3.9.1 Correlation Coefficient

For the purpose of this investigation, we have utilized a comprehensive data observed for the three distinct sampling sites at river Dhamola during the period of two years from July 1988 to June 1990. In order to calculate the correlation coefficients among the water quality parameters of river Dhamola, we have used all the fourteen water quality parameters determined in the present studies. These are turbidity total solids, pH, hardness, chloride, $CO_2$, DO, BOD, COD, MPN, SPC, algae, diatoms and protozoans.

Let x and y are two variables (water quality parameters in the present case) and $x_1y_1$ be n pairs of the observed values of these variables (i = 1,2,3,4....,....n and n = 48 in the present case). Then the correlation coefficient 'r' between the variables x and y can be represented by the relation :

$$r = \frac{\Sigma YX}{[\Sigma X^2 . \Sigma Y^2]^{\frac{1}{2}}} \qquad ..... 1$$

where

$$X = (x-\bar{x}), \quad Y = (y-\bar{y}) \qquad ..... 2$$

and $x = [\Sigma x]/n, \quad y = [\Sigma y]/n \qquad ..... 3$

and all the summation [ x or y] are to be taken for n number of observations.

### 3.9.2 Parameters of Straight Line

If the correlation coefficient 'r' between two variables x and y is fairly large, it can be calculated that a linear relationship of the form:

$$y = A + Bx \qquad ..... 4$$

exists between the two variables. In this equation A and B are the parameters of the straight line and the value of A and B are constant for a particular line. It has been showed by Wonnacott and Wonnacott [127] and Spiegel [128] that the best estimates of the parameters A and B can be represented by the equation :

$$B = \frac{\Sigma (x-\bar{x}) \quad (y-\bar{y})}{\Sigma (x-\bar{x})^2}$$

i.e.

$$B = \frac{\Sigma x.y - \bar{x}.\Sigma y}{\Sigma x^2 - \bar{x}.\Sigma x} \qquad \ldots\ldots 5$$

$$A = \bar{y} - B\bar{x} \qquad \ldots\ldots 6$$

where

A is the intercept and

B is regression coefficient i.e. slope of the line. The summations are to be taken from 1 to n as in the earlier case.

## 3.10 BIOMASS OF HYDROPHYTES

Total biomass of hydrophytes was determined in the terms of dry mass of plants. A known quantity of plant was taken and dried in an oven at 110°C for 15 minutes. It's mass was then determined. The temperature of the oven was then reduced to 50-55°C and the plants were dried for a week. The mass of dried plant was then determined. Biomass was then calculated as the percentage of the dried weight.

Change in Biomass = Final biomass - initial biomass

Final biomass = Mass obtained after one week

Initial biomass = Mass obtained after 15 minutes

## 3.11 REMOVAL OF POLLUTION LOAD

The waste water samples collected for domestic sewage and industrial effluent (collection points 4 and 5, Fig. 3.2) were transferred into 60 litres polyethylene container and allowed to settle for 2-3 hours. After the sedimentation, the waste water was poured into the aspirator bottle (20 litre) and allowed to flow until all the jars shown in Fig. 3.3 were atleast half filled. The stopper of all the jars was then closed so that the flow of sample from one jars to another could be stopped. The following hydrophytes were taken in the jars:

Stage I - Eichhornia crassipes

Stage II - Lemna minor

Stage III - Ceratophyllum demorsum

Stage IV - Eichhornia crassipes and Lemna minor

Stage V - Lemna minor and Ceratophyllum demorsum

A sketch of the plant species used in stage I to III is presented in fig. 3.4. Three such arrangements were made so that the data can be obtained in triplicate.

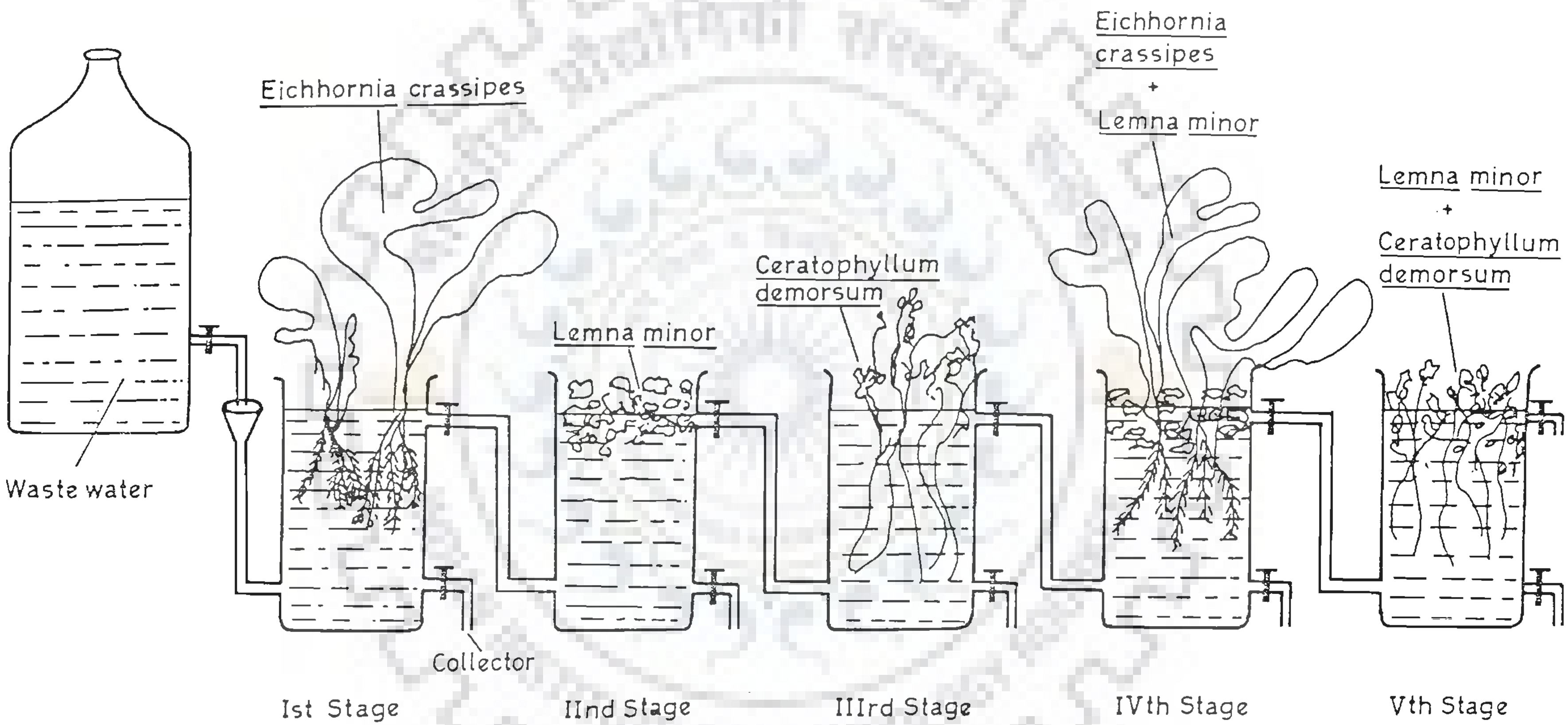


Fig. 3.3 Details of the treatment process used for the water samples with the selected hydrophytes


Fig. 3.4 Outlines of the different species of hydrophytes used

The hydrophytes added at each stage was fixed in such a manner so that the surface area of the sample was totally covered. All the experiments were performed at room temperature. The samples were analysed for the physico-chemical and biological parameters at different times, viz., zero, seven, fourteen, twenty one and twenty eight days. The values obtained are represented as a percent reduction in the values of physico-chemical and biological parameters.

# CHAPTER - IV

# RESULTS AND DISCUSSIONS

To determine the extent of pollution in river Dhamola, the various samples of water collected were analysed for three basic criteria to evaluate the quality of water. They are physical, chemical and biological. The physical and chemical parameters are concerned with a variety of procedures and in general depend on the source and many other factors. However, a complete chemical analysis of water provides a reasonably accurate picture of the quality of water. The biological analysis indicates about the pollution in terms of the presence of intestinal bacteria and other microscopic organisms in water.

## 4.1 RIVER WATER OBSERVATIONS

The water samples in river Dhamola were collected for the period July 1988 to June 1990. The details and frequency of the collection have been described in Chapter - 3. The physico-chemical characteristics of the analysed samples are described below :

### 4.1.1 Turbidity

The turbidity of the samples collected at various sampling stations of river Dhamola was found in the range of 18-130 NTU. It was however, observed that turbidity for all the three sampling stations was higher in the monsoon season [August, September, 1988] and then decreased in the period of October 1988 to April 1989. It was interesting to note that the value of turbidity at sampling station 1 was always lower than stations 2 and 3 through out the year. The higher values of turbidity at all the three sampling stations in the monsoon season have been ascribed to the rainfall which increase the amount of suspended solids and thus causes an increase in turbidity. Similar observation has also been reported in the literature by Canale et al. [129]. A detailed seasonal variation of turbidity is presented in Fig. 4.1(a).

### 4.1.2 Total Solids

The total solids (mg/l)determined at sampling station 1 was always found much lesser than at sampling stations 2 and 3 as prescribed in Fig. 4.1(b). The value of total solids during the rainy season (July - September, 1988) were always found higher at all the three sampling stations. This may be due to the presence of sandy particles coming from mountains as suggested by Valdiya and Bartarya [130]. A similar phenomenon has also been observed for Ganga water [131] which indicated that the maximum number of total solids was found during the rainy season, whereas, minimum was in winter and summer. Vander-Weijden et al. [62] have also observed the higher value of total solids during rainy season in Rhine river and explained it due to the deposition of suspended matter in river. The total solids were also found to be practically similar at stations 2 and 3 during the period of April to June, 1989 and thus indicated that during this period the heavy particles present in river Dhamola do not settle for a stretch of about 5 kms. (distance between sampling station 2 and 3). Hence the increase in total solids due to the mixing of waste water/effluents at station - 2 remains same even after 5 kms of mixing at station 3. The higher value of total solids observed at sampling stations 2 and 3 was due to the mixing of waste water further finds support from the observation of Bendic and Stojanta [10] according to which municipal sewage and effluents have been reported to possess higher value of suspended particles.

### 4.1.3 pH

The value of pH represents the $H^+$ concentration for samples. The change of pH with seasonal variations for all the three sampling stations are presented in Fig. 4.1(c). It is observed that the pH value of river water at sampling station 1 varied in the pH range of 7.15 - 7.95. It was found lower than sampling stations 2 and 3 in all seasons except in the month of September, 1988, where the value exceeded to 7.95. One of the probable reasons for this increase in pH may be the heavy rains which were observed in the month of September 1988 (rainfall in September 1988, 139 mm). At sampling stations 2 and 3 the pH value of the samples was slightly

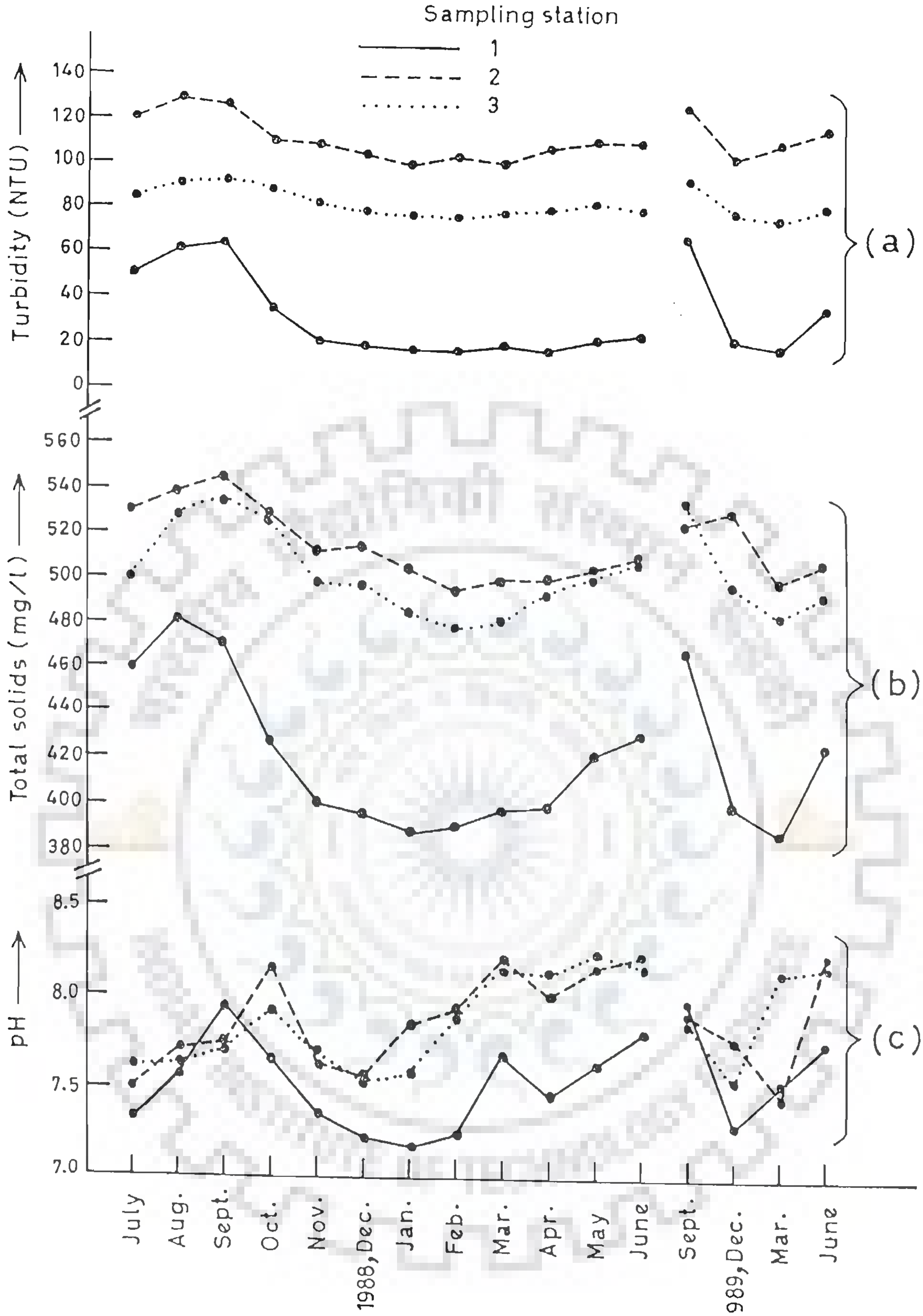


Fig. 4.1 Seasonal variations observed for turbidity, total solids and pH at different sampling stations from July 1988 to June 1990

higher in October 1988 and in the period of March - June 1989. During the winter season (November 1988 to February, 1989), the pH values were relatively lower at all the three sampling stations. The increase in the pH value of the river water during rainy season has also been suggested by Hutchinson [132] and Welch [133]. Such an increase has been suggested due to some oxidation - reduction reactions in the presence of degradable and non-degradable matter, during rainy season. The decrease in pH values during winter has been suggested due to the lowering of suspended matter and also due to the decrease in temperature [134]. The carbon dioxide equilibrium also causes a decrease in pH. It affects the water quality due to the changes in biological activity [135,136]. The variation in pH in 1989-90 also indicated practically similar trend.

### 4.1.4 Total Hardness

The total hardness value of samples collected at sampling station 1 was found in the range of 129-151 mg/litre during the entire period of investigation and thus indicated that water at sampling station 1 is not hard in nature. The variations in the hardness at sampling station 1 with seasonal variation were not significant and are depicted in figure 4.2(a). However, the value of hardness observed at sampling stations 2 and 3 was much higher and practically identical at stations 2 and 3. Thus, after the mixing of waste water from sewage and industrial effluents, the hardness increased upto 249.0 mg/l. It was thus concluded that due to the mixing of effluents and sewage in the river Dhamola, there is a significant increase in hardness, which lasted atleast for a stretch of 5 kms (distance between points 2 and 3). The increase in total hardness upto about 350 ppm in Ganga and Bhagirathi river waters due to the mixing of industrial effluents has also been reported in the literature [137,138].

### 4.1.5 Chloride

The value of chloride ion ($Cl^-$) content in the water samples collected at sampling station 1, was always observed lower than sampling stations 2 and 3, throughout the period of this investigation. The higher value of $Cl^-$ in the waste water stimulates the $Cl^-$ concentration in running water [59]. The maximum value of chloride ($Cl^-$) ions was found in the month of December 1988 and 1989 (24 mg/l and 21 mg/l respectively). The minimum value of chloride at same sampling station was found during September - October,1988. Takakoe [11] on the other hand found maximum value of chloride ions in the month of September - October of 1977 in Nagase river in Japan. The value of chloride was found much higher at sampling stations 2 and 3 in comparison to sampling station 1 during the course of the investigation. Nevertheless, the value of chloride at all the three sampling stations reached to a maximum during winter season. The detailed seasonal variations of chloride ion at all the three sampling stations are presented in Fig. 4.2(b).

### 4.1.6 Free Carbon-dioxide

Fig. 4.2(c) depicts the effect of seasonal variation on the free $CO_2$ of water samples at all the three sampling stations. The carbon dioxide content was found to change significantly with seasonal variations. At sampling station 1, the $CO_2$ value showed a variation in the range of 0.2 - 1.1 mg/l during the entire investigation period. Samples from sampling stations 2 and 3 indicated an increase in $CO_2$ value in all seasons except in the months of March, June and September, 1989. The higher value of $CO_2$ at sampling stations 2 and 3 were probably due to the mixing of waste water from domestic sewage as well as industrial effluents at about 1 km upstream than sampling station No.2. After 5 kms downstream from the sampling station 2, the $CO_2$ value slightly decreased but was still higher than upstream (station 1). The low value of $CO_2$ observed at sampling station 1 is probably due to the great utilization of free $CO_2$ during the photosynthesis process by the aquatic phytoplankton in fresh water, which liberates dissolved as well as free oxygen. Whereas, at sampling stations 2 and 3, the higher values of $CO_2$ are due to the degradation of organic matter by the waste water discharge. Thus, it is anticipated that $CO_2$ will exhibit

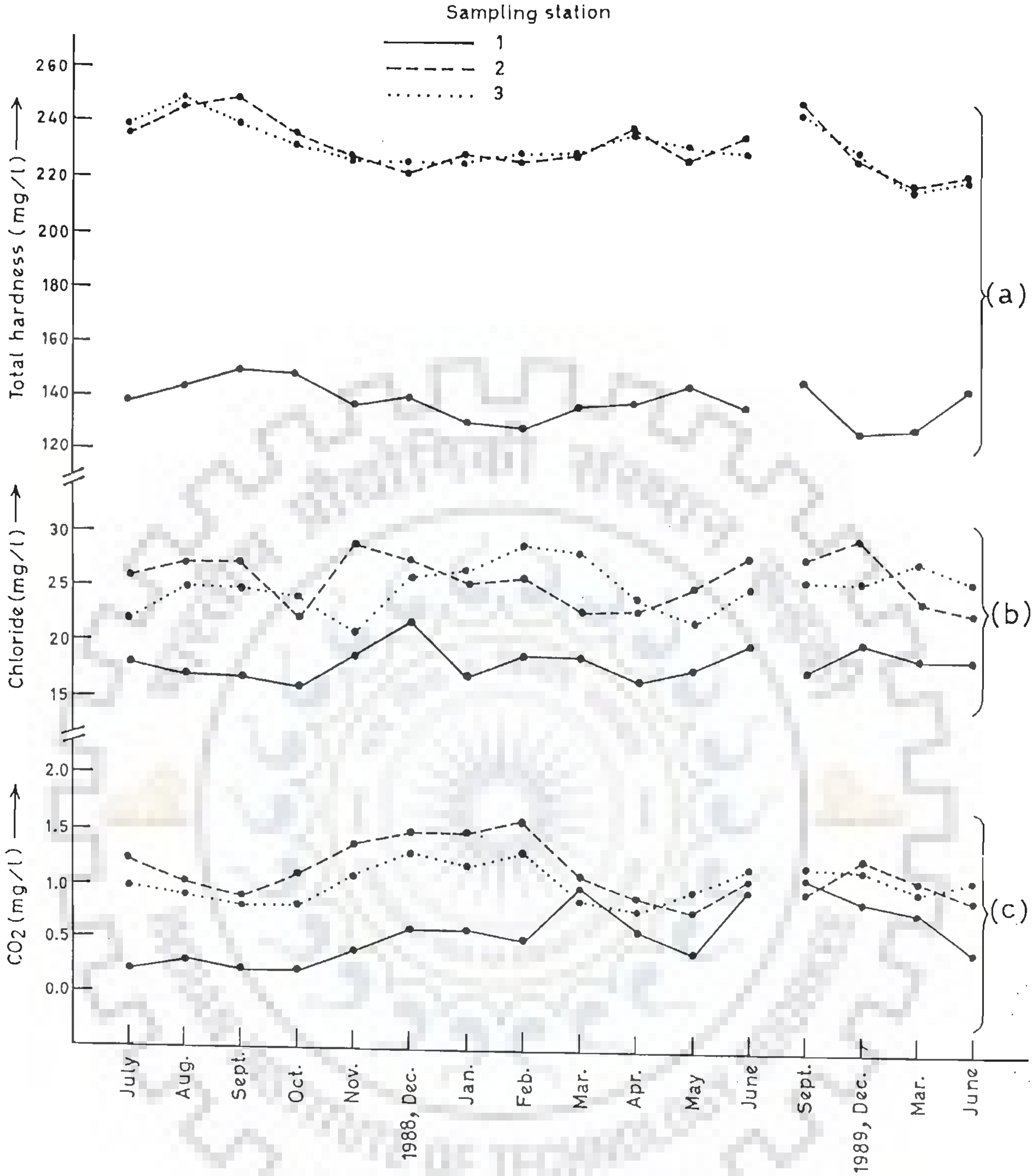


Fig. 4.2 Observed seasonal variations for total hardness, chloride ($Cl^-$) and $CO_2$ from July 1988 to June 1990

an inverse relationship with dissolved oxygen. Similar observation has also been reported in the literature by Shashi Kant and Raina [139] during limnological studies of two ponds in Jammu. Sinha et al.[140] has also observed a similar behaviour in Ganga water.

### 4.1.7 Dissolved Oxygen (DO)

The variations in dissolved oxygen content with changes in season are presented in Fig. 4.3(a)whichclearly indicates that the amount of dissolved oxygen at sampling station 1 is much higher that at sampling stations 2 and 3 during the entire period of investigation. The DO value observed at station 2, did not indicate a significant variation except in the months of June, September and December 1989 where the values observed were slightly higher. The high value of DO at station 1 can be assigned to the low organic degradable matter and high population of phytoplankton in the river Dhamola which provides a large amount of oxygen through photosynthesis [141]. The direct relationship of DO with phytoplankton, algae etc. has also been reported in the literature [142-144]. Sampling stations 2 and 3 indicated a lower value of DO probably due to the mixing of sewage and effluents and thus has been found very close to 5.0 mg/l. It thus indicated that the DO value at stations 2 and 3 is very close to the value required by aquatic life. The depletion in DO level after the mixing of waste water occurred probably due to the degradation of organic matter by foreign particles of sewage as well as industrial waste. Such a depletion of DO by sewage water as well as industrial waste has been observed for several miles downstream by Alabaster [145].

### 4.1.8 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand in fresh water of the river Dhamola was found to be influenced significantly by the mixing of waste water of domestic sewage and industrial effluents. At sampling station 1 (upstream), the BOD value was in the range of 8.0 - 18.0 mg/l throughout the period of investigations. The minimum BOD at point 1 was found during August and September 1989. The low value of BOD in upstream region of Ganga river during the period of August and September in 1980's has also been observed earlier by Sinha et al.[131] and has been accounted for on the basis of heavy rainfall. In August and September 1989, the northern part of India also observed a heavy rainfall (139 mm) and hence probably caused a decrease in BOD value. After the mixing of waste water, the BOD value increased to 86 mg/l at sampling station 2. The increase in the BOD value after the mixing of waste discharge usually occurs due to the deposition of organic degradable matter in river water and indicate the organic pollution load in the water [146]. Similar observation has also been reported by Seung et al.[147]. A 600% increase in BOD value due to mixing of industrial waste in Beronka river has also been observed earlier by

Vymazol [148]. Respess [149] has also shown the elevation in BOD value due to the mixing of sewage as well as effluents in river water. The BOD value at sampling stations 2 and 3 was almost identical during the period of July to October 1989 and then the value indicated a slight decrease at sampling station 3. The reduction in BOD value at sampling station 3, in comparison to sampling station 2, may be due to the self purification nature of sewage/effluent water [150]. The relation of BOD at all three stations with seasonal changes are presented in Fig. 4.3(b).

### 4.1.9 Chemical Oxygen Demand (COD)

Like biochemical oxygen demand the chemical oxygen demand value of fresh water (sampling station1, Fig. 3.2) was also found to increase after the mixing of sewage and industrial waste water. The value of COD at sampling station 1 was found in the range of 27-38 mg/l as presented in Fig. 4.3(c). In the months of August and September 1988, the values were lowest and in the months of May and June, highest. The low value of COD during the months of August and September, is usually observed due to the rainfall whereas, maximum value is observed in the summer season. Similar observations have also been reported in literature by large number of workers [131,134]. The COD value at this point was very low in comparison to the sampling stations 2 and 3. At sampling

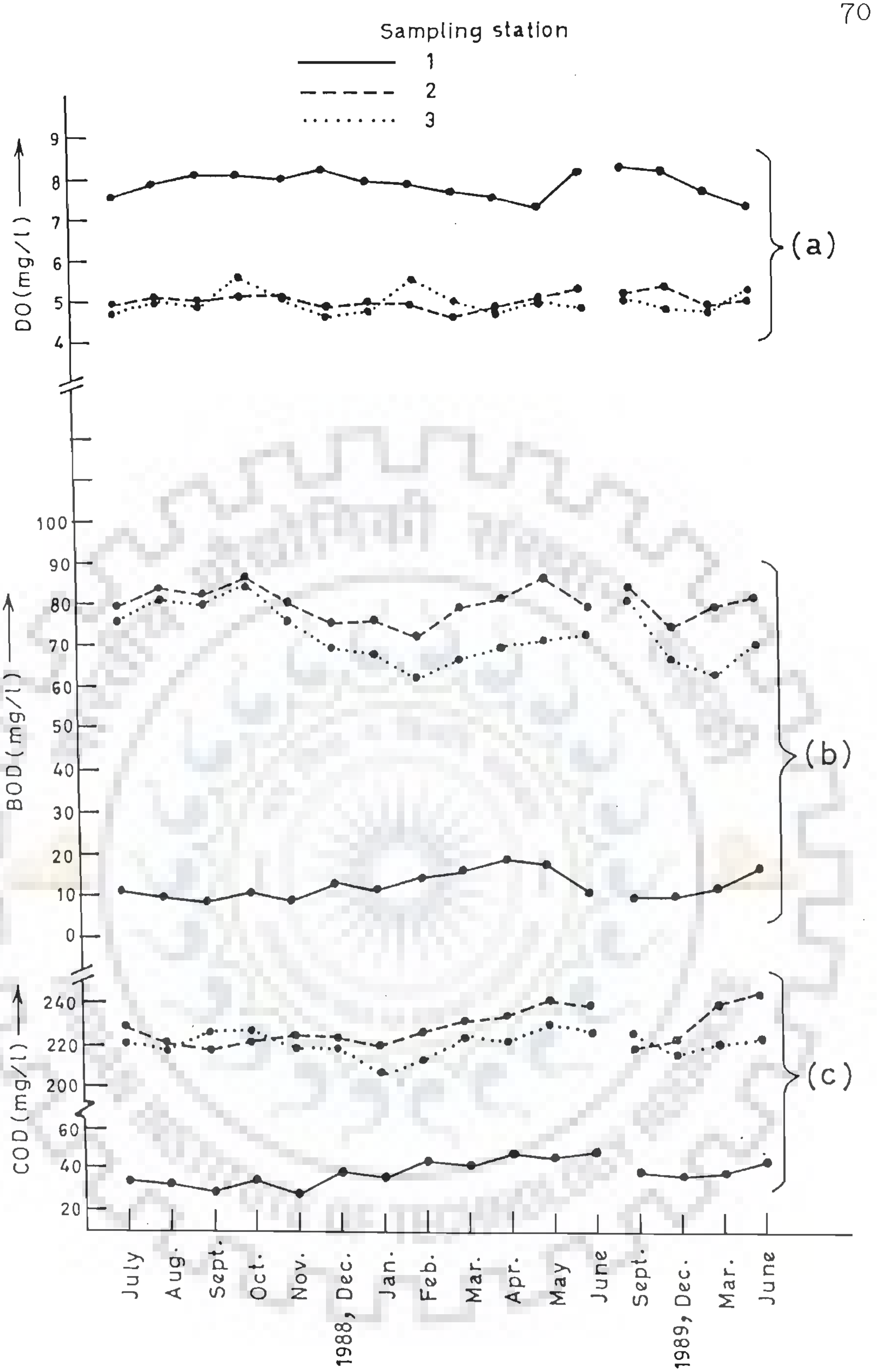


Fig. 4.3 Seasonal variations observed for DO, BOD and COD at different sampling stations

station 2, the value of COD was found in the range of 218-244 mg/l and was practically identical to sampling station 3 for the months of July to November 1988. Lalman and Dixit [138] and others [6] have also suggested the elevation in COD value of fresh water at downstream point due to the mixing of industrial waste disposal.

The use of river water with high value of COD may cause health hazards to both humans and domestic animals as suggested by Bermejo et al.[151]. Therefore, it was concluded that the water of river Dhamola should not be used for bathing purpose for mammals. After November, the COD value indicated a decreasing trend at sampling station 3 in comparison to station 2. The values of COD observed at all the three sampling stations are presented in Fig. 4.3(c).

## 4.2 BIOLOGICAL PARAMETERS

### 4.2.1 Bacteriological Population

The bacteriological characteristics determined for the various samples obtained for the river Dhamola are presented in Figs. 4.4 and 4.5.

#### 4.2.1.1 Most Probable Number of Coliform Bacteria

The most probable numbers (MPN) of coliform bacteria at sampling station 1 (upstream) were found in the range of 23-460 per 100 ml in most of the months of

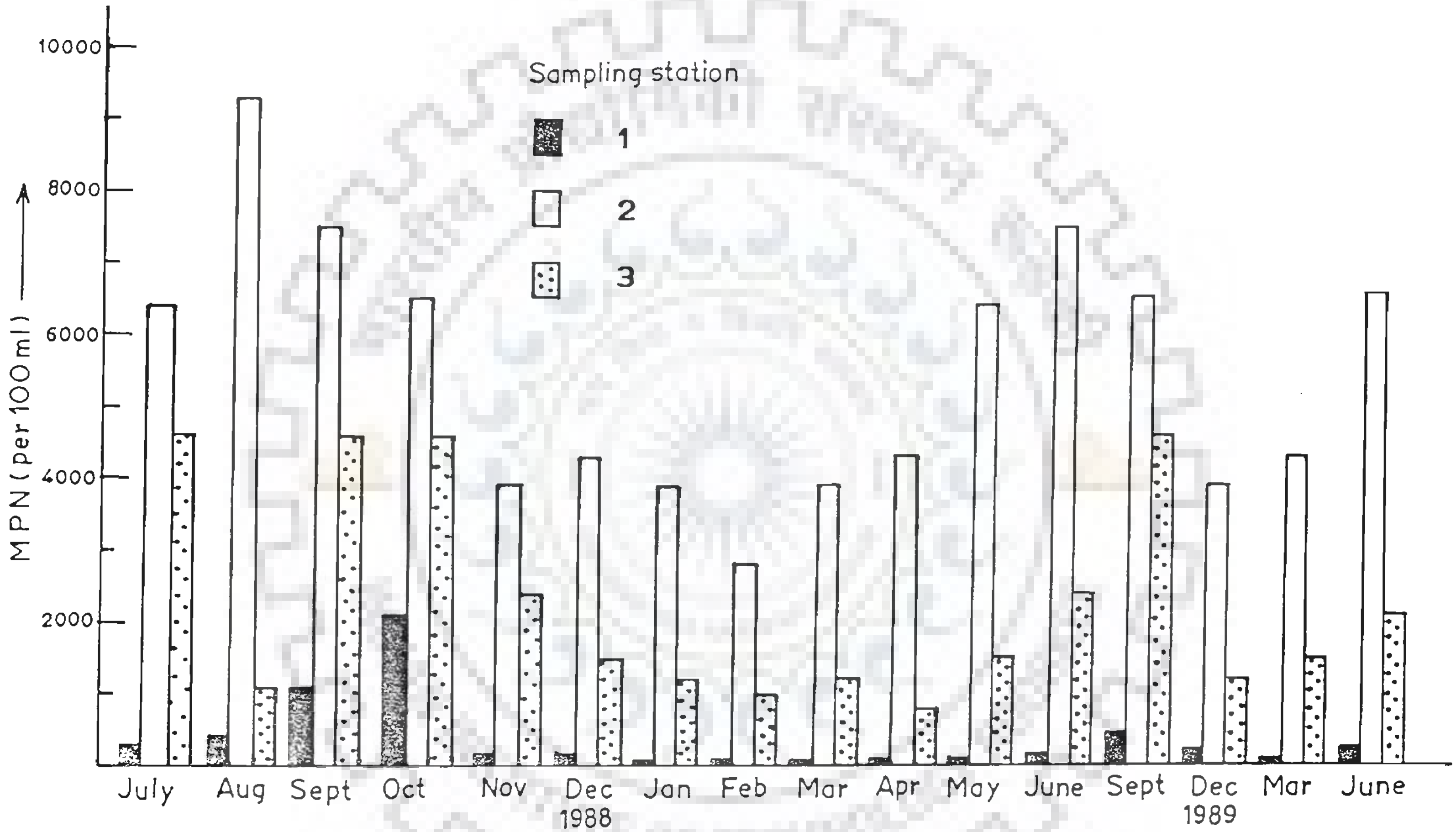


Fig. 4.4 Seasonal variations observed for MPN at sampling stations 1,2 and 3

investigations. An unusually high value (2100 per 100 ml) was however, observed in the month of October, 1988 probably due to the heavy rains observed in October 1988 in the northern part of India. The higher value of MPN during September - October, 1988 can be assigned to the heavy rainfall. This period has been claimed as the best survival period for coliform bacteria [129]. The MPN values at sampling stations 2 and 3 were much higher than at sampling station 1 during the entire course of the investigations and are presented in Fig. 4.4. It is thus concluded that mixing of municipal sewage and industrial effluents provided a medium suitable for the growth of bacteria, which caused a tremendous increase in MPN count. Much higher value of MPN at confluence point has also been observed earlier and is explained due to the mixing of sewage water as well as industrial effluents. The suspended organisms in waste water provide the nutrient level as well as organic matter for survival of coliform bacteria [6,152,153]. Dmitriew and Malyutin [12] have also suggested that the elevation in coliform bacteria occurs due to the mixing of waste water in river. This value, decreased at sampling station 3 most probably due to self-purification as reported in the literature [150].

#### 4.2.1.2 Standard Plate Count

Like most probable number of coliform bacteria (MPN), the value of SPC also changed significantly with seasonal changes. All three sampling stations indicated a

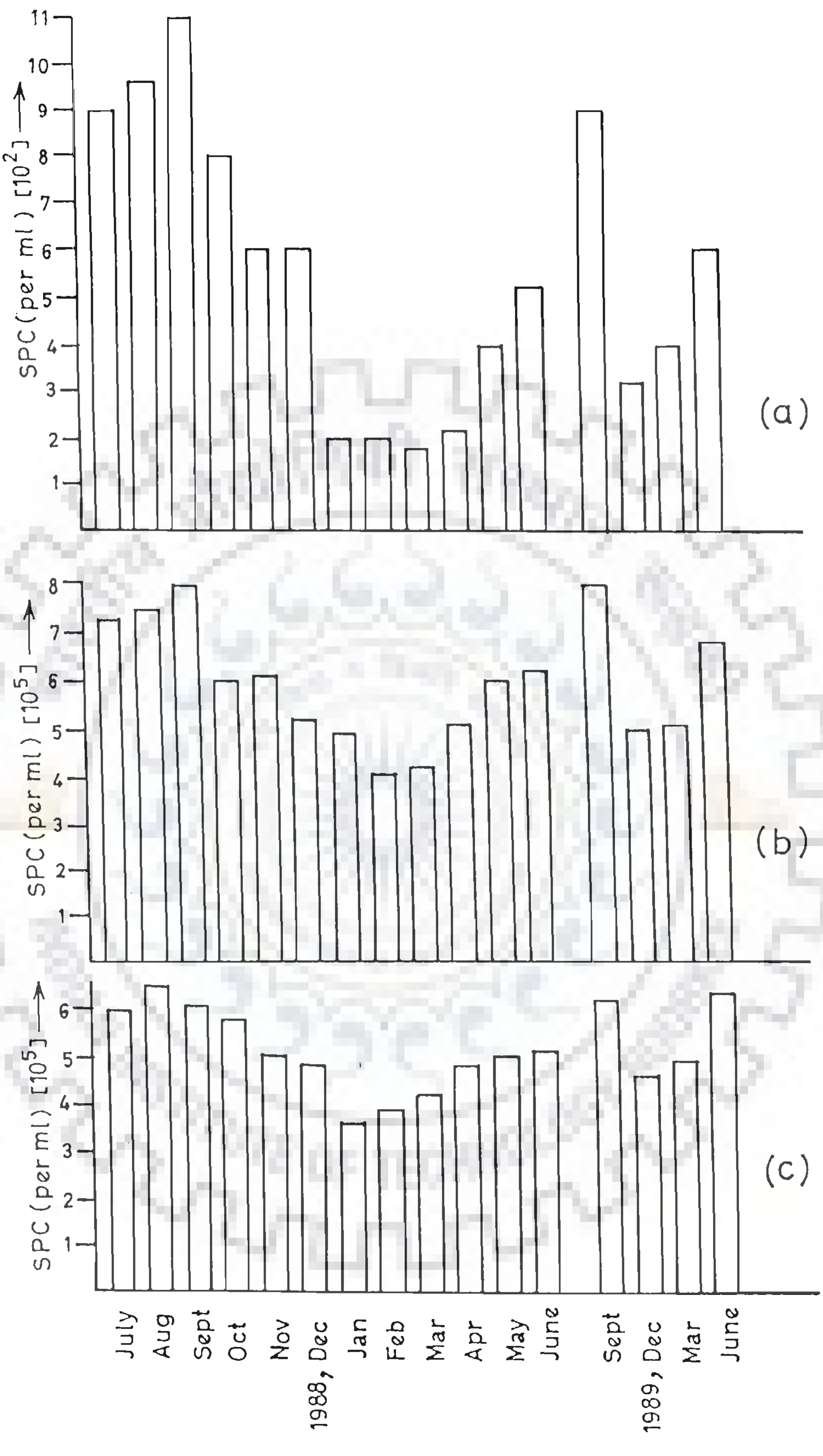


Fig. 4.5 Seasonal variations observed for SPC at sampling stations $(a)_1 (b)_2$ and $(c)_3$

similar pattern of increase, decrease and increase in standard plate count of coliform bacteria due to the seasonal variations. The maximum number of SPC was found in the month of September 1988 at all the three sampling stations and minimum was found in the months of January - March 1989. The reduction in SPC during the months of January to March has also been reported by Canale et al.[129] as least survival period for total coliform bacteria. At sampling station 1, the SPC of coliform bacteria were very low (1.8 - 11.0 x $10^2$/ml) as compared to the sampling stations 2 and 3 during the entire course of investigation. It is clear from the presented data that the value of SPC increased to about $10^3$ times at sampling station 2, in comparison to station 1 due to the mixing of waste water. Nevertheless, the decrease in SPC value at station 3 was not significant. In the case of MPN, the value decreased to about 40 - 50% at station 3 in comparison to station 2, whereas in SPC, the value decreased to only about 10 - 20%. This difference in behaviour may be accounted for on the basis of selfpurification of sewage water as suggested by Pillai et al.[150].

### 4.2.2 Planktonic Population

The various plankton species identified in the water samples collected from the different sampling stations are presented in table 4.1. It can be clearly seen that several pathogenic protozoans were identified only at

Table 4.1 List of different species of algae, diatoms and protozoans identified in the water samples collected from different sampling stations

| Parameters | Phyllum | Nature | Plankton species/ genus | Sampling Stations 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| **Algae** | Chlorophyta | Filamentus | Pithophora | * | | | | |
| | | | Schizameris | * | | | | |
| | | | Zygnema | * | * | * | | |
| | | | Spirogyra | | * | * | * | |
| | | | Hylotheca | * | | | | |
| | | | Chladophora | * | | | | |
| | | Coccoid | Dictyosphaerium | * | | | | |
| | | | Westella | * | | | | |
| | | | Chlorella | * | | | | |
| | | | Crucigenia | | * | * | * | |
| | | | Chlamydomonas | | * | * | * | |
| | Cyanophyta | Filamentus | Occillatoria | | * | * | * | |
| | | | Pinnularia | * | | * | | |
| | | | Lyngbya | | * | * | | |
| | | | Anabaena | | * | * | * | |
| | | | Gleotrichia | * | | * | | |
| | | Coccoid | Anacystis | | * | * | | |
| **Diatoms** | Chrysophyta | Pennate | Diatoma | | * | * | * | |
| | | | Fragilaria | * | * | * | | |
| | | | Synedra | | * | * | * | |
| | | | Achnanthes | | * | * | * | |
| | | | Navicula | * | | * | | |
| | | | Surirella | * | | * | | |
| | | Centric | Cyclotella | * | | * | | |
| | | | Coscinodiscus | | * | * | | |
| | | | Melosira | | * | * | * | |
| **Protozoans** | Protozoa | Amoebas | Amoeba sp. | | * | * | * | |
| | | | Difflugia | | * | * | * | |
| | | | Arcella | | * | * | * | |

Contd..... /-

| | | | | | |
|---|---|---|---|---|---|
| Ciliates | Pleuronema | | * | * | * |
| | Paramecium | | * | * | * |
| | Coepoda | | * | * | * |
| | Euplotes | | * | * | * |
| | Aspidisca | | * | * | * |
| | Vorticella | | * | * | * |
| | Euglina | * | * | * | * |
| Non-pigmented | Peranema | * | | * | |
| | Astaria | * | | * | |
| | Dinomonas | * | | * | |
| | Mastigomo-eba | * | | * | |
| | Cercomonas | * | | * | |

*Presence of plankton species

stations 2 to 4 during the entire course of investigation and thus indicate that the water of river Dhamola is polluted at stations 2 and 3. The most probable cause of such a pollution appears to be mixing of municipal sewage (station 4), which also indicated a positive test for these pathogenic protozoans. Similarly several species of diatoms were identified only in water samples obtained from station 1, whereas stations 2 to 5 did not indicate their presence. Thus mixing of sewage waste and industrial effluents kills the diatoms of fresh water.

#### 4.2.2.1 Algae

Fig. 4.6(a) represents an interesting alterations in algal count (primary producer) of the water of river Dhamola, after the mixing of waste water. The algal population varied with the change in season and varied in the range of 1050 - 1500 per ml for station 1. The maximum number of algal population was observed in the months of September, October, 1988 and June 1989, 1990. The increase in the algal count in these months is probably due to the dilution of water caused by heavy rains. Fogg [154] and Hutchinson et al.[155] have also suggested the presence of maximum number of algae in the rainy seasons as this period provides the required amount of nutrients. The value of algal count decreased to about five to six times at station 2 and 3 in the entire seasons of investigations. The observed reduction in algal count after the mixing of waste water is due to the influence of temperature and excess of chloride ($Cl^-$) in the waste water [155,156]. Hutchinson and Stokes [155] have also suggested the low value of algae after mixing of municipal sewage due to the increase of organic and inorganic content. The algal population at stations 2 and 3 were essentially same and thus it was concluded that the algal population remained the same for the stretch of about 5 kms after mixing of the domestic sewage and industrial effluents. This behaviour is in conformity with the findings of Buzzel et al. [157] and Joseph et al [158].

#### 4.2.2.2 Diatoms

The observed variations of total number of diatoms per millilitre during the period of two years is presented in Fig. 4.6(b). It indicated a very significant change in the population of diatoms in the water of river Dhamola after mixing of domestic sewage and industrial effluents. The value of diatoms at sampling station 1 was practically constant (in the range of 50-80/ml) during the entire course of investigations. The value increased to about 18-25 times at sampling station 2. The increase in the value of diatoms at sampling station 2 is due to the mixing of organic matter from the industrial effluents, which provides nutrients for the growth of diatoms as suggested by Patrick [159]. The diatoms value then decreased at sampling station 3. The highest value of diatoms at stations 2 and 3 was observed in the month of

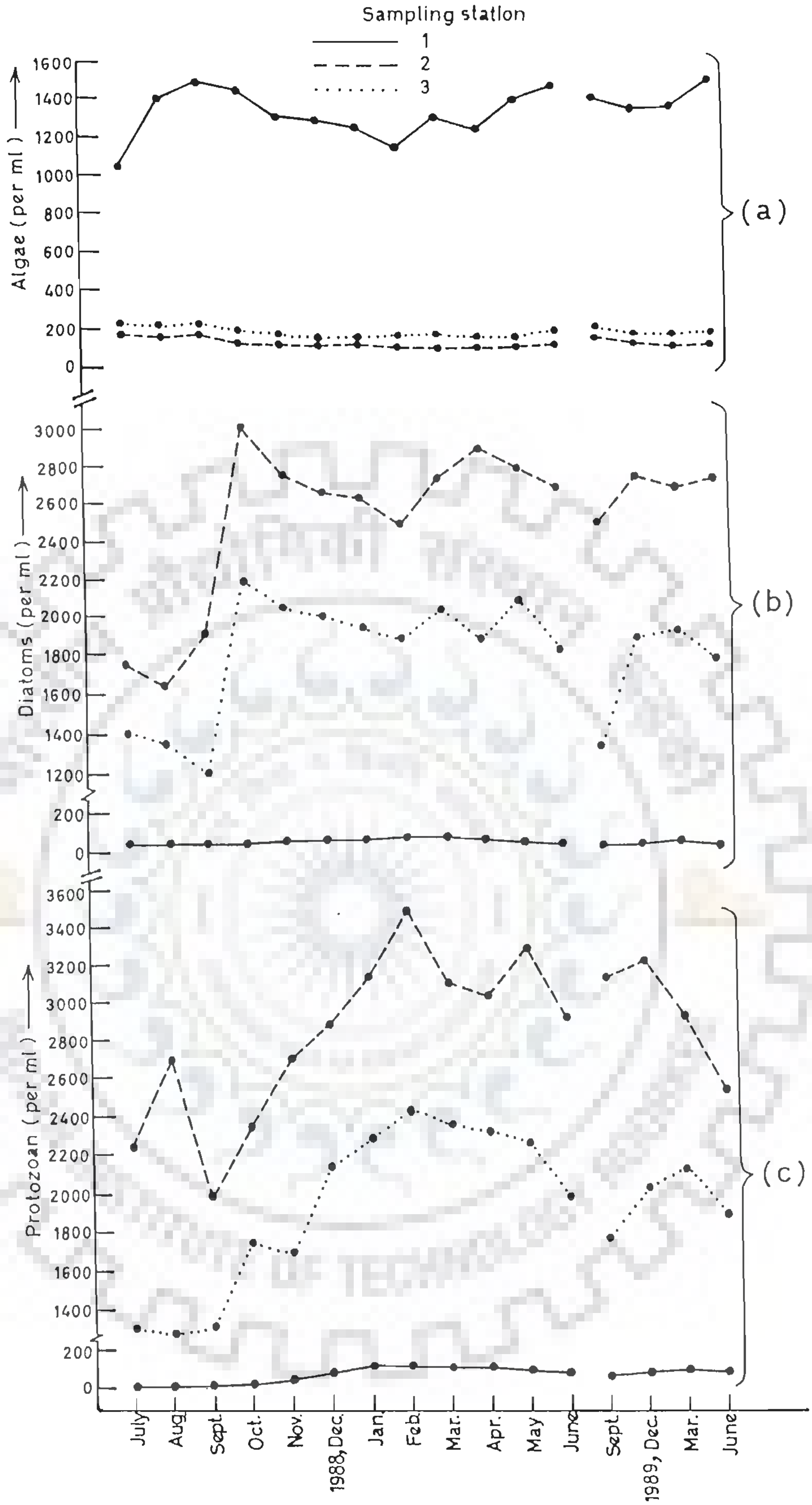


Fig. 4.6 Seasonal variations observed for (a) algae, (b) diatoms and (c) protozoans from July 1988 to June 1990

October 1988. This behaviour may be accounted for on the basis of increase in BOD value in the month of October 1988 at sampling stations 2 and 3, which caused the increase in diatoms value. Similar observations have also been reported in the literature for Periyar river [153]

#### 4.2.2.3 Protozoans

Fig. 4.6(c) presents the change in the population of protozoans with seasonal variations. The value of protozoans at station 1, was almost constant and did not change with seasonal fluctuations. However, this value increased significantly after mixing of municipal sewage and effluents. Thus at station 2, the value of protozoans did not show any regular pattern but had an increasing trend from September 1988 to February 1989. The maximum values of protozoans were observed in the month of February 1989 at both the stations 2 and 3 (3500 and 2440 per ml, respectively). The elevation in protozoans population after mixing the municipal sewage has also been observed earlier [6,160].

## 4.3 WASTE WATER CHARACTERISTICS

The analysis of waste water is important because it provides information about the nature and extent of pollution load present in it. Hence, it becomes easier to find ways and means to reduce the pollution in the river in which it mixes. In the present investigation the physico-chemical and biological analysis of waste water from domestic sewage (sampling station 4, Fig. 3.2) and industrial effluents (station 5, Fig. 3.2) mixing in the river Dhamola were carried out during the period of July 1988 to June 1990. The method for the collection of samples and their frequency were essentially the same as that for the river water samples and have been described in Chapter 3. The results obtained for the various parameters are summarised in Table 4.2 for the domestic sewage and in Table 4.3 for industrial effluents.

It is clear from the Table 4.2 that all the physico-chemical parameters for the samples of domestic sewage collected during the entire period of investigation were much higher than fresh water parameters except the dissolved oxygen which was found very low (1.6-2.6 mg/l). The value of DO was thus very less than the minimum permissible limits [161] of Indian Standard as well as of World Health Organisation (5.0 mg/l). The low value of DO throughout the period of two years in the domestic sewage indicated the presence of high pollution load, which was further confirmed by the high value of BOD, COD and other physico-chemical parameters. The low value of DO in domestic sewage has also been observed earlier [157] and assigned to the high value of BOD, COD and absence of phytoplankton (primary produce).

All biological parameters were also found to be very high in the samples of domestic sewage (Station 4) except the algal population which indicated a decreasing trend.

**Table 4.2** Observed physico-chemical and biological characteristics of domestic sewage at sampling station - 4.

| Year | 1988 | | | | | | 1989 | | | | | | | 1990 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month / Parameter | July | Aug. | Sept | Oct | Nov | Dec | Jan | Feb | March | Apr | May | June | Sept | Dec | March | June |
| Turbidity (NTU) | 295 ±5 | 297 ±5 | 290 ±4 | 270 ±6 | 255 ±4 | 242 ±4 | 207 ±5 | 201 ±7 | 266 ±4 | 276 ±3 | 269 ±4 | 277 ±5 | 276 ±5 | 235 ±4 | 269 ±5 | 270 ±3 |
| Total solids(mg/l) | 875 ±7 | 860 ±7 | 880 ±7 | 810 ±7 | 774 ±4 | 766 ±5 | 750 ±5 | 714 ±4 | 695 ±8 | 725 ±7 | 717 ±6 | 763 ±7 | 720 ±6 | 780 ±8 | 711 ±8 | 715 ±7 |
| pH | 7.99 ±0.1 | 8.10 ±0.1 | 8.00 ±0.1 | 8.09 ±0.1 | 8.17 ±0.1 | 8.01 ±0.1 | 8.03 ±0.1 | 8.07 ±0.0 | 8.04 ±0.0 | 8.13 ±0.1 | 8.12 ±0.1 | 8.04 ±0.2 | 8.10 ±0.1 | 8.00 ±0.1 | 8.10 ±0.1 | 8.10 ±0.0 |
| Total hardness(mg/l) | 271 ±3 | 283 ±3 | 278 ±2 | 269 ±2 | 362 ±2 | 371 ±2 | 366 ±3 | 369 ±4 | 273 ±2 | 271 ±3 | 269 ±2 | 275 ±1 | 280 ±1 | 380 ±2 | 282 ±1 | 274 ±2 |
| Chloride (mg/l) | 30 ±0.1 | 31 ±1.1 | 30 ±1.2 | 29 ±1.0 | 28 ±1.2 | 28 ±1.0 | 29 ±1.0 | 29 ±1.0 | 30 ±1.0 | 28 ±1.0 | 28 ±1.0 | 28 ±0.9 | 32 ±1.0 | 28 ±0.9 | 31 ±1.9 | 30 ±1.0 |
| $CO_2$(mg/l) | 2.6 ±0.0 | 2.5 ±0.1 | 2.3 ±0.1 | 2.0 ±0.1 | 2.9 ±0.1 | 2.2 ±0.1 | 2.0 ±0.1 | 2.1 ±0.2 | 2.9 ±0.1 | 2.7 ±0.1 | 2.8 ±0.1 | 2.9 ±0.1 | 3.0 ±0.1 | 1.9 ±0.1 | 3,1 ±0.1 | 3.0 ±0.1 |
| DO(mg/l) | 2.6 ±0.2 | 2.4 ±0.2 | 2.6 ±0.2 | 1.9 ±0.3 | 2.4 ±0.3 | 2.3 ±0.4 | 1.7 ±0.2 | 1.6 ±0.2 | 1.9 ±0.2 | 1.7 ±0.3 | 1.7 ±0.3 | 1.8 ±0.3 | 2,5 ±0.3 | 2.5 ±0.3 | 2.0 ±0.2 | 2.2 ±0.2 |
| BOD(mg/l) | 175 ±2 | 210 ±2 | 217 ±2 | 231 ± | 209 2±2 | 213 ±2 | 231 ±2 | 237 ±2 | 243 ±3 | 234 ±3 | 235 ±3 | 231 ±3 | 240 ±3 | 205 ±2 | 251 ±2 | 232 ±2 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COD (mg/l) | 209 ±2 | 227 ±2 | 224 ±2 | 240 ±1 | 225 ±2 | 237 ±2 | 260 ±2 | 259 ±3 | 267 ±2 | 250 ±1 | 262 ±2 | 249 ±3 | 245 ±1 | 234 ±2 | 259 ±2 | 239 ±3 |
| MPN x $10^4$ (per 100 ml) | 25 ±0.3 | 23 ±0.4 | 19 ±0.4 | 20 ±0.3 | 18 ±0.2 | 15 ±0.2 | 16 ±0.2 | 19 ±0.3 | 20 ±0.2 | 23 ±0.6 | 18 ±1.0 | 14 ±0.8 | 17 ±0.2 | 15 ±0.3 | 18 ±1.0 | 12 ±1.0 |
| SPC x $10^5$ (per ml) | 28 ±1.0 | 28 ±1.3 | 28 ±1.0 | 27 ±1.0 | 28 ±1.0 | 26 ±1.4 | 27 ±1.3 | 28 ±2.0 | 26 ±1.0 | 23 ±1.0 | 24 ±1.0 | 22 ±1.0 | 23 ±1.0 | 25 ±1.0 | 24 ±1.0 | 20 ±1.0 |
| Algae (per ml) | 75 ±6 | 60 ±5 | 65 ±5 | 10 ±4 | - | - | 5 ±3 | - | - | - | - | - | 20 ±4 | 25 ±4 | - | - |
| Diatoms (per ml) | 2500 ±15 | 2400 ±16 | 2590 ±14 | 3500 ±21 | 3700 ±18 | 4300 ±21 | 4250 ±19 | 4100 ±20 | 4000 ±18 | 4400 ±18 | 4350 ±19 | 4450 +20 | 2700 ±18 | 4200 ±17 | 3900 ±19 | 4300 ±17 |
| Protozoans (per ml) | 4000 ±23 | 4150 ±23 | 4050 ±24 | 4400 ±19 | 4750 ±18 | 5300 ±21 | 5100 ±21 | 5250 ±21 | 5700 ±22 | 5600 ±21 | 5750 ±21 | 5890 ±21 | 4500 ±23 | 5500 ±19 | 5800 ±20 | 5900 ±21 |

* All values reported are an average of atleast two replicate determinations

Table 4.3 Observed physico-chemical and biological characteristics of industrial effluent at sampling station 5

| Year | 1988 | | | | | | 1989 | | | | | | | | 1990 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month / Parameter | July | Aug | Sept | Oct | Nov | Dec | Jan | Feb | March | Apr | May | June | Sept | Dec | March | June |
| Turbidity (NTU) | 336 ±4 | 358 ±4 | 349 ±5 | 330 ±5 | 332 ±5 | 317 ±5 | 316 ±5 | 309 ±5 | 319 ±4 | 330 ±3 | 337 ±4 | 341 ±3 | 356 ±4 | 348 ±4 | 325 ±5 | 339 ±4 |
| Total Solids (mg/l) | 1105 ±9 | 1140 ±9 | 1095 ±7 | 989 ±8 | 992 ±8 | 1002 ±10 | 978 ±9 | 999 ±6 | 1040 ±8 | 1080 ±7 | 1043 ±7 | 969 ±8 | 1125 ±10 | 992 ±8 | 1025 ±9 | 999 ±7 |
| pH | 8.39 ±0.3 | 8.47 ±0.2 | 8.43 ±0.1 | 8.24 ±0.3 | 8.06 ±0.3 | 7.93 ±0.3 | 7.97 ±0.2 | 7.95 ±0.2 | 8.13 ±0.1 | 8.01 ±0.2 | 8.19 ±0.1 | 8.23 ±0.1 | 8.56 ±0.1 | 7.91 ±0.2 | 8.22 ±0.2 | 8.05 ±0.2 |
| Total hardness (mg/l) | 310 ±4 | 313 ±5 | 302 ±5 | 320 ±4 | 339 ±6 | 326 ±5 | 329 ±5 | 319 ±5 | 307 ±4 | 319 ±4 | 325 ±4 | 328 ±6 | 296 ±5 | 346 ±6 | 315 ±6 | 339 ±6 |
| Chloride (mg/l) | 28 ±1 | 26 ±1 | 24 ±1 | 27 ±1 | 26 ±1 | 27 ±1 | 29 ±1 | 28 ±2 | 30 ±2 | 29 ±2 | 28 ±2 | 28 ±1 | 22 ±2 | 28 ±3 | 29 ±3 | 26 ±2 |
| $CO_2$ (mg/l) | 3.4 ±0.0 | 3.2 ±0.3 | 3.1 ±0.2 | 3.2 ±0.2 | 3.8 ±0.6 | 3.9 ±0.7 | 3.5 ±0.6 | 3.4 ±0.4 | 3.2 ±0.6 | 3.9 ±0.5 | 4.1 ±0.6 | 4.3 ±0.3 | 2.9 ±0.2 | 4.2 ±0.4 | 3.1 ±1.0 | 4.2 ±1.0 |
| DO (mg/l) | 1.3 ±0.0 | 1.4 ±0.1 | 1.6 ±0.2 | 1.5 ±0.1 | 1.0 ±0.3 | 0.8 ±0.3 | 0.8 ±0.2 | 2.0 ±0.3 | 1.7 ±0.3 | 1.6 ±0.2 | 1.4 ±0.3 | 1.2 ±0.3 | 1.8 ±0.3 | 0.9 ±0.2 | 1.9 ±0.4 | 1.4 ±0.2 |

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| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BOD (mg/l) | 302 ±3 | 290 ±7 | 276 ±4 | 299 ±10 | 343 ±9 | 329 ±8 | 331 ±8 | 319 ±6 | 301 ±9 | 293 ±10 | 298 ±9 | 317 ±9 | 268 ±10 | 302 ±8 | 279 ±9 | 296 ±6 |
| COD(mg/l) | 338 ±9 | 322 ±8 | 309 ±10 | 367 ±9 | 447 ±9 | 423 ±9 | 468 ±8 | 417 ±9 | 399 ±6 | 349 ±5 | 360 ±6 | 367 ±8 | 299 ±8 | 401 ±7 | 385 ±9 | 376 ±8 |
| MPN x $10^4$ (per 100 ml) | 27 ±5 | 26 ±7 | 26 ±6 | 23 ±5 | 21 ±6 | 25 ±3 | 29 ±5 | 26 ±3 | 27 ±6 | 25 ±5 | 26 ±4 | 26 ±4 | 24 ±6 | 22 ±6 | 23 ±5 | 22 ±5 |
| SPC x $10^5$ (per ml) | 36 ±1 | 38 ±3 | 33 ±2 | 37 ±2 | 40 ±2 | 44 ±3 | 43 ±3 | 43 ±2 | 39 ±2 | 34 ±2 | 38 ±4 | 42 ±4 | 31 ±4 | 41 ±3 | 34 ±2 | 37 ±3 |
| Algae (per ml) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Diatoms (per ml) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Protozoans (per ml) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

*All values reported are an average of atleast two replicate determination.

The number of algal population was practically zero, except in the months of rainy season. It appears that insignificant value of algae is due to the high values of BOD and COD in the domestic sewage. It seems reasonable to conclude that the zero population of algae caused the low value of DO observed in the samples. The presence of MPN, SPC, diatoms and protozoans also indicate the high rate of pollution in the domestic sewage.

In the case of samples obtained from sampling station 5 (industrial effluents), the values of all the physico-chemical parameters, except DO were found higher than the permissible limit to discharge of waste water into inland surface water by Indian Standards [162]. The value of DO was found in the range of 0.5 - 2.0 mg/l during the entire period of investigation. The higher values of physico-chemical parameters indicated the high pollution load in the industrial effluents. The high values of BOD and COD pointed the higher organic pollution load due to the presence of organic matter whereas, other parameters indicated that the pollution is mostly due to the presence of inorganic as well as metallic ions.

The low value of DO and high values of BOD and COD observed in the industrial effluents during the entire period of investigation did not permit the growth of plankton populations. Hence, the total planktonic population was found to be practically zero. The absence of planktonic population in industrial effluents is well known and has been assigned to the presence of organic and inorganic pollutants present in it. Area receiving the waste water discharge (pollution impact zones) has been reported to be completely devoid of all life except bacterial population at down stream of effluent [7]. Only MPN and SPC were observed in the samples collected at this sampling station. Such a behaviour is usual phenomenon as minimum permissible value of DO for the existence of aquatic life is 5.0 mg/l.

In general, it is observed that the values of all the physico-chemical parameters except DO were greater in industrial effluents than in the domestic sewage samples whereas, the value of DO in the industrial effluent was much lower than in the domestic sewage during the entire course of investigations. The plankton population was totally absent in industrial effluent. The MPN and SPC values were also higher in the industrial effluent than in the sewage water. The lower value of BOD in domestic sewage in comparison to the industrial effluents can be assigned to the excess of chloride ions in the domestic sewage and is in confirmity with the observation of Santhgate [163] and Snow [164] who have assessed that the chlorination of the domestic sewage and industrial effluents caused a sharp decrease in the BOD value.

## 4.4 OXYGEN SAG

The dependence of DO was also monitored against the down stream distance from the mixing point of waste water in the river Dhamola to get an idea about the nature of oxygen sag curve. The curve obtained for the dependence of DO is presented in Fig. 4.7. It was thus observed that if the net influx of oxygen from the atmosphere to the river Dhamola at sampling station 1, is considered as 100% saturation, there is a considerable decrease in DO after the mixing of waste water. It is reported that if BOD loading from the waste water is sufficiently large the oxygen concentration in the river/stream may drop to virtually zero and may remain same for a considerable distance [150]. In the present studies, the DO of water decreased to about 50% after the mixing of the municipal and the industrial effluents. After about 5 kms of the mixing point, the DO value further indicated an increase to about 75%. Thus, it appears that the effects of reaeration and declining respiration rate allow the oxygen concentration to build up again during the stretch of 5 kms. It is well known [150] that the zone of anoxic water may extend to many kms before the oxygen concentration reaches to 100% again. Thus it could be concluded that it will be further several kms down stream from station 3, where the oxygen concentration build up to 100% again.

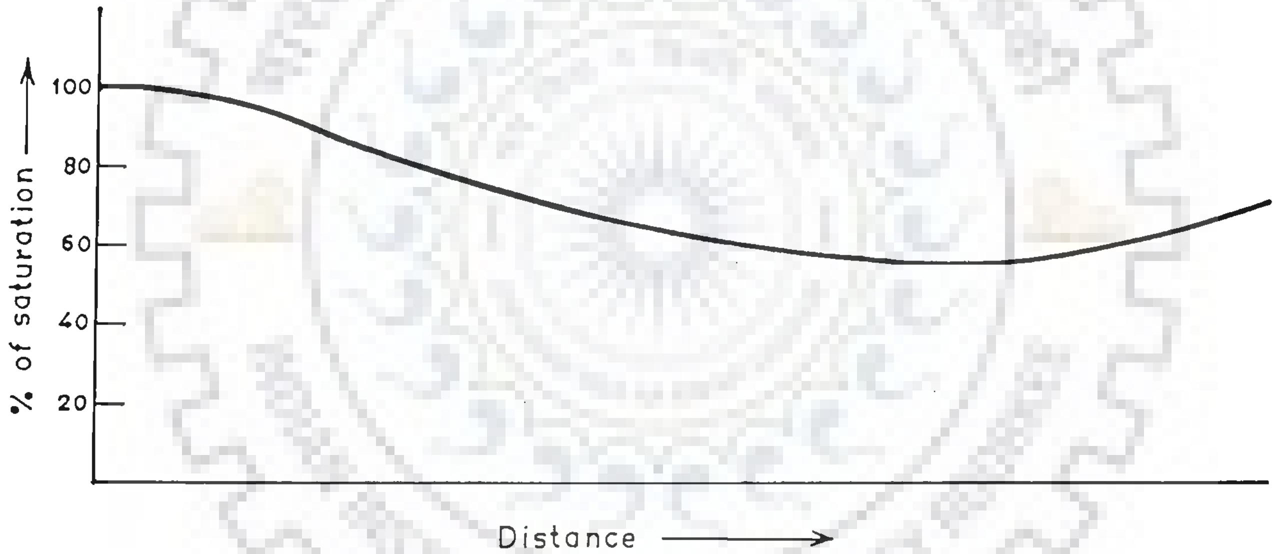


Fig. 4.7 Observed Oxygen Sag for the river Dhamola

It was considered necessary to compare the pollution load of the municipal sewage and industrial effluents mixing in the river Dhamola with the physico-chemical characteristics suggested by Indian Standard Institute [162] for waste water before allowing it to mix in the river. A comparison of four important characteristics, viz., pH, total solids, BOD and COD of municipal sewage, industrial effluent and suggested data by ISI is presented in Table 4.4. It was found that the values of pH of both the waste waters were in the range suggested by ISI (Indian Standard Institute) during the entire course of investigation. However, the values of BOD and COD were found much higher than the values recommended by ISI. Therefore, it is highly desirable that the waste water should be properly treated before allowing it to pass into the river Dhamola. If the waste water with such a high values for BOD and COD is allowed to mix (as it is happening in the present case) in the river, then it is expected that it would kill the aquatic life except bacterial population as suggested by Dickman et al.[7].

The physico-chemical and bacteriological parameters of the water samples collected at sampling stations 1 to 3 have also been compared with the ISI standards suggested for the domestic and agricultural uses of the water and are presented in Table 4.5.

**Table 4.4** A comparison of some important characteristics of domestic waste and industrial effluent mixing in the river Dhamola with the ISI suggested values[165)

| Parameters | ISI (max tolerable value) | Domestic waste | Industrial effluent |
|---|---|---|---|
| pH | 5.5 - 9.0 | 7.99 - 8.17 | 7.91 - 8.56 |
| Total solids (mg/l) | 2500 | 695 - 880 | 968 - 1140 |
| BOD (mg/l) | 20 - 30 | 175 - 243 | 276 - 343 |
| COD(mg/l) | 250 | 209 - 267 | 299 - 468 |

**Table 4.5** A comparison of observed value of physico-chemical and biological parameters for Dhamola river at sampling stations 1,2 & 3 during 1988-90 with ISI value of water quality parameters

| Parameter | Indian Standard | | | Sampling Station 1 | Sampling station 2 | Sampling station 3 |
|---|---|---|---|---|---|---|
| | Bathing | Drinking | Agriculture | | | |
| Turbidity (NTU) | 30 (max) | 25 (max) | - | 18-64 | 100-129 | 77-96 |
| Total Solids (mg/l) | 600 (max) | 500 (max) | 2100 (max) | 389-489 | 496-546 | 469-537 |
| pH | 6-9 | 6-9 | 5.5-9.0 | 7.18-7.97 | 7.52-8.23 | 7.56-8.24 |
| Chloride (mg/l) | 600 (max) | - | 600 (max) | 16-22 | 22-30 | 21-29 |
| $CO_2$(mg/l) | 0.8 (max) | - | - | 0.2-1.1 | 0.8-1.6 | 0.8-1.3 |
| DO(mg/l) | 5.0 or 40% Saturation | 5.0 (min) | 3.0 | 7.2-8.2 | 4.6-5.3 | 4.6-5.6 |
| BOD(mg/l) | 30 (max) | 3-6 | 100 (max) | 8.2-20.5 | 72-86 | 62-85 |
| COD(mg/l) | 50 (max) | Not more than 10 | 250 | 28-49 | 217-244 | 205-229 |
| MPN (per 100 ml) | Not more than 100 | Not more than 10 | - | 23-460 | 28000-93000 | 7500-46000 |
| SPC(per ml) | Not more than 200 | - | - | 18-110 | 41000-80000 | 36000-65000 |

All the parameters at upstream sites of river Dhamola (sampling station 1) were found well within the range suggested by ISI for bathing and agriculture purposes [165]. The higher value of turbidity (64 NTU) was observed only during rainy season due to criping of upper soil layer from mountains. The value of COD was also about 2-3 times higher than recommended by ISI and therefore, it is concluded that the water of river Dhamola is not suitable for drinking even at sampling station 1. However, the physico-chemical and biological parameters at sampling station 1 clearly indicates that it can be used safely for bathing and agricultural purposes.

After the mixing of waste water from domestic sewage and industrial effluents, all the parameters altered significantly and indicated that the water quality of Dhamola river reaches to disbalanced conditions. The higher values of BOD, COD, $CO_2$ chloride ions, hardness and coliform bacteria than the recommended standard values suggests that the water of river Dhamola at middle and down streams is polluted and is not suitable for domestic use. Its use in bathing may cause some dangerous cronic diseases in human beings as well as in the domestic animals. The value of BOD and MPN are much beyond the permissible limits for water intended for even bathing at sampling stations 2 and 3 and hence the water should be used only for agricultural purposes.

## 4.5 REMOVAL OF POLLUTION LOAD

Removal of pollution load, created by municipal sewage and industrial effluents is one of the major tasks to be handled by the appropriate agencies to control the disastrous results of pollution in future. The report of the Central Pollution Board, New Delhi indicating that only 30% of the industries along the banks of the Ganga and its tributries are following some kind of pollution control measures, emphasizes the need of strict measures to be taken to control water pollution. Though, nature has its own system of checks and balances of replenishing the sources of air, water, vegetation and animal life, still the exploitation of nature's gifts should be stopped. In recent years, it has been found that several plants are capable of reducing toxic elements, like arsenic, cadmium, lead, zinc, vanadium, iron, mercury, chromium and other chemicals. The use of water hyacinth lagoon and Azolla, Valessneria, Lemna minor etc. for removing toxic elements in the river and lake water has recently been reported in the literature [94,98-101,116, 117,166-168]. Though, only inorganic and organic pollution studies have been carried out in the present investigations, it was considered interesting to use some of the plant species to find out if organic and inorganic pollution load is also decreased by these species. Very few attempts have been made in this direction and little information is available in the literature[169].

In the present study, three different aquatic plant species, viz., E. crassipes, L. minor and C. demorsum have been employed for the removal of pollution load, created by domestic and industrial effluents. All the physico-chemical, bacteriological and biological parameters e.g., turbidity, total solids, pH, total hardness, chloride, DO biochemical oxygen demand (BOD), chemical oxygen demand (COD), carbon dioxide ($CO_2$), most probable number (MPN) and standard plate count (SPC) of coliform bacteria were determined at an interval of one week and showed significant change. The water quality of waste water had improved after about 4 weeks of the treatment. The experiments divided into five categories have been described in the materials and methods section of the thesis.

### 4.5.1. Stage I

The physico-chemical, bacteriological and biological parameters obtained for Eichhornia crassipes culture are given in Table 4.6. It was observed that in the case of domestic sewage, the value of DO increased to about two times after 4 weeks. The maximum value of DO 214%, 5.6 mg/l was found in the month of June 1990 and is close to the minimum permissible value suggested by WHO and Indian Standard for aquatic life [161,165]. BOD, COD and free $CO_2$ decreased in comparison to the control values. The values of BOD and COD reduced to about 55% and 57%

**Table 4.6** Observed values of various parameters for the stage I treated domestic sewage and industrial effluent

| Parameters | Month | Domestic sewage | | | | | | | | | | Industrial effluent | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | |
| | | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T |
| Turbidity | Sept | 100 | 100 | 22 | 16 | 18 | 13 | 12 | 6.5 | 9 | 5 | 100 | 100 | 19 | 15 | 15 | 11 | 10 | 6 | 10 | 4 |
| | Dec | 100 | 100 | 26 | 19 | 22 | 14 | 15 | 8 | 13 | 6 | 100 | 100 | 19 | 15 | 15 | 11 | 10 | 5 | 10 | 4 |
| | March | 100 | 100 | 25 | 18 | 19 | 15 | 14 | 8 | 12 | 6 | 100 | 100 | 23 | 15 | 19 | 13 | 12 | 7 | 11 | 5 |
| | June | 100 | 100 | 20 | 15 | 17 | 12 | 14 | 7 | 11 | 5 | 100 | 100 | 20 | 15 | 15 | 12 | 10 | 6 | 11 | 5 |
| Total solids | Sept | 100 | 100 | 56 | 55 | 53 | 42 | 25 | 10 | 23 | 9 | 100 | 100 | 72 | 72 | 45 | 36 | 19 | 7 | 16 | 6 |
| | Dec | 100 | 100 | 66 | 66 | 56 | 49 | 25 | 10 | 22 | 9 | 100 | 100 | 83 | 83 | 50 | 40 | 21 | 8 | 17 | 7 |
| | March | 100 | 100 | 56 | 54 | 53 | 42 | 27 | 26 | 25 | 10 | 100 | 100 | 80 | 78 | 49 | 39 | 20 | 8 | 18 | 7 |
| | June | 100 | 100 | 56 | 55 | 53 | 42 | 28 | 25 | 24 | 9 | 100 | 100 | 80 | 80 | 49 | 40 | 20 | 7 | 17 | 7 |
| pH | Sept | 100 | 100 | 99 | 99 | 98 | 94 | 93 | 86 | 91 | 83 | 100 | 100 | 99 | 98 | 95 | 94 | 92 | 82 | 91 | 79 |
| | Dec | 100 | 100 | 100 | 99 | 88 | 87 | 93 | 86 | 94 | 85 | 100 | 100 | 100 | 103 | 99 | 103 | 97 | 93 | 97 | 89 |
| | March | 100 | 100 | 99 | 99 | 98 | 96 | 93 | 89 | 93 | 85 | 100 | 100 | 99 | 99 | 98 | 97 | 93 | 89 | 91 | 84 |
| | June | 100 | 100 | 99 | 99 | 98 | 93 | 94 | 93 | 91 | 84 | 100 | 100 | 100 | 99 | 100 | 95 | 95 | 89 | 95 | 85 |
| Total hardness | Sept | 100 | 100 | 102 | 97 | 103 | 92 | 109 | 92 | 110 | 89 | 100 | 100 | 102 | 98 | 103 | 93 | 107 | 91 | 108 | 90 |
| | Dec | 100 | 100 | 102 | 97 | 102 | 94 | 106 | 66 | 106 | 66 | 100 | 100 | 101 | 96 | 103 | 93 | 108 | 92 | 109 | 91 |
| | March | 100 | 100 | 105 | 99 | 103 | 96 | 105 | 93 | 109 | 93 | 100 | 100 | 104 | 98 | 105 | 95 | 109 | 95 | 102 | 95 |
| | June | 100 | 100 | 102 | 97 | 104 | 92 | 107 | 91 | 112 | 92 | 100 | 100 | 101 | 102 | 101 | 98 | 105 | 97 | 105 | 96 |
| Chloride | Sept | 100 | 100 | 100 | 78 | 97 | 62 | 94 | 47 | 94 | 45 | 100 | 100 | 95 | 73 | 95 | 43 | 86 | 32 | 86 | 27 |
| | Dec | 100 | 100 | 100 | 78 | 93 | 68 | 89 | 54 | 89 | 52 | 100 | 100 | 100 | 86 | 98 | 66 | 91 | 50 | 89 | 50 |
| | March | 100 | 100 | 97 | 84 | 95 | 61 | 93 | 48 | 90 | 48 | 100 | 100 | 100 | 90 | 96 | 71 | 93 | 59 | 89 | 52 |
| | June | 100 | 100 | 93 | 73 | 97 | 60 | 93 | 53 | 87 | 48 | 100 | 100 | 100 | 79 | 98 | 63 | 96 | 50 | 94 | 48 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | Sept | 100 | 100 | 120 | 83 | 130 | 67 | 170 | 33 | 190 | 20 | 100 | 100 | 107 | 86 | 136 | 72 | 162 | 31 | 197 | 21 |
| | Dec | 100 | 100 | 137 | 79 | 158 | 63 | 237 | 37 | 289 | 26 | 100 | 100 | 107 | 60 | 117 | 48 | 138 | 24 | 145 | 14 |
| | March | 100 | 100 | 113 | 81 | 132 | 71 | 148 | 58 | 161 | 36 | 100 | 100 | 109 | 97 | 131 | 66 | 163 | 31 | 191 | 16 |
| | June | 100 | 100 | 120 | 70 | 127 | 67 | 150 | 50 | 190 | 20 | 100 | 100 | 110 | 97 | 119 | 76 | 144 | 51 | 154 | 39 |
| DO | Sept | 100 | 100 | 80 | 120 | 60 | 136 | 24 | 180 | - | 188 | 100 | 100 | 78 | 117 | 67 | 139 | 17 | 217 | - | 228 |
| | Dec | 100 | 100 | 80 | 112 | 164 | 124 | 24 | 70 | 8 | 176 | 100 | 100 | 67 | 156 | 44 | 200 | - | 322 | - | 333 |
| | March | 100 | 100 | 80 | 125 | 50 | 145 | 30 | 175 | 10 | 210 | 100 | 100 | 84 | 110 | 53 | 132 | 21 | 189 | - | 195 |
| | June | 100 | 100 | 91 | 136 | 64 | 155 | 55 | 177 | - | 214 | 100 | 100 | 71 | 114 | 43 | 136 | 7 | 221 | - | 236 |
| BOD | Sept | 100 | 100 | 113 | 94 | 110 | 88 | 122 | 77 | 127 | 73 | 100 | 100 | 106 | 95 | 108 | 90 | 118 | 77 | 122 | 73 |
| | Dec | 100 | 100 | 115 | 96 | 119 | 90 | 131 | 76 | 135 | 72 | 100 | 100 | 108 | 96 | 110 | 91 | 116 | 81 | 120 | 77 |
| | March | 100 | 100 | 120 | 96 | 110 | 92 | 116 | 83 | 120 | 76 | 100 | 100 | 113 | 96 | 115 | 94 | 123 | 82 | 127 | 78 |
| | June | 100 | 100 | 115 | 95 | 113 | 90 | 124 | 80 | 131 | 75 | 100 | 100 | 111 | 95 | 114 | 91 | 118 | 80 | 123 | 77 |
| COD | Sept | 100 | 100 | 106 | 93 | 111 | 88 | 122 | 74 | 125 | 69 | 100 | 100 | 106 | 93 | 110 | 89 | 113 | 74 | 123 | 75 |
| | Dec | 100 | 100 | 107 | 94 | 111 | 89 | 125 | 77 | 129 | 73 | 100 | 100 | 104 | 71 | 106 | 69 | 113 | 60 | 114 | 57 |
| | March | 100 | 100 | 112 | 98 | 110 | 93 | 117 | 81 | 121 | 76 | 100 | 100 | 104 | 72 | 107 | 76 | 115 | 65 | 115 | 63 |
| | June | 100 | 100 | 106 | 94 | 111 | 88 | 121 | 79 | 128 | 71 | 100 | 100 | 105 | 97 | 107 | 92 | 116 | 84 | 121 | 83 |
| MPN | Sept | 100 | 100 | 88 | 71 | 82 | 59 | 65 | 35 | 47 | 12 | 100 | 100 | 92 | 83 | 88 | 75 | 67 | 54 | 46 | 33 |
| | Dec | 100 | 100 | 89 | 73 | 87 | 61 | 60 | 33 | 46 | 14 | 10 | 100 | 95 | 86 | 81 | 73 | 68 | 51 | 52 | 22 |
| | March | 100 | 100 | 89 | 94 | 76 | 56 | 67 | 47 | 57 | 34 | 100 | 100 | 91 | 78 | 88 | 70 | 67 | 50 | 49 | 48 |
| | June | 100 | 100 | 92 | 75 | 83 | 54 | 100 | 50 | 68 | 17 | 100 | 100 | 81 | 81 | 86 | 71 | 62 | 38 | 45 | 19 |
| SPC | Sept | 100 | 100 | 103 | 80 | 113 | 58 | 100 | 35 | 84 | 22 | 100 | 100 | 91 | 78 | 113 | 52 | 87 | 26 | 74 | 13 |
| | Dec | 100 | 100 | 102 | 88 | 100 | 68 | 85 | 46 | 69 | 34 | 100 | 100 | 113 | 77 | 127 | 59 | 109 | 34 | 91 | 23 |
| | March | 100 | 100 | 106 | 85 | 117 | 64 | 103 | 41 | 85 | 23 | 100 | 100 | 100 | 75 | 108 | 50 | 100 | 37 | 79 | 25 |
| | June | 100 | 100 | 95 | 84 | 97 | 65 | 84 | 38 | 70 | 24 | 100 | 100 | 90 | 55 | 105 | 40 | 110 | 35 | 85 | 15 |

C = Control values (without *E. crassipes*), T = Treated values using *E. crassipes* respectively in comparison to the control values in the month of December, September and June while the value of control simultaneously increased from day zero to day 28 of experiments during each season. The value of turbidity and total solids in control as well as in the treated water showed a decreasing trend from zero day to 28 day but the decrease in domestic sewage was more pronounced than in the control. The self purification of sewage water to cause decrease in turbidity and total solids is well documented in the literature [150]. The amount of chloride ions present, indicated a decreasing trend with time in the control as well as in the treated sewage water. Nevertheless, the treated water exhibited more reduction in the chloride ion concentration as presented in Table 4.6. The effect of treatment on other physico-chemical parameters is summarized in Table 4.6. However, it was felt that the effect of treatment on these parameters is not very significant. The values of MPN and SPC also decreased significantly in comparison to the control from day 0 to day 28th. The maximum reduction in MPN and SPC values were 52% and 70% in the month of June 1990 respectively. The significant reduction in MPN and SPC values was observed in other months also.

The treatment of industrial effluent by E. crassipes also indicated a significant change in the water quality. The value of DO increased about 3.3 times in comparison to the control. The value of DO in control decreased with time and reached to zero after 4 weeks. But the treated water showed an increase in DO with time. The maximum value of DO (333%) was observed in the month of Dec 1989 followed by the month of June 1990 (about 236%). The maximum reduction in $CO_2$ and BOD values was also found in the months of December 1989 and March 1990. The value of COD also indicated a minimum value in the month of December 1989, after 4 weeks treatment. The values of $CO_2$, BOD and COD and other parameters observed for the control and treated effluent are presented in Table 4.6. The decrease in the values of chloride ions was about 40-50% throughout the period of study. The values of MPN and SPC were also decreased significantly in comparison to the control. The total reduction in MPN and SPC were about 30% and 60% in the months of December 1989 and March 1990, respectively.

### 4.5.2 Stage II

At stage II, the water samples collected from the domestic sewage and industrial effluents were treated with the culture of *L. minor* plant species for a period of 4 weeks. The samples were taken out after each week and the physico-chemical and biological parameters were analysed. In the case of domestic sewage, the value of DO was always found to be more in comparison to the control. Whereas in the control the DO value decreased gradually with time. The DO value observed in the control after 4 weeks was found as zero, whereas the DO

**Table 4.7** Observed values of various parameters for the stage II treated domestic sewage and industrial effluent

| Parameters | Month | Domestic sewage | | | | | | | | | | Industrial effluent | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | |
| | | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T |
| Turbidity | Sept | 100 | 100 | 22 | 19 | 14 | 12 | 12 | 9 | 12 | 7 | 100 | 100 | 19 | 17 | 12 | 10 | 10 | 8 | 9 | 6 |
| | Dec | 100 | 100 | 26 | 22 | 17 | 13 | 15 | 11 | 13 | 6 | 100 | 100 | 19 | 17 | 12 | 10 | 10 | 8 | 10 | 6 |
| | March | 100 | 100 | 23 | 19 | 14 | 11 | 12 | 9 | 11 | 7 | 100 | 100 | 20 | 18 | 13 | 11 | 11 | 8 | 10 | 7 |
| | June | 100 | 100 | 24 | 20 | 5 | 11 | 13 | 11 | 12 | 7 | 100 | 100 | 20 | 17 | 12 | 9 | 10 | 8 | 10 | 6 |
| Total solids | Sept | 100 | 100 | 57 | 56 | 28 | 25 | 25 | 9 | 23 | 9 | 100 | 100 | 72 | 69 | 22 | 18 | 19 | 6 | 16 | 6 |
| | Dec | 100 | 100 | 66 | 64 | 26 | 24 | 25 | 9 | 22 | 9 | 100 | 100 | 83 | 69 | 23 | 20 | 20 | 7 | 17 | 7 |
| | March | 100 | 100 | 57 | 55 | 27 | 26 | 25 | 10 | 24 | 9 | 100 | 100 | 79 | 68 | 21 | 19 | 19 | 7 | 17 | 7 |
| | June | 100 | 100 | 54 | 56 | 28 | 26 | 25 | 10 | 24 | 9 | 100 | 100 | 80 | 68 | 23 | 20 | 20 | 7 | 17 | 7 |
| pH | Sept | 100 | 100 | 99 | 98 | 94 | 88 | 93 | 80 | 91 | 80 | 100 | 100 | 99 | 93 | 94 | 87 | 92 | 82 | 91 | 81 |
| | Dec | 100 | 100 | 100 | 98 | 95 | 90 | 94 | 85 | 94 | 83 | 100 | 100 | 107 | 100 | 99 | 93 | 97 | 89 | 97 | 86 |
| | March | 100 | 100 | 99 | 96 | 94 | 87 | 93 | 80 | 92 | 82 | 100 | 100 | 99 | 95 | 95 | 88 | 93 | 79 | 91 | 78 |
| | June | 100 | 100 | 99 | 96 | 94 | 86 | 93 | 80 | 91 | 80 | 100 | 100 | 100 | 100 | 97 | 90 | 95 | 85 | 95 | 83 |
| Total hardness | Sept | 100 | 100 | 102 | 100 | 105 | 98 | 109 | 98 | 110 | 97 | 100 | 100 | 102 | 99 | 105 | 96 | 107 | 94 | 107 | 94 |
| | Dec | 100 | 100 | 102 | 99 | 104 | 97 | 106 | 97 | 106 | 97 | 100 | 100 | 101 | 99 | 104 | 97 | 108 | 97 | 108 | 97 |
| | March | 100 | 100 | 102 | 100 | 105 | 98 | 109 | 97 | 110 | 97 | 100 | 100 | 102 | 99 | 105 | 97 | 108 | 97 | 108 | 97 |
| | June | 100 | 100 | 107 | 100 | 109 | 98 | 114 | 98 | 114 | 97 | 100 | 100 | 101 | 99 | 103 | 98 | 105 | 97 | 105 | 97 |
| Chloride | Sept | 100 | 100 | 100 | 84 | 97 | 50 | 96 | 48 | 95 | 47 | 100 | 100 | 95 | 80 | 93 | 39 | 91 | 36 | 91 | 34 |
| | Dec | 100 | 100 | 100 | 82 | 95 | 55 | 95 | 54 | 93 | 50 | 100 | 100 | 98 | 91 | 96 | 50 | 95 | 56 | 94 | 50 |
| | March | 100 | 100 | 97 | 85 | 95 | 52 | 94 | 48 | 94 | 45 | 100 | 100 | 100 | 90 | 98 | 57 | 97 | 57 | 93 | 55 |
| | June | 100 | 100 | 100 | 88 | 99 | 57 | 97 | 53 | 97 | 47 | 100 | 100 | 98 | 85 | 98 | 52 | 93 | 46 | 92 | 44 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | Sept | 100 | 100 | 120 | 90 | 153 | 60 | 170 | 37 | 190 | 27 | 100 | 100 | 107 | 96 | 145 | 69 | 155 | 55 | 189 | 31 |
| | Dec | 100 | 100 | 137 | 111 | 221 | 79 | 237 | 58 | 289 | 42 | 100 | 100 | 107 | 91 | 121 | 64 | 138 | 50 | 145 | 38 |
| | March | 100 | 100 | 117 | 90 | 153 | 63 | 167 | 37 | 187 | 27 | 100 | 100 | 113 | 97 | 155 | 64 | 168 | 48 | 187 | 32 |
| | June | 100 | 100 | 117 | 87 | 150 | 63 | 170 | 37 | 190 | 25 | 100 | 100 | 116 | 95 | 134 | 61 | 144 | 49 | 154 | 37 |
| DO | Sept | 100 | 100 | 80 | 92 | 44 | 52 | 24 | 36 | - | 16 | 100 | 100 | 78 | 100 | 50 | 61 | 17 | 72 | - | 44 |
| | Dec | 100 | 100 | 80 | 96 | 44 | 72 | 24 | 52 | 8 | 36 | 100 | 100 | 67 | 100 | 22 | 44 | - | 22 | - | |
| | March | 100 | 100 | 80 | 95 | 30 | 45 | 5 | 30 | - | 15 | 100 | 100 | 79 | 95 | 42 | 53 | 21 | 37 | - | 21 |
| | June | 100 | 100 | 73 | 86 | 27 | 36 | 5 | 27 | - | 14 | 100 | 100 | 71 | 100 | 29 | 50 | 7 | 28 | - | 14 |
| BOD | Sept | 100 | 100 | 113 | 105 | 120 | 115 | 123 | 117 | 127 | 123 | 100 | 100 | 106 | 103 | 112 | 109 | 118 | 110 | 122 | 116 |
| | Dec | 100 | 100 | 115 | 107 | 124 | 118 | 131 | 121 | 135 | 129 | 100 | 100 | 108 | 105 | 112 | 110 | 116 | 112 | 121 | 115 |
| | March | 100 | 100 | 110 | 106 | 116 | 115 | 120 | 116 | 123 | 122 | 100 | 100 | 112 | 105 | 115 | 114 | 136 | 112 | 124 | 120 |
| | June | 100 | 100 | 122 | 117 | 129 | 125 | 134 | 128 | 141 | 132 | 100 | 100 | 111 | 104 | 116 | 112 | 119 | 114 | 123 | 117 |
| COD | Sept | 100 | 100 | 106 | 106 | 118 | 113 | 122 | 118 | 125 | 122 | 100 | 100 | 105 | 105 | 114 | 109 | 117 | 114 | 122 | 116 |
| | Dec | 100 | 100 | 107 | 106 | 119 | 114 | 125 | 119 | 118 | 113 | 100 | 100 | 104 | 104 | 110 | 108 | 113 | 110 | 114 | 112 |
| | Maech | 100 | 100 | 105 | 104 | 117 | 113 | 121 | 116 | 124 | 119 | 100 | 100 | 104 | 103 | 111 | 108 | 114 | 111 | 115 | 113 |
| | June | 100 | 100 | 115 | 114 | 127 | 125 | 133 | 126 | 136 | 130 | 100 | 100 | 103 | 103 | 111 | 108 | 115 | 111 | 119 | 114 |
| MPN | Sept | 100 | 100 | 88 | 82 | 76 | 53 | 65 | 47 | 48 | 35 | 100 | 100 | 94 | 92 | 79 | 77 | 67 | 60 | 46 | 38 |
| | Dec | 100 | 100 | 87 | 87 | 76 | 60 | 60 | 43 | 47 | 24 | 100 | 100 | 95 | 86 | 85 | 70 | 68 | 55 | 52 | 27 |
| | March | 100 | 100 | 83 | 78 | 68 | 51 | 57 | 41 | 45 | 28 | 100 | 100 | 91 | 87 | 84 | 71 | 67 | 28 | 48 | 16 |
| | June | 100 | 100 | 125 | 117 | 102 | 76 | 85 | 62 | 68 | 42 | 100 | 100 | 88 | 84 | 79 | 63 | 60 | 47 | 41 | 23 |
| SPC | Sept | 100 | 100 | 91 | 91 | 104 | 52 | 87 | 35 | 74 | 20 | 100 | 100 | 103 | 103 | 106 | 71 | 100 | 58 | 84 | 42 |
| | Dec | 100 | 100 | 100 | 100 | 108 | 60 | 96 | 42 | 80 | 20 | 100 | 100 | 102 | 102 | 97 | 76 | 85 | 61 | 70 | 51 |
| | March | 100 | 100 | 96 | 96 | 92 | 46 | 79 | 33 | 58 | 13 | 100 | 100 | 106 | 106 | 112 | 65 | 103 | 50 | 85 | 29 |
| | June | 100 | 100 | 115 | 110 | 110 | 55 | 95 | 40 | 70 | 15 | 100 | 100 | 95 | 95 | 95 | 68 | 84 | 51 | 70 | 38 |

C= Control values (without _L. minor_ ), T = Treatment with _L. minor_ level in the treated samples was found in the range of 14-36 percent (Table 4.7) during different months of investigations. The reductions in $CO_2$, chloride ions and SPC was more significant than other physico-chemical parameters in comparison to control. The $CO_2$ content in the control increased with time and became 289% of zero day observation in 4 weeks. Whereas in the treated samples the $CO_2$ content decreased with time and became 25-40 percent of the zero day values. Thus, the value of $CO_2$ reduced to about 12-15 percent of the control after 4 weeks of treatment. The reduction in total hardness, BOD, COD, MPN, turbidity and total solids were also observed after a treatment of 4 weeks throughout the course of investigations. The details of the values observed for all the parameters during the course of investigations are presented in Table 4.7.

The analysis of industrial effluents treated with *L. minor* indicated that the DO value did not change for the treated samples for the first week, whereas, after 4 weeks it changed to 44 percent. The corresponding control indicated practically zero values for the DO. The maximum values of DO was observed in the month of September 1989. The trends of reduction of BOD and COD were found almost similar. The changes in BOD and COD level in the control samples were practically similar to the treated samples. Hence, it appears that BOD and COD are not affected by the treatment of effluent with *L.*

minor. Total hardness and pH also did not indicate a significant change by the treatment. However, the reduction in carbon dioxide value was found significant after treatment and was in the range of 25-28 percent in comparison to the corresponding values for the control.

### 4.5.3 Stage III

The treatment of waste water with Ceratophyllum demorsum caused a change in all the physico-chemical and biological parameters, except COD, chloride ions and pH. In the case of domestic sewage, the control indicated a systematic change in DO with increasing duration. The DO decreased to about 10-25 percent after 4 weeks. The DO level for the treated samples also indicated a decreasing trend. However, the analysis at each week indicated a significant increase in DO corresponding to the control at the same time. Thus, it was concluded that C. demorsum prevented a decrease in DO of samples which would have occured more drastically without the treatment, as indicated by the controls. The BOD value did not decrease rapidly in comparison to control. It was found that the treatment caused an insignificant change in the BOD values. The reduction of $CO_2$ was also found much lower in comparison to E. crassipes (Stage I) and L. minor (Stage II) processes. The values of MPN and SPC also found to be decreased after treatment throughout the period of investigations. The details of changes in the value of physico-chemical and biological

**Table 4.8** Observed values of various parameters for the stage III treated domestic sewage and industrial effluent

| Parameters | Month | Industrial effluent | | | | | | | | | | Domestic sewage | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | |
| | | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T |
| Turbidity | Sept | 100 | 100 | 19 | 17 | 15 | 14 | 12 | 11 | 10 | 10 | 100 | 100 | 34 | 30 | 28 | 24 | 22 | 19 | 19 | 15 |
| | Dec | 100 | 100 | 19 | 17 | 15 | 13 | 12 | 10 | 10 | 9 | 100 | 100 | 46 | 40 | 38 | 33 | 30 | 26 | 26 | 23 |
| | March | 100 | 100 | 20 | 18 | 16 | 14 | 12 | 13 | 11 | 10 | 100 | 100 | 36 | 31 | 29 | 25 | 22 | 18 | 19 | 15 |
| | June | 100 | 100 | 19 | 17 | 15 | 13 | 12 | 10 | 10 | 8 | 10 | 100 | 23 | 20 | 18 | 16 | 14 | 11 | 12 | 9 |
| Total Solids | Sept | 100 | 100 | 72 | 73 | 45 | 37 | 22 | 18 | 19 | 13 | 100 | 100 | 56 | 56 | 53 | 44 | 28 | 26 | 25 | 18 |
| | Dec | 100 | 100 | 82 | 81 | 50 | 41 | 23 | 21 | 20 | 14 | 100 | 100 | 66 | 67 | 56 | 49 | 26 | 25 | 24 | 18 |
| | March | 100 | 100 | 79 | 78 | 48 | 39 | 21 | 21 | 19 | 14 | 100 | 100 | 54 | 55 | 53 | 44 | 27 | 27 | 25 | 18 |
| | June | 100 | 100 | 80 | 80 | 49 | 40 | 23 | 21 | 20 | 14 | 100 | 100 | 55 | 54 | 53 | 44 | 27 | 27 | 25 | 18 |
| pH | Sept | 100 | 100 | 99 | 99 | 95 | 94 | 94 | 94 | 91 | 88 | 100 | 100 | 99 | 99 | 97 | 93 | 94 | 91 | 93 | 86 |
| | Dec | 100 | 100 | 100 | 100 | 99 | 98 | 98 | 95 | 97 | 91 | 100 | 100 | 100 | 98 | 98 | 94 | 95 | 93 | 94 | 88 |
| | March | 100 | 100 | 99 | 98 | 98 | 95 | 93 | 95 | 93 | 87 | 100 | 100 | 99 | 99 | 98 | 94 | 94 | 93 | 93 | 86 |
| | June | 100 | 100 | 100 | 98 | 100 | 93 | 97 | 92 | 95 | 89 | 100 | 100 | 99 | 99 | 98 | 94 | 94 | 93 | 93 | 86 |
| Total hardness | Sept | 100 | 100 | 76 | 74 | 77 | 73 | 78 | 72 | 80 | 72 | 100 | 100 | 102 | 100 | 103 | 99 | 105 | 99 | 109 | 98 |
| | Dec | 100 | 100 | 101 | 100 | 103 | 99 | 104 | 103 | 108 | 97 | 100 | 100 | 102 | 99 | 102 | 99 | 103 | 97 | 106 | 75 |
| | March | 100 | 100 | 102 | 99 | 104 | 99 | 105 | 97 | 107 | 97 | 100 | 100 | 102 | 100 | 103 | 99 | 105 | 99 | 110 | 98 |
| | June | 100 | 100 | 101 | 99 | 102 | 98 | 103 | 98 | 105 | 98 | 100 | 100 | 106 | 105 | 106 | 103 | 110 | 102 | 112 | 101 |
| Chloride | Sept | 100 | 100 | 95 | 89 | 93 | 86 | 93 | 77 | 91 | 77 | 100 | 100 | 100 | 98 | 98 | 98 | 94 | 94 | 94 | 92 |
| | Dec | 100 | 100 | 99 | 96 | 97 | 96 | 96 | 87 | 95 | 87 | 100 | 100 | 100 | 93 | 98 | 93 | 96 | 87 | 96 | 86 |
| | March | 100 | 100 | 98 | 95 | 97 | 93 | 96 | 86 | 95 | 86 | 100 | 100 | 98 | 97 | 98 | 93 | 97 | 87 | 97 | 87 |
| | June | 100 | 100 | 100 | 96 | 98 | 96 | 97 | 94 | 96 | 94 | 100 | 100 | 102 | 102 | 101 | 97 | 100 | 93 | 103 | 90 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | Sept | 100 | 100 | 107 | 107 | 134 | 96 | 159 | 90 | 162 | 76 | 100 | 100 | 117 | 107 | 130 | 100 | 153 | 97 | 170 | 76 |
| | Dec | 100 | 100 | 107 | 95 | 117 | 93 | 121 | 92 | 138 | 74 | 100 | 100 | 137 | 110 | 158 | 100 | 221 | 100 | 236 | 73 |
| | March | 100 | 100 | 113 | 103 | 132 | 100 | 155 | 97 | 168 | 84 | 100 | 100 | 113 | 103 | 132 | 97 | 145 | 93 | 161 | 84 |
| | June | 100 | 100 | 107 | 102 | 117 | 97 | 131 | 96 | 140 | 90 | 100 | 100 | 120 | 107 | 140 | 100 | 150 | 96 | 167 | 90 |
| DO | Sept | 100 | 100 | 78 | 83 | 66 | 78 | 50 | 61 | 16 | 44 | 100 | 100 | 80 | 92 | 60 | 72 | 44 | 52 | 24 | 36 |
| | dec | 100 | 100 | 66 | 100 | 44 | 66 | 22 | 44 | - | 33 | 100 | 100 | 80 | 96 | 64 | 84 | 44 | 72 | 24 | 52 |
| | March | 100 | 100 | 79 | 95 | 56 | 79 | 42 | 52 | 21 | 37 | 100 | 100 | 80 | 95 | 50 | 65 | 30 | 45 | 10 | 30 |
| | June | 100 | 100 | 71 | 100 | 43 | 71 | 29 | 50 | 7 | 28 | 100 | 100 | 73 | 86 | 45 | 59 | 27 | 51 | 9 | 23 |
| BOD | Sept | 100 | 100 | 106 | 105 | 108 | 106 | 111 | 109 | 117 | 110 | 100 | 100 | 122 | 110 | 118 | 118 | 134 | 126 | 138 | 129 |
| | Dec | 100 | 100 | 108 | 104 | 110 | 108 | 112 | 110 | 116 | 109 | 100 | 100 | 128 | 116 | 138 | 122 | 147 | 135 | 160 | 142 |
| | March | 100 | 100 | 112 | 105 | 113 | 108 | 114 | 114 | 121 | 115 | 100 | 100 | 118 | 110 | 118 | 116 | 127 | 124 | 134 | 126 |
| | June | 100 | 100 | 111 | 104 | 114 | 110 | 116 | 112 | 118 | 113 | 100 | 100 | 122 | 115 | 120 | 120 | 127 | 124 | 130 | 125 |
| COD | Sept | 100 | 100 | 106 | 105 | 110 | 109 | 114 | 114 | 118 | 117 | 100 | 100 | 106 | 105 | 110 | 110 | 118 | 115 | 122 | 120 |
| | Dec | 100 | 100 | 104 | 104 | 106 | 106 | 110 | 109 | 113 | 110 | 100 | 100 | 107 | 102 | 111 | 108 | 119 | 114 | 125 | 119 |
| | March | 100 | 100 | 103 | 103 | 105 | 105 | 111 | 111 | 115 | 114 | 100 | 100 | 104 | 104 | 110 | 108 | 116 | 113 | 121 | 117 |
| | June | 100 | 100 | 103 | 103 | 106 | 104 | 111 | 107 | 114 | 110 | 100 | 100 | 115 | 112 | 120 | 117 | 127 | 120 | 131 | 129 |
| MPN | Sept | 100 | 100 | 96 | 82 | 88 | 83 | 79 | 75 | 66 | 62 | 100 | 100 | 88 | 82 | 82 | 59 | 76 | 58 | 65 | 47 |
| | Dec | 100 | 100 | 95 | 95 | 90 | 81 | 84 | 68 | 68 | 75 | 100 | 100 | 89 | 86 | 86 | 70 | 76 | 63 | 60 | 43 |
| | March | 100 | 100 | 91 | 89 | 88 | 78 | 69 | 83 | 67 | 52 | 100 | 100 | 83 | 83 | 75 | 64 | 68 | 55 | 56 | 42 |
| | June | 100 | 100 | 99 | 85 | 88 | 77 | 86 | 64 | 79 | 51 | 100 | 100 | 125 | 121 | 113 | 96 | 101 | 83 | 86 | 60 |
| SPC | Sept | 100 | 100 | 103 | 103 | 113 | 90 | 106 | 74 | 100 | 61 | 100 | 100 | 91 | 91 | 113 | 82 | 104 | 52 | 87 | 43 |
| | Dec | 100 | 100 | 102 | 102 | 100 | 88 | 97 | 80 | 85 | 63 | 100 | 100 | 112 | 100 | 108 | 76 | 96 | 64 | 96 | 40 |
| | March | 100 | 100 | 106 | 105 | 117 | 88 | 114 | 111 | 103 | 50 | 100 | 100 | 96 | 95 | 108 | 66 | 95 | 50 | 79 | 33 |
| | June | 100 | 100 | 96 | 94 | 97 | 84 | 94 | 70 | 84 | 54 | 100 | 100 | 126 | 115 | 130 | 80 | 110 | 60 | 95 | 40 |

C = Control values ( without C. demorsum ), T = Treatment with C. demorsum parameters of control as well as treated samples, with time (from zero day to 4 weeks) are presented in Table 4.8.

The treatment of industrial effluents with C. demorsum at stage III also indicated a behaviour similar to the domestic sewage.

A comparison of values of various parameters determined for sewage and industrial effluents in the month of September 1989 is presented in Table 4.9. It is clearly seen that the values observed for domestic sewage after 4 weeks treatment provide a water of reasonably pure quality, the values observed are well within the range suggested by WHO for agriculture purposes [161]. On the other hand the value of DO in the case of sewage as well as effluents is very low and hence even after the treatment the water is not suitable for bathing or drinking purposes. Hence, it could be concluded that the treated water for municipal sewage as well as effluent is not reasonably pure even for bathing due to high values of MPN and SPC and therefore some other treatments are necessary before it is mixed in the river Dhamola.

### 4.5.4 Stage IV

As water hyacinth (E. crassipes, Stage I) was found more effective in reducing BOD, COD, MPN and $CO_2$ of the waste water samples and L. minor (Stage II) was

**Table 4.9** A comparison of various physico-chemical and biological parameters for domestic sewage and industrial effluent after the treatment with <u>C. demorsum</u> for a period of 4 weeks in the month of September, 1989.

| Parameters* | Domestic sewage | Industrial effluent |
|---|---|---|
| Turbidity (NTU) | 27.5 | 36.0 |
| Total Solids (mg/l) | 129.0 | 146.0 |
| pH | 7.0 | 7.5 |
| Total Hardness (mg/l) | 275.0 | 284.0 |
| Chloride (mg/l) | 29.6 | 17.0 |
| DO (mg/l) | 0.9 | 0.8 |
| BOD (mg/l) | 181.0 | 196.0 |
| COD (mg/l) | 294.0 | 245.0 |
| $CO_2$-free (mg/l) | 2.3 | 2.2 |
| MPN x $10^4$ (per 100 ml) | 9.9 | 17.0 |
| SPC x $10^5$ (per ml) | 12.0 | 23.0 |

* All values reported are an average of atleast two replicate determinations.

useful in reducing turbidity, total solids, chlorides and total hardness, it was considered interesting to observe the effect of equal amount of both the plant species together. In stage IV, a mixture of both the plant species (E. crassipes and L. minor) was taken in equal amount for the treatment of waste water. It was observed that the concentration of DO in stage IV increased much more than in the case of individual plant species during the entire course of investigation. The values of DO for the controls and treated samples are presented in Table 4.10. The BOD and COD values also decreased to about 50% of the control values during the entire period. Turbidity, total solids, chlorides and $CO_2$ indicated a significant decrease in the sewage water after the treatment at stage IV. Thus, it seems reasonable to conclude that the mixture of two different plant species, viz., water hyacinth (E. crassipes) and L. minor are more effective in removing pollution load in sewage water in comparison to the individual species.

The industrial effluent treated at stage IV also indicated a similar behaviour in which DO increased to a level similar to the domestic sewage. BOD, COD and other parameters indicated a decrease in the values. However, an overall effect of the two species on physico-chemical and biological parameters for the sewage water and effluent was found practically similar and are summarized in Table 4.10.

Table 4.10 Observed values of various parameters for the stage IV treated domestic sewage and industrial effluent

| Parameters | Month | Industrial effluent | | | | | | | | | | Domestic sewage | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | |
| | | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T |
| Turbidity | Sept | 100 | 100 | 19 | 14 | 15 | 10 | 10 | 5 | 9 | 4 | 100 | 100 | 22 | 16 | 14 | 7 | 12 | 6 | 11 | 4 |
| | Dec | 100 | 100 | 19 | 14 | 12 | 6 | 10 | 5 | 10 | 4 | 100 | 100 | 26 | 20 | 17 | 9 | 15 | 7 | 13 | 6 |
| | March | 100 | 100 | 20 | 15 | 13 | 7 | 11 | 6 | 10 | 4 | 100 | 100 | 23 | 16 | 14 | 6 | 12 | 6 | 11 | 4 |
| | June | 100 | 100 | 19 | 14 | 12 | 6 | 10 | 5 | 9 | 4 | 100 | 100 | 21 | 15 | 14 | 7 | 12 | 5 | 11 | 4 |
| Total solids | Sept | 100 | 100 | 72 | 68 | 45 | 33 | 19 | 5 | 16 | 5 | 100 | 100 | 56 | 55 | 28 | 25 | 25 | 7 | 23 | 7 |
| | Dec | 100 | 100 | 82 | 66 | 23 | 20 | 20 | 6 | 17 | 5 | 100 | 100 | 65 | 55 | 26 | 24 | 25 | 7 | 22 | 6 |
| | March | 100 | 100 | 79 | 64 | 20 | 19 | 19 | 5 | 17 | 5 | 100 | 100 | 54 | 42 | 27 | 25 | 24 | 7 | 23 | 6 |
| | June | 100 | 100 | 80 | 62 | 23 | 19 | 20 | 6 | 17 | 5 | 100 | 100 | 56 | 56 | 28 | 25 | 24 | 7 | 23 | 6 |
| pH | Sept | 100 | 100 | 99 | 99 | 95 | 93 | 92 | 82 | 91 | 77 | 100 | 100 | 99 | 109 | 94 | 89 | 92 | 84 | 91 | 80 |
| | Dec | 100 | 100 | 100 | 102 | 98 | 89 | 97 | 97 | 97 | 85 | 100 | 100 | 100 | 99 | 95 | 94 | 94 | 85 | 94 | 80 |
| | March | 100 | 100 | 99 | 100 | 95 | 93 | 93 | 85 | 91 | 79 | 100 | 100 | 99 | 98 | 94 | 89 | 92 | 84 | 91 | 80 |
| | June | 100 | 100 | 100 | 97 | 97 | 87 | 95 | 97 | 95 | 81 | 100 | 100 | 99 | 96 | 94 | 87 | 92 | 81 | 91 | 77 |
| Total hardness | Sept | 100 | 100 | 102 | 97 | 103 | 92 | 107 | 91 | 108 | 90 | 100 | 100 | 102 | 95 | 105 | 90 | 109 | 89 | 110 | 89 |
| | Dec | 100 | 100 | 101 | 97 | 104 | 92 | 108 | 92 | 109 | 91 | 100 | 100 | 102 | 99 | 104 | 94 | 106 | 94 | 106 | 93 |
| | March | 100 | 100 | 102 | 97 | 105 | 92 | 107 | 91 | 108 | 91 | 100 | 100 | 102 | 95 | 105 | 91 | 109 | 91 | 110 | 89 |
| | June | 100 | 100 | 101 | 103 | 103 | 99 | 105 | 98 | 105 | 98 | 100 | 100 | 102 | 95 | 106 | 92 | 111 | 92 | 112 | 90 |
| Chloride | Sept | 100 | 100 | 95 | 66 | 95 | 41 | 91 | 29 | 91 | 27 | 100 | 100 | 100 | 78 | 97 | 50 | 97 | 45 | 96 | 44 |
| | Dec | 100 | 100 | 100 | 82 | 98 | 50 | 97 | 55 | 96 | 50 | 100 | 100 | 100 | 78 | 98 | 53 | 96 | 53 | 95 | 52 |
| | March | 100 | 100 | 100 | 91 | 98 | 55 | 97 | 53 | 96 | 53 | 100 | 100 | 97 | 74 | 96 | 47 | 92 | 45 | 90 | 42 |
| | June | 100 | 100 | 100 | 77 | 98 | 52 | 95 | 50 | 94 | 46 | 100 | 100 | 100 | 80 | 103 | 53 | 103 | 45 | 103 | 47 |

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| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | Sept | 100 | 100 | 107 | 86 | 134 | 69 | 162 | 31 | 195 | 17 | 100 | 100 | 117 | 81 | 150 | 47 | 170 | 30 | 188 | 17 |
| | Dec | 100 | 100 | 88 | 71 | 121 | 43 | 138 | 57 | 145 | 21 | 100 | 100 | 189 | 84 | 221 | 53 | 231 | 37 | 281 | 26 |
| | March | 100 | 100 | 113 | 93 | 155 | 58 | 168 | 29 | 187 | 13 | 100 | 100 | 113 | 90 | 145 | 55 | 161 | 32 | 181 | 13 |
| | June | 100 | 100 | 107 | 93 | 131 | 62 | 140 | 45 | 150 | 33 | 100 | 100 | 119 | 73 | 147 | 47 | 170 | 30 | 189 | 17 |
| DO | Sept | 100 | 100 | 78 | 111 | 67 | 133 | 17 | 217 | - | 222 | 100 | 100 | 80 | 125 | 44 | 152 | 24 | 176 | - | 184 |
| | Dec | 100 | 100 | 67 | 155 | 22 | 322 | - | 266 | - | 333 | 100 | 100 | 80 | 108 | 44 | 140 | 24 | 160 | 8 | 172 |
| | March | 100 | 100 | 79 | 105 | 42 | 163 | 21 | 184 | - | 189 | 100 | 100 | 80 | 130 | 30 | 170 | 10 | 210 | - | 215 |
| | June | 100 | 100 | 71 | 107 | 28 | 185 | 7 | 221 | - | 228 | 100 | 100 | 91 | 136 | 45 | 173 | 27 | 200 | - | 214 |
| BOD | Sept | 100 | 100 | 106 | 94 | 108 | 89 | 117 | 74 | 122 | 72 | 100 | 100 | 113 | 93 | 120 | 81 | 122 | 76 | 127 | 72 |
| | Dec | 100 | 100 | 108 | 94 | 112 | 80 | 116 | 84 | 120 | 76 | 100 | 100 | 115 | 95 | 124 | 83 | 131 | 74 | 135 | 71 |
| | March | 100 | 100 | 112 | 93 | 115 | 83 | 121 | 79 | 124 | 76 | 100 | 100 | 111 | 92 | 116 | 82 | 120 | 75 | 123 | 72 |
| | June | 100 | 100 | 111 | 95 | 116 | 84 | 118 | 78 | 123 | 76 | 100 | 100 | 115 | 95 | 123 | 84 | 127 | 78 | 131 | 73 |
| COD | Sept | 100 | 100 | 106 | 93 | 110 | 88 | 117 | 77 | 122 | 74 | 100 | 100 | 106 | 93 | 118 | 80 | 122 | 73 | 125 | 69 |
| | Dec | 100 | 100 | 104 | 70 | 110 | 60 | 113 | 64 | 114 | 57 | 100 | 100 | 107 | 94 | 119 | 81 | 125 | 77 | 129 | 73 |
| | March | 100 | 100 | 104 | 70 | 111 | 70 | 114 | 64 | 114 | 61 | 100 | 100 | 104 | 93 | 117 | 79 | 121 | 75 | 124 | 71 |
| | June | 100 | 100 | 103 | 69 | 111 | 86 | 115 | 82 | 119 | 80 | 100 | 100 | 107 | 92 | 120 | 81 | 125 | 74 | 128 | 69 |
| MPN | Sept | 100 | 100 | 94 | 79 | 88 | 71 | 67 | 50 | 46 | 30 | 100 | 100 | 88 | 70 | 76 | 44 | 65 | 32 | 48 | 11 |
| | Dec | 100 | 100 | 95 | 86 | 84 | 48 | 68 | 59 | 52 | 20 | 100 | 100 | 89 | 70 | 76 | 53 | 60 | 30 | 47 | 12 |
| | March | 100 | 100 | 91 | 73 | 83 | 63 | 67 | 48 | 48 | 24 | 100 | 100 | 83 | 67 | 68 | 44 | 57 | 32 | 45 | 20 |
| | June | 100 | 100 | 88 | 74 | 79 | 53 | 60 | 32 | 44 | 18 | 100 | 100 | 117 | 83 | 108 | 58 | 92 | 42 | 67 | 16 |
| SPC | Sept | 100 | 100 | 103 | 77 | 113 | 55 | 100 | 32 | 86 | 22 | 100 | 100 | 91 | 78 | 104 | 39 | 87 | 26 | 74 | 130 |
| | Dec | 100 | 100 | 102 | 85 | 97 | 44 | 85 | 56 | 69 | 32 | 100 | 100 | 100 | 68 | 108 | 34 | 96 | 28 | 80 | 20 |
| | March | 100 | 100 | 106 | 76 | 111 | 50 | 103 | 30 | 85 | 20 | 100 | 100 | 96 | 75 | 92 | 37 | 79 | 25 | 58 | 12 |
| | June | 100 | 100 | 95 | 81 | 95 | 49 | 84 | 35 | 70 | 22 | 100 | 100 | 100 | 85 | 120 | 40 | 100 | 31 | 85 | 15 |

C = Control values ( without *E. crassipes* and *L. minor* ), T = Treatment with *E. crassipes* and *L. minor*

### 4.5.5 Stage V

At stage V, the waste water samples were treated with a mixture of L. minor and C. demorsum plant species. It was observed that the mixture of these plant species had almost similar effect on the physico-chemical and biological parameters of domestic sewage and effluents as was observed in the case of individual species. Thus the turbidity, total solids, total hardness, chloride ions, $CO_2$, BOD, COD and SPC reduced to an extent as was observed in stage II and stage III treatment separately. The value of DO was increased to about 25-30 percent in the presence of L. minor and C. demorsum in comparison to the control after 4 weeks. In the individual plants treatment at stage II and III, the maximum increase in DO was 10-20 percent. The details of all the physico-chemical and biological parameters are presented in Table 4.11.

In general, Eichhornia crassipes (Stage I) has been found more effective in reducing the pollution load in the present studies. It may be due to the fact that E. crassipes is a large leaf plant. As large leaf covers large area, more transpiration occurs during the photosynthesis process which leads the increase in DO level. Thus, increase in DO level at stages I and IV may be due to the large leaf area, well developed arenchyma and root system of E. crassipes. However, decrease in BOD and COD values may be due to better availability of

**Table 4.11** Observed values of various parameters for the stage V treated domestic sewage and industrial effluent

| Parameters | Month | Domestic sewage | | | | | | | | | | Industrial effluent | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | | 0 day | | 7 days | | 14 days | | 21 days | | 28 days | |
| | | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T | C | T |
| Turbidity | Sept | 100 | 100 | 19 | 16 | 12 | 8 | 10 | 6 | 9 | 5 | 100 | 100 | 22 | 18 | 14 | 9 | 12 | 7 | 11 | 5 |
| | Dec | 100 | 100 | 19 | 15 | 12 | 8 | 10 | 7 | 10 | 6 | 100 | 100 | 26 | 21 | 17 | 11 | 15 | 9 | 13 | 6 |
| | March | 100 | 100 | 20 | 16 | 13 | 8 | 11 | 7 | 10 | 6 | 100 | 100 | 23 | 18 | 14 | 8 | 12 | 7 | 11 | 5 |
| | June | 100 | 100 | 19 | 15 | 11 | 8 | 10 | 6 | 9 | 5 | 100 | 100 | 21 | 18 | 13 | 13 | 11 | 7 | 11 | 5 |
| Total solids | Sept | 100 | 100 | 72 | 70 | 21 | 18 | 19 | 7 | 16 | 7 | 100 | 100 | 56 | 55 | 27 | 25 | 25 | 10 | 23 | 10 |
| | Dec | 100 | 100 | 82 | 68 | 22 | 20 | 20 | 8 | 17 | 8 | 100 | 100 | 65 | 63 | 26 | 25 | 25 | 10 | 22 | 9 |
| | March | 100 | 100 | 78 | 68 | 20 | 18 | 19 | 8 | 16 | 8 | 100 | 100 | 57 | 54 | 27 | 26 | 25 | 11 | 23 | 10 |
| | June | 100 | 100 | 80 | 69 | 23 | 19 | 20 | 9 | 17 | 7 | 100 | 100 | 56 | 55 | 27 | 24 | 24 | 10 | 22 | 10 |
| pH | Sept | 100 | 100 | 99 | 95 | 94 | 89 | 92 | 83 | 90 | 82 | 100 | 100 | 99 | 97 | 94 | 87 | 92 | 85 | 91 | 80 |
| | Dec | 100 | 100 | 100 | 105 | 98 | 94 | 97 | 89 | 97 | 89 | 100 | 100 | 100 | 100 | 95 | 92 | 94 | 87 | 93 | 86 |
| | March | 100 | 100 | 100 | 99 | 96 | 95 | 93 | 83 | 91 | 83 | 100 | 100 | 98 | 97 | 94 | 87 | 92 | 84 | 91 | 80 |
| | June | 100 | 100 | 100 | 101 | 97 | 92 | 95 | 87 | 95 | 85 | 100 | 100 | 98 | 97 | 94 | 96 | 91 | 84 | 91 | 80 |
| Total hardness | Sept | 100 | 100 | 102 | 98 | 105 | 95 | 107 | 91 | 107 | 90 | 100 | 100 | 102 | 97 | 104 | 95 | 109 | 95 | 109 | 90 |
| | Dec | 100 | 100 | 103 | 96 | 104 | 91 | 108 | 91 | 108 | 90 | 100 | 100 | 101 | 98 | 104 | 92 | 106 | 92 | 106 | 65 |
| | March | 100 | 100 | 102 | 98 | 104 | 94 | 107 | 94 | 108 | 94 | 100 | 100 | 102 | 98 | 105 | 92 | 109 | 92 | 110 | 101 |
| | June | 100 | 100 | 103 | 101 | 103 | 96 | 105 | 96 | 105 | 95 | 100 | 100 | 73 | 98 | 106 | 89 | 109 | 91 | 109 | 91 |
| Chloride | Sept | 100 | 100 | 95 | 68 | 91 | 32 | 91 | 32 | 88 | 27 | 100 | 100 | 100 | 78 | 97 | 50 | 95 | 47 | 95 | 45 |
| | Dec | 100 | 100 | 100 | 87 | 98 | 55 | 96 | 50 | 96 | 50 | 100 | 100 | 100 | 78 | 97 | 53 | 97 | 53 | 95 | 50 |
| | March | 100 | 100 | 100 | 89 | 98 | 55 | 96 | 53 | 94 | 52 | 100 | 100 | 97 | 79 | 95 | 47 | 95 | 46 | 93 | 45 |
| | June | 100 | 100 | 100 | 77 | 98 | 50 | 98 | 48 | 96 | 46 | 100 | 100 | 103 | 73 | 100 | 50 | 100 | 46 | 98 | 46 |

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| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ | Sept | 100 | 100 | 107 | 93 | 159 | 69 | 162 | 55 | 193 | 31 | 100 | 100 | 120 | 90 | 153 | 60 | 170 | 37 | 190 | 23 |
| | Dec | 100 | 100 | 107 | 88 | 121 | 62 | 136 | 48 | 140 | 36 | 100 | 100 | 137 | 105 | 221 | 79 | 237 | 53 | 289 | 37 |
| | March | 100 | 100 | 113 | 97 | 155 | 61 | 168 | 48 | 190 | 29 | 100 | 100 | | | | | | | | |
| | June | 100 | 100 | 107 | 93 | 131 | 57 | 141 | 45 | 150 | 36 | 100 | 100 | 100 | 87 | 147 | 57 | 67 | 37 | 183 | 27 |
| DO | Sept | 100 | 100 | 78 | 105 | 50 | 67 | 17 | 50 | - | 33 | 100 | 100 | 80 | 92 | 44 | 60 | 24 | 40 | - | 24 |
| | Dec | 100 | 100 | 67 | 111 | 22 | 67 | - | 44 | - | 11 | 100 | 100 | 80 | 100 | 44 | 76 | 24 | 40 | 8 | 24 |
| | March | 100 | 100 | 79 | 108 | 42 | 68 | 21 | 42 | - | 26 | 100 | 100 | 50 | 100 | 40 | 50 | 5 | 37 | - | 20 |
| | June | 100 | 100 | 71 | 107 | 29 | 64 | 7 | 43 | - | 14 | 100 | 100 | 91 | 100 | 45 | 64 | 27 | 41 | - | 27 |
| BOD | Sept | 100 | 100 | 106 | 101 | 111 | 108 | 117 | 109 | 122 | 116 | 100 | 100 | 113 | 104 | 120 | 112 | 122 | 116 | 127 | 122 |
| | Dec | 100 | 100 | 108 | 103 | 112 | 109 | 116 | 111 | 120 | 114 | 100 | 100 | 115 | 106 | 124 | 116 | 131 | 119 | 135 | 127 |
| | March | 100 | 100 | 64 | 60 | 66 | 65 | 70 | 66 | 71 | 68 | 100 | 100 | 111 | 104 | 116 | 112 | 120 | 115 | 123 | 120 |
| | June | 100 | 100 | 111 | 102 | 116 | 108 | 119 | 113 | 123 | 115 | 100 | 100 | 116 | 108 | 108 | 116 | 123 | 116 | 129 | 125 |
| COD | Sept | 100 | 100 | 106 | 101 | 114 | 108 | 117 | 114 | 122 | 87 | 100 | 100 | 106 | 102 | 118 | 111 | 122 | 116 | 125 | 119 |
| | Dec | 100 | 100 | 104 | 101 | 110 | 106 | 113 | 109 | 114 | 111 | 100 | 100 | 107 | 103 | 119 | 112 | 125 | 117 | 129 | 121 |
| | March | 100 | 100 | 104 | 103 | 111 | 106 | 114 | 109 | 114 | 111 | 100 | 100 | 104 | 104 | 117 | 110 | 121 | 114 | 123 | 116 |
| | June | 100 | 100 | 103 | 102 | 111 | 106 | 115 | 109 | 119 | 111 | 100 | 100 | 108 | 102 | 120 | 113 | 121 | 117 | 126 | 121 |
| MPN | Sept | 100 | 100 | 94 | 87 | 79 | 71 | 67 | 58 | 46 | 35 | 100 | 100 | 88 | 82 | 76 | 53 | 65 | 41 | 48 | 14 |
| | Dec | 100 | 100 | 95 | 84 | 84 | 70 | 68 | 52 | 52 | 25 | 100 | 100 | 89 | 80 | 76 | 53 | 60 | 40 | 47 | 20 |
| | March | 100 | 100 | 91 | 83 | 84 | 69 | 67 | 52 | 48 | 30 | 100 | 100 | 83 | 72 | 68 | 50 | 57 | 39 | 45 | 27 |
| | June | 100 | 100 | 88 | 79 | 79 | 60 | 60 | 46 | 44 | 21 | 100 | 100 | 125 | 116 | 108 | 75 | 92 | 58 | 68 | 21 |
| SPC | Sept | 100 | 100 | 103 | 100 | 106 | 68 | 100 | 58 | 84 | 39 | 100 | 100 | 91 | 83 | 104 | 52 | 87 | 39 | 74 | 19 |
| | Dec | 100 | 100 | 102 | 97 | 97 | 76 | 85 | 61 | 69 | 51 | 100 | 100 | 100 | 88 | 108 | 56 | 96 | 40 | 80 | 20 |
| | March | 100 | 100 | 106 | 100 | 112 | 62 | 103 | 47 | 85 | 26 | 100 | 100 | 96 | 87 | 92 | 48 | 79 | 33 | 58 | 12 |
| | June | 100 | 100 | 95 | 89 | 95 | 67 | 84 | 49 | 70 | 35 | 100 | 100 | 105 | 95 | 120 | 60 | 100 | 45 | 85 | 22 |

C = Control values ( without L. *minor* & C. *demorsum* ), T = Treatment with L. *minor* & C. *demorsum* oxygen in root tissue of *E. crassipes*. The change in the pH value during the treatment process is possibly due to the volatilization as suggested by Stratton [170]. The significant decrease in MPN and SPC (coliform bacteria) by *E. crassipes* is well reported in the literature [169] and has been assigned to the agglomeration of colloidal particles in the waste water which carries the bacteria to the bottom [171].

The practically similar values of BOD and COD of the control and treated samples at stage II (*L. minor*) can be assigned to the accumulation of the decayed plant at the bottom of the containers during the treatment [4]. Such an accumulation would result in the degradation of organic matter by micro-organisms. These organisms consume the dissolved oxygen for the decomposition of organic matter and cause an increase in BOD and COD values.

### 4.5.6 Biomass of Hydrophytes

The percentage changes in the biomass of different hydrophytes after a treatment of four weeks for domestic waste and industrial effluents were carried out for all the plant species used in the investigation. The amount of biomass obtained after a 4 weeks treatment in various months are depicted in fig. 4.8. It can be clearly seen that the biomass of *E. crassipes* is almost 2 to 3 times greater than all the other plant species used in the domestic sewage as well as in industrial effluents. L. minor and C. demorsum on the other hand indicated a loss in biomass. Such a behaviour of L. minor and C. demorsum is well reported in the literature [172] and has been accounted for on the basis of destruction of the membrane system of the chloroplast of these hydrophytes in the waste water. Huber et al. [173] have also found a reduction in biomass of these hydrophyte due to the reduction of the photosynthesis of aquatic macrophytes by the waste water.

Thus, it is clear from the treatment of domestic sewage and industrial effluents by various plant species that these plants are capable of reducing the organic and inorganic pollution load of waste water. However, a comparison of various treatment clearly indicated that such a treatment alone is not sufficient for making the water useful for bathing or drinking purposes. The analysis of the various parameters pointed out that the treatment with the plant species reduces the pollution load to such an extent so that the water samples can be used for agricultural purposes. Nevertheless, it is felt that some more treatment are necessary to make it more useful and should also be carried out before mixing it in the river Dhamola to control the pollution load in the river water.

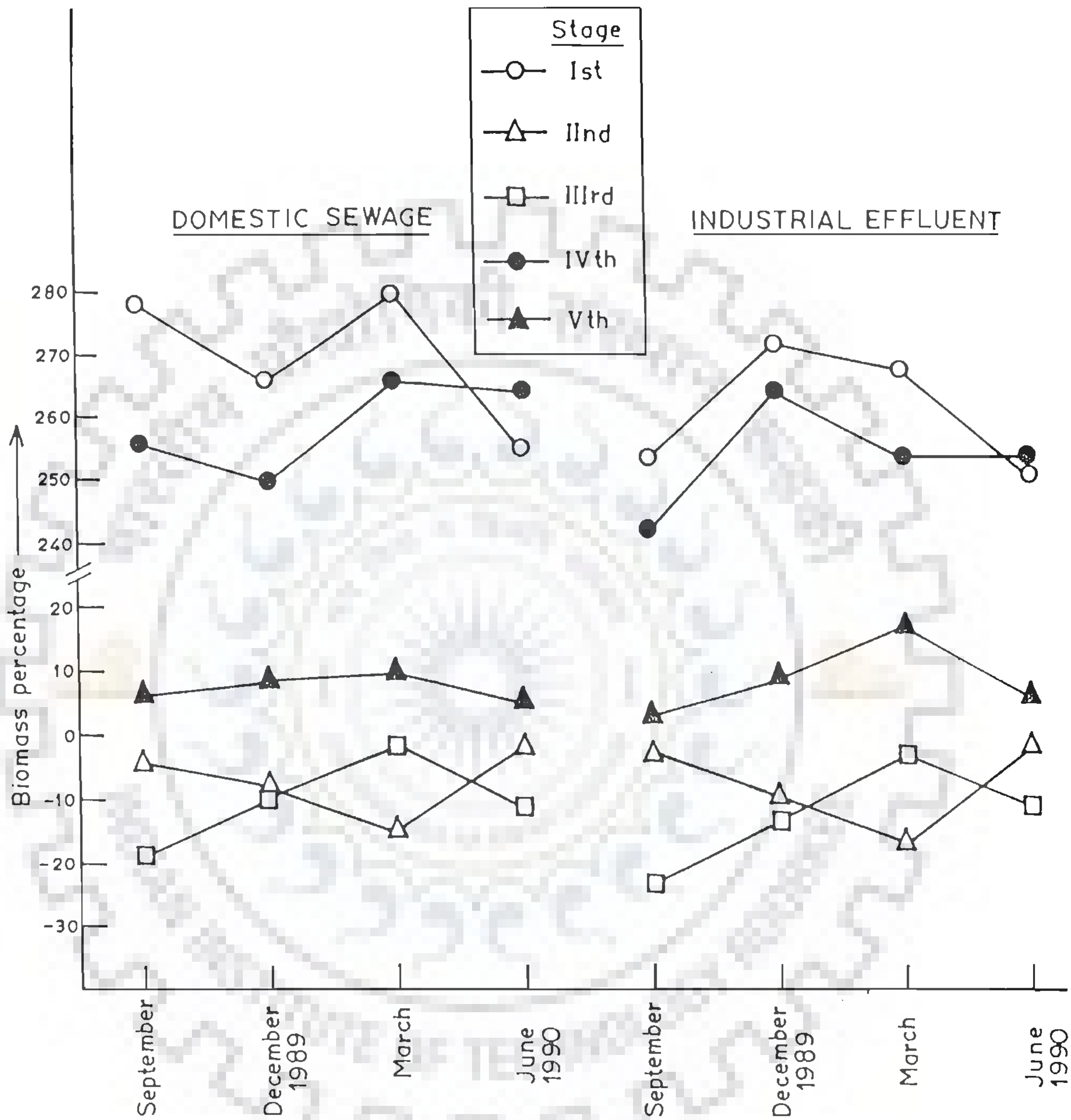


Fig. 4.8 Percentage change in biomass of treated hydrophytes after 4 weeks during different seasons of 1989-90

## 4.6 STATISTICAL CORRELATIONS

Correlations among water quality parameters provides an important information about the overall quality of water. Since other parameters and their functions can be explained on the basis of these correlations. Attempts have also been made to calculate the correlation coefficients among the physico-chemical and biological parameters determined for the three sampling stations for the river Dhamola. The entire information collected for a period of 2 years was used for determining the value of correlation coffiicient 'r' which was calculated using the equation -

$$r = \frac{\Sigma YX}{(\Sigma X^2 \cdot \Sigma Y^2)^{\frac{1}{2}}}$$

Where,

$x = (x - \overline{x})$, $y = (y - \overline{y})$

$x = \Sigma X/n$, $y = \Sigma y/n$

n = total number of observations.

To carry out the extensive numerical calculations in a systematic manner, a LOTOUS programme ( by using a package ) was used to calculate the parameters A and B of linear regression line, y = A + Bx. For fourteen parameters determined in the present investigation, the total numbers of correlation possible were ninety one. All numerical values of correlation coefficient 'r' for 91 pairs are presented in Table 4.12. It was observed

Table 4.12 Correlation coefficient values observed among various physico-chemical and biological parameters

| | Total solids | pH | Total hardness | Chloride | $CO_2$ | DO | BOD | COD | MPN | SPC | Algae | Diatoms | Protozoans |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Turbidity | 0.89 | 0.29 | 0.51 | 0.55 | 0.34 | 0.82 | 0.82 | 0.66 | 0.58 | 0.84 | 0.76 | 0.76 | 0.76 |
| Total solids | | 0.29 | 0.49 | 0.49 | 0.30 | 0.69 | 0.77 | 0.73 | 0.52 | 0.79 | 0.70 | 0.60 | 0.58 |
| pH | | | 0.22 | 0.14 | 0.09 | 0.29 | 0.28 | 0.31 | 0.15 | 0.24 | 0.25 | 0.33 | 0.31 |
| Total hardness | | | | 0.33 | 0.22 | 0.64 | 0.64 | 0.63 | 0.41 | 0.63 | 0.60 | 0.45 | 0.42 |
| Chloride | | | | | 0.55 | 0.67 | 0.66 | 0.71 | 0.36 | 0.65 | 0.72 | 0.62 | 0.70 |
| $CO_2$ | | | | | | 0.50 | 0.46 | 0.50 | 0.14 | 0.37 | 0.51 | 0.51 | 0.54 |
| DO | | | | | | | 0.93 | 0.96 | 0.46 | 0.83 | 0.94 | 0.81 | 0.80 |
| BOD | | | | | | | | 0.97 | 0.55 | 0.93 | 0.95 | 0.85 | 0.81 |
| COD | | | | | | | | | 0.49 | 0.89 | 0.98 | 0.87 | 0.85 |
| MPN | | | | | | | | | | 0.63 | 0.47 | 0.39 | 0.40 |
| SPC | | | | | | | | | | | 0.86 | 0.73 | 0.70 |
| Algae | | | | | | | | | | | | 0.87 | 0.86 |
| Diatoms | | | | | | | | | | | | | 0.95 |

Table 4.13 Least square fitting of the relation $y = A+Bx$ among various parameters

| x | y | r* | A | B |
|---|---|---|---|---|
| Turbidity | Total solids | 0.89 | 383.48 | 1.28 |
| DO | BOD | 0.93 | 180.75 | -21.30 |
| DO | COD | 0.96 | 531.32 | -62.47 |
| DO | Algae | 0.94 | -1778.48 | 394.85 |
| BOD | COD | 0.97 | 6.40 | 2.84 |
| BOD | SPC | 0.93 | -112640.04 | 8816.85 |
| BOD | Algae | 0.95 | 1538.52 | -17.89 |
| COD | SPC | 0.89 | 114560.72 | 2994.52 |
| COD | Algae | 0.98 | 86.16 | -6.32 |
| Diatoms | Protozoans | 0.94 | 57.4 | 1.07 |

*r- Correlation coefficient between x and y that the value of r was significant, i.e. equal or larger than 0.89 for only ten pairs of parameters. The values of A and B for these ten significant pairs were calculated and are presented in Table 4.13. A detailed description of the ten significant correlations is presented below:

The correlation between turbidity and total solids of the collected water samples for river Dhamola is found to be statistically significant. The values of r, A and B calculated by the linear regression output were found as 0.89, 383.48 and 1.28, respectively. Thus, both the parameters are dependent on each other, i.e., if amount of total solids is increased, turbidity also increased and hence a straight line is obtained between two parameters (Fig. 4.9a). It can be concluded on the basis of the observed behaviour that the turbidity in the water of Dhamola river was mainly due to the presence of total solids present in the river water.

A graphical relationship between dissolved oxygen and biochemical oxygen demand is presented in Figure - 4.9b . It can be clearly seen that an inverse relation, i.e. increase in BOD caused decrease in DO. The value of r determined for the linear relation was found to be 0.93. The observed relationship further confirmed our earlier observation that the value of DO decreased due to the mixing of organic matter which increased the value of BOD and therefore indicated pollution in the river water [174].

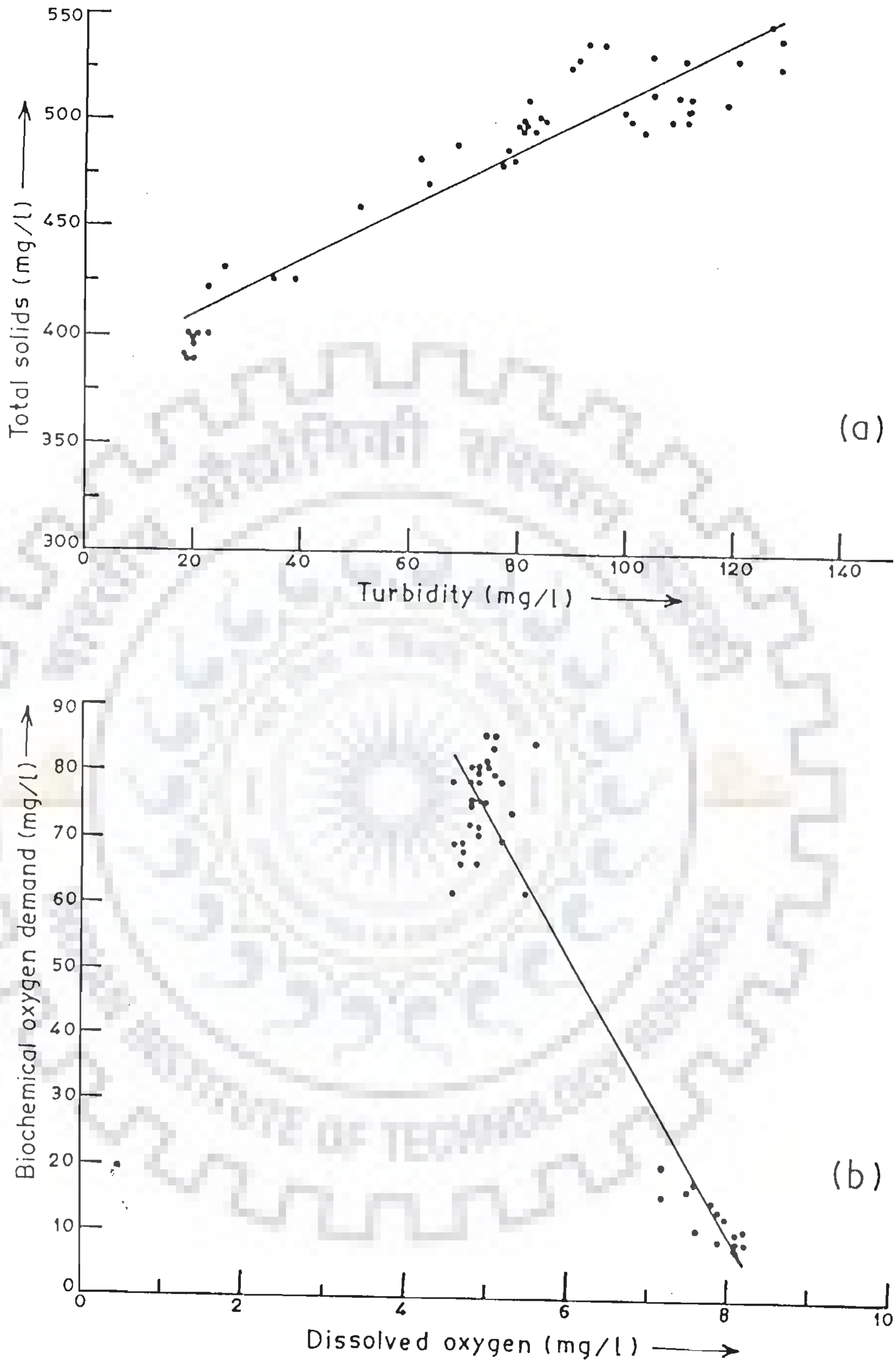


Fig. 4.9 Linear relations observed between turbidity and total solids (a) and DO and BOD (b)

The correlation between DO and COD is also found statistically significant and value of 'r' was found as 0.96. The dependence of DO on COD for various samples obtained during a period of two years is presented in Fig.4.10a and indicates an inverse relationship, which indicates that the decrease in DO will cause an increase in COD value. Such a behaviour is a common phenomenon as mixing of organic/inorganic materials in river Dhamola will require DO for chemical oxidation and hence DO will decrease [174]. Therefore, the value of COD will increase and hence an inverse relation is expected in such cases. In the present investigation similar behaviour is observed and therefore it can be safely concluded that DO is inversely dependent on the COD value obtained for river Dhamola.

The relationship between DO and algae (primary producer) is presented in Fig. 4.10b and has been found significant. The value of r, obtained for a linear regression was 0.94. This relationship indicate that DO value of water samples increased due to the increase of algal population which liberates oxygen (free as well as dissolved) in aquatic system. An increase in DO due to increase of algal population has been well documented in literature [141]. The values of regression output are summarised in Table 4.13.

The correlation obtained between BOD and COD values was found as statistically significant with the

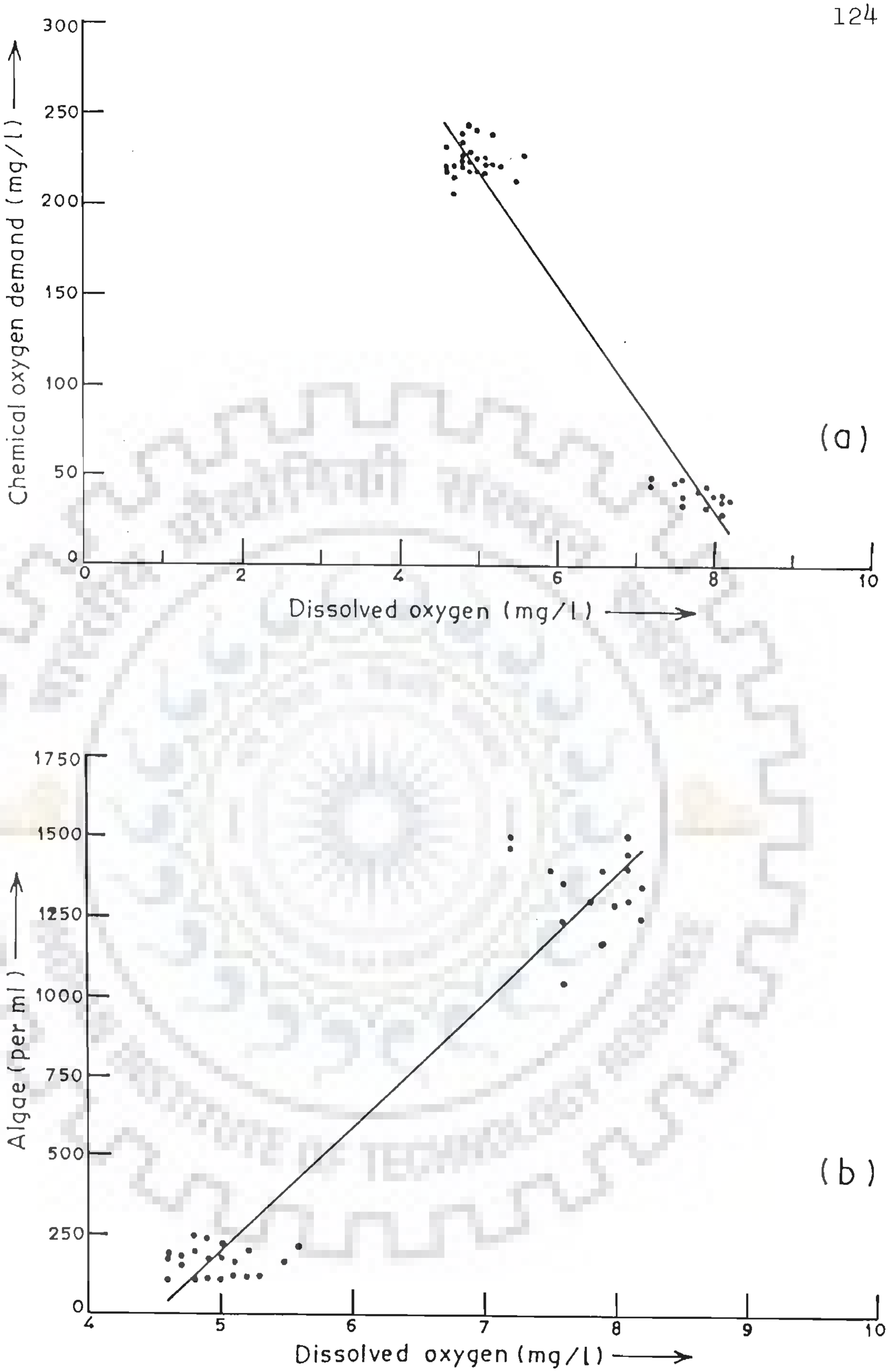


Fig. 4.10 Linear correlations observed between DO and COD (a) and DO versus algae (b)

value of r as 0.97. A direct linear relation between BOD and COD clearly indicates that an increase in BOD caused a simultaneous increase in COD of the water samples. Thus an increase in organic pollution load in river Dhamola will indicate an increase in BOD as well as COD of water samples collected at different points. The details of regression output of BOD and COD are presented in Fig.4.11a. An increase in BOD and COD due to the mixing of organic pollution load in Ganga river has been observed earlier by Tiwari et al.[175].

The relationship between BOD and SPC (micro-organisms, coliform bacteria) is also found statistically significant with r = 0.93. The values of all the regression factors are given in Table 4.13. A direct linear line between BOD and SPC (Fig.4.11b) clearly indicated that increase in BOD caused an increase in SPC. Thus, after mixing of waste water the population of microorganisms (coliform bacteria, SPC) increased tremendously, which caused an increase in BOD of the water samples. A linear relation between microorganisms and BOD has also been observed earlier by Chiu and Frost for Medlock river in England [176].

The correlation between BOD and algae on the other hand was inverse and statistically significant (r = 0.95). The details of regression output are given in Table 4.13 and Fig. 4.12a.

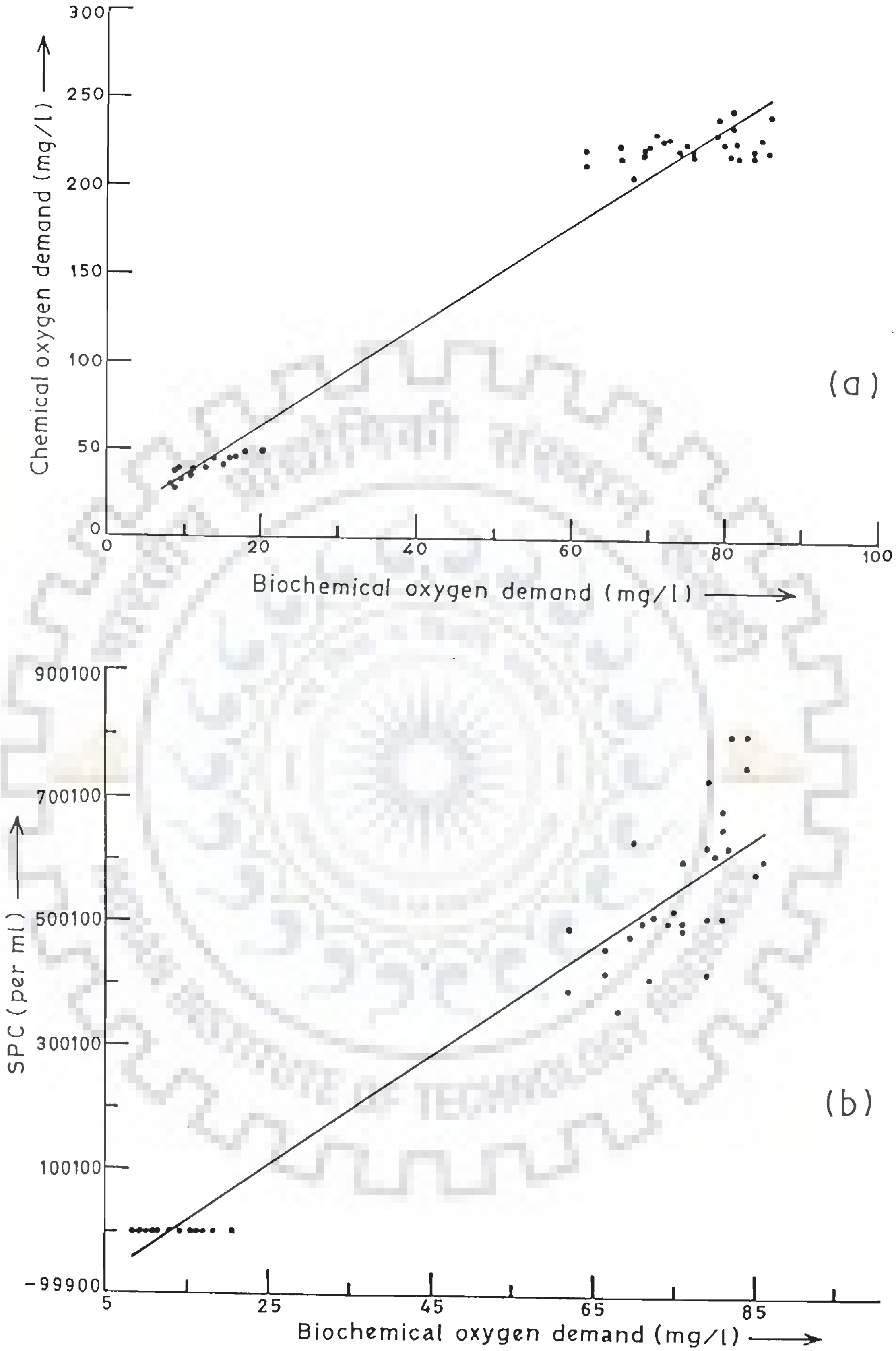


Fig. 4.11 Linear relation obtained between BOD versus COD (a) and BOD versus SPC (b)

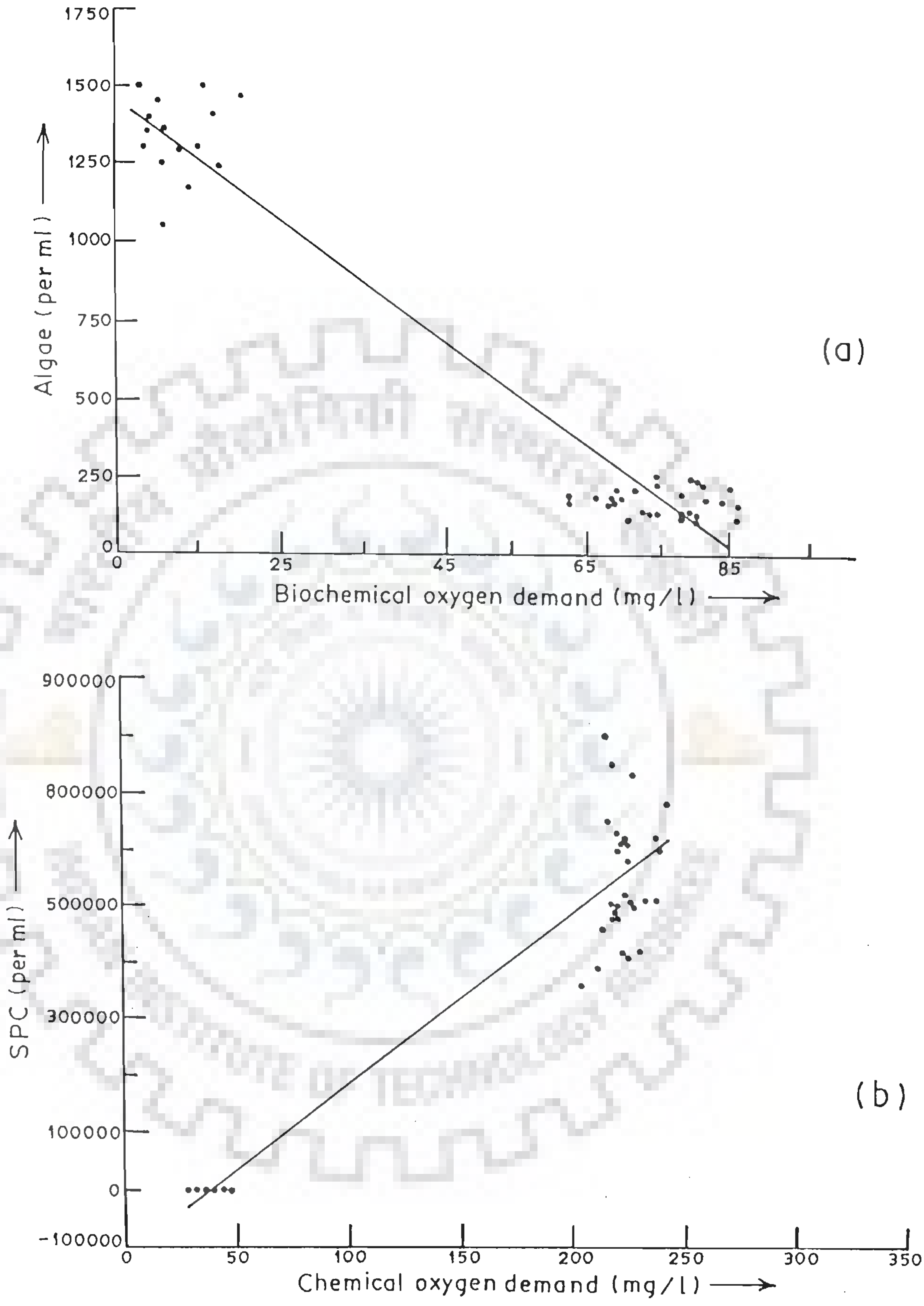


Fig. 4.12 Linear relation observed between BOD versus Algae (a) and COD versus SPC (b)

Fig.4.12 b , represents the statistical correlation between COD and SPC. The regression output between these parameters was a direct linear line. Thus COD of water samples increased due to the microorganisms (coliform bacteria, SPC). The microorganisms decompose the organic matter present in water and consume the oxygen, which causes an increase in COD value. The value of correlation coefficient (r). A and B are presented in Table 4.13.

A relationship between COD and algae is also found statistically significant and confirmed that the pollution load in river water was observed due to the high value of COD. As observed earlier, at high COD values the algal population was low. The value of correlation coefficient was 0.98. The inverse linear regression for COD and algae is presented in Fig. 4.13a

The value of 'r' for diatoms and protozoans number is significant (0.94) and directly correlates with each other. A direct linear line between diatoms and protozoans indicates that increase in diatoms in water samples collected also caused an increase in protozoans. The linear relation between diatoms and protozoans is presented in Fig. 4.13b

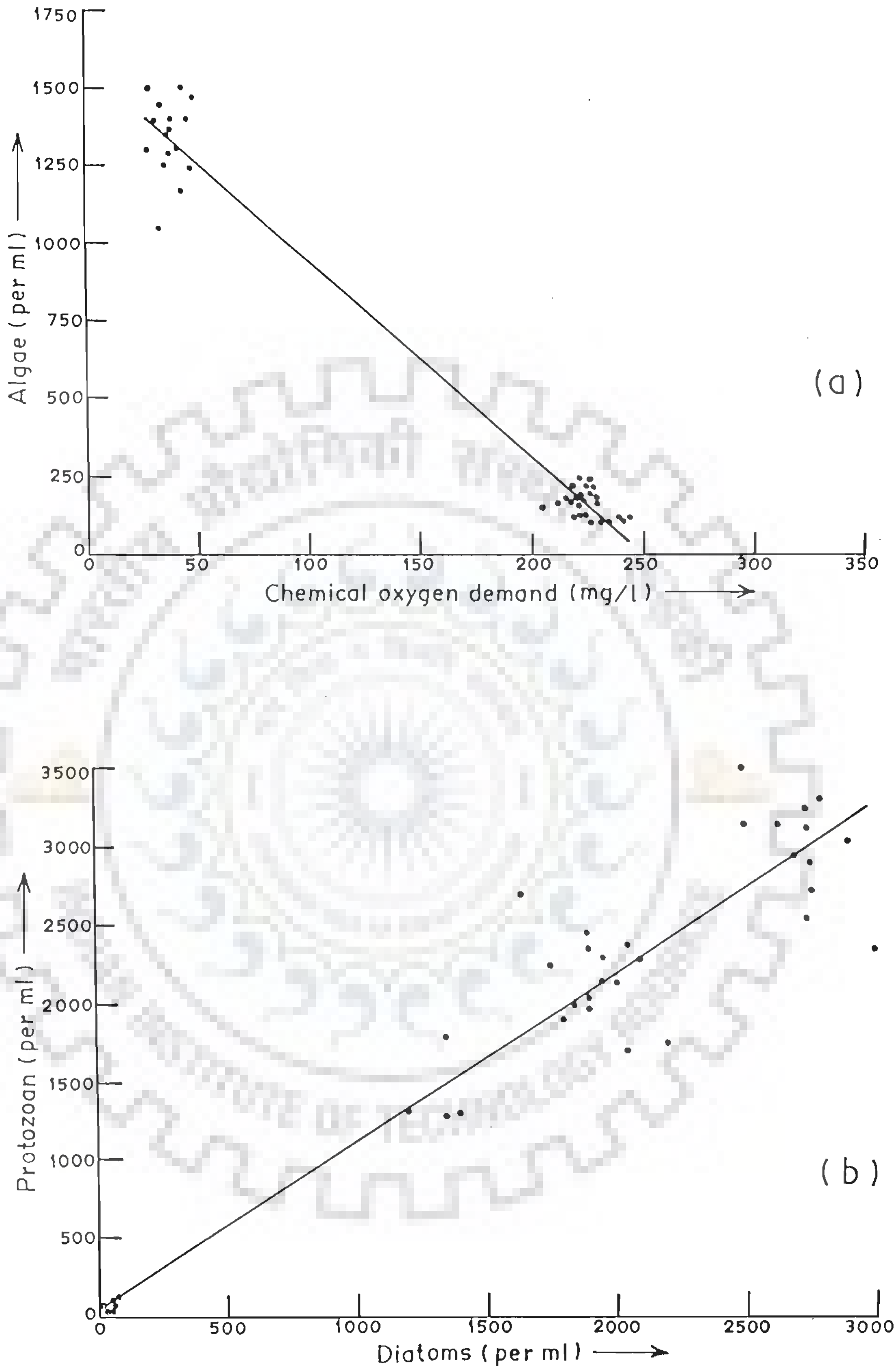


Fig. 4.13 Linear correlation observed between COD versus algae (a) and diatoms versus protozoans (b)

# CHAPTER – V

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