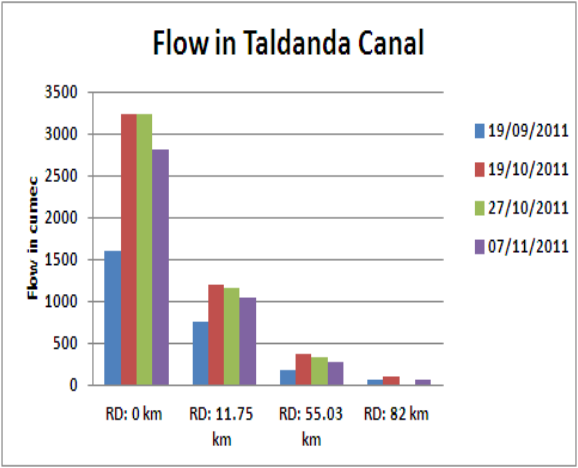
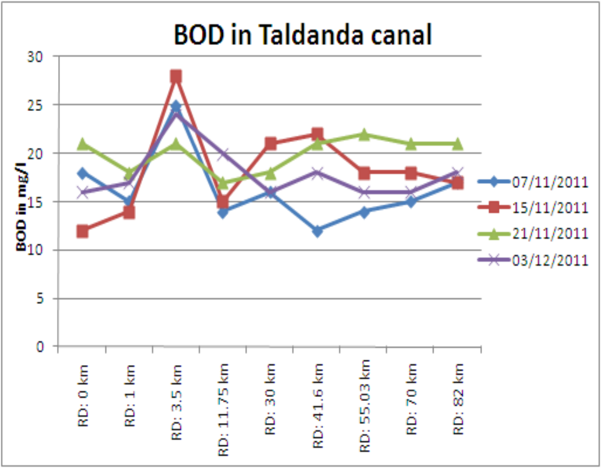
WATER QUALITY MONITORING AND MODELLING OF TALDANDA CANAL

(Year-2012)





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CHAPTER 1

INTRODUCTION

The life and activities of plants and animals, including humans, contribute to the pollution of the earth, assuming that pollution is defined as the deterioration of the existing state. The purpose of this chapter is to review the various sources of water pollution and demonstrate the objectives of the present project work in order to recognize the opportunities for eliminating, minimizing, reusing or treating these sources so that their negative effect on the environment will be minimized. When pollution control is considered, these questions should be asked and answered.

1. Can the pollution source be eliminated?

- Is it absolutely necessary?
- Can it be substituted by another source that accomplishes the same purpose but is less polluting to the environment?

2. Can the pollution source be minimized?

- Can the source be operated more efficiently to lower pollution?
- Can the pollutants be converted to another state (gaseous, liquid or solid) which is less polluting to the environment

3. Can the pollutants be reused?

- Can the pollutants be purified and reused as raw materials?

- Can relatively pure water be separated from the pollutants and reused?
- Can the pollutant be recycled to a different source?

4. Can the pollutant be treated?

- Is the effect on the environment minimized by altering, destroying or concentrating the pollutant?
- Can the treated pollutant be reused or recycled?

5. Can the physical processes involved be studied?

- Is it possible to develop water quality models?
- Is it possible to study the advection, dispersion, diffusion, dilution and reaction phenomena?
- Is it possible to establish water quality parameters?

The following are common sources of pollution.

1.1 Industrial Sources of Water Pollution

Any industry, in which water obtained from a water treatment system or a well comes in contact with a process or product can add pollutants to the water. The resulting water is then classified as a wastewater.

Non-Contact Water are; Boiler feed water, Cooling water, Heating water, Cooling condensate

Contact Water are; Water used to transport products, materials or chemicals; Washing and rinsing water (product, equipment, floors), Solubilizing water, Diluting water, Direct contact cooling or heating water, Sewage, Shower and sink water

The wastewater can contain physical, chemical and/or biological pollutants in any form or quantity and cannot adequately be quantified without actual measuring and testing. The wastewater will typically either be discharged directly into a receiving body of water or into the sewerage system of a municipality, or it will be reused or recycled.

1.2 Municipal Sources of Water Pollution

The non-industrial municipal sources of water are typically as follows; Dwellings, Commercial establishments, Institutions (schools, hospitals, prisons, etc), Governmental operations. It is assumed that a non-industrial municipal wastewater source will contain no pollutants except for the following: Feces, Urine, Paper, Food waste, Laundry wastewater, Sink, shower, and bath water.

These pollutants are all biological and as such can be readily biodegraded. Any extraneous nonindustrial pollutants other than those listed above can be physical or chemical in nature, and ideally should be prevented from entering a municipal system with a Pre-treatment Ordinance, or removed from the municipal wastewater using some method of pre-treatment.

1.3 Agricultural Sources of Water Pollution

Normally, agricultural water pollutants are transported to an aboveground or underground receiving stream by periodic storm water. Agricultural wastewater can be of animal or vegetable origin or be from a nutrient, fertilizer, pesticide or herbicide source. Animal or vegetable sources will be limited to biodegradable feces, urine or vegetable constituents. Nutrients or fertilizers will be typically some formulation of carbon, phosphorous, nitrogen and/or trace metals. Pesticides and herbicides will consist of formulated organic chemicals, many with complex molecular structures, designed to be very persistent in the environment. Pesticides such as Chlorodane and Heptachlor, which consist of a multitude of different organic chemicals, can still exist in the soil. Agricultural activities can also allow the runoff of soil into receiving streams. In such cases, pollutants can be any organic or inorganic constituent of the soil.

1.4 Natural Sources of Water Pollution

Areas unaffected by human activity can still pollute receiving steams due to storm water runoff, which can be classified into animal, vegetable and soil sources. Again, animal and vegetable water pollution sources should be readily biodegradable. Soil sources will consist of any organic and inorganic material in the soil.

1.5 Storm water Sources of Water Pollution

Storm water has been mentioned above under agricultural and natural sources of water pollution, but will also transport industrial and municipal water pollutants to a receiving stream or underground water supply.

1.6 Landfill Water Pollution Sources

Public, private, and industrial landfills can be a source of stormwater pollution because of runoff from the surface and underground leachate. Landfill regulations require daily cover, but during the day, rainfall can cause pollution from surface runoff. When stormwater leaches through the surface cap and downward through the landfill, the horizontally or vertically migrating discharge from below the landfill is known as leachate and can pollute surface or underground water. Because of the bacteria present in the dirt and in landfill material, there will always be aerobic and anaerobic biological activity occurring in a landfill. Aerobic and anaerobic biological activity will emit carbon dioxide. Carbon dioxide in the presence of water form the weak acid, carbonic acid will lower the pH in a landfill to around 4.8. This low pH tends to dissolve certain organics and inorganics, which can leach out of the landfill as pollution. Landfills are normally required to provide leachate, and in some cases, runoff collection and treatment or disposal to prevent contamination of the environment.

The following section talks on physical processes involved in water quality modeling.

1.7 Physical Processes of Pollution

It is essential for water resources planners and managers to understand various physical processes involved in a stream/river prior to the implementation of any water resources projects. When a pollutant is discharged in a stream/river, it is subjected to initial dilution immediately due to density difference between the receiving water and the pollutant (Figure 1). As can be seen from the figure, the longitudinal, vertical and two-dimensional profiles of pollutant concentration indicate the density gradient between pollutant and receiving water. After the initial dilution, the processes are governed by advection, reaction and dispersion phenomena that tend to modify the initial pollutant concentrations as shown in Figure 2 (Pawlow et al., 1983). In the figure, advection phenomena represent the downstream transport of a discrete element of the waste load by the stream flow. The reaction phenomena represent the decay of biodegradable materials in the waste under the action of naturally occurring bacteria in the stream. The dispersion phenomena represents that under the influence of turbulence, eddy currents, and similar mixing forces, a discrete element of the waste load tends not to remain intact, but to mix with adjacent upstream and downstream elements. In rivers and streams the influence of dispersion phenomena is usually relatively small compared with advection and reaction phenomena; however, it can be important in some circumstances. For example, when a slug load results from a spill or accidental dump, dispersion effects can have an important influence on resulting peak concentrations, particularly at longer distances from the point of discharge. Intermittent discharges, such as storm runoff, are also influenced by dispersion. However, for continuous discharges (e.g. from wastewater treatment plants) and steady-state flow conditions, dispersion effects are usually insignificant.

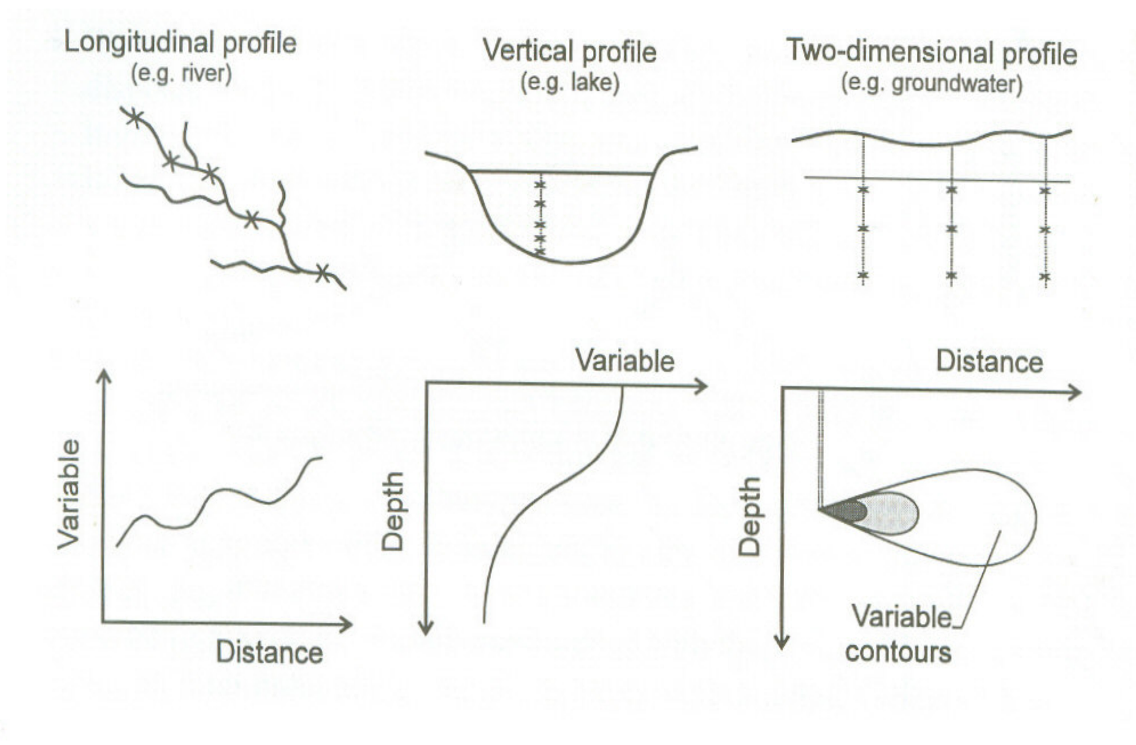


Figure 1: Spatial movement of water quality variable

As a result of these processes, the pollution level at the downstream of wastewater disposal site varies with time and space. In the following section the importance of dilution of pollutants downstream of its discharge based on various physical processes as described above, mixing length of pollutants (mixing zone) and design flows have been described.

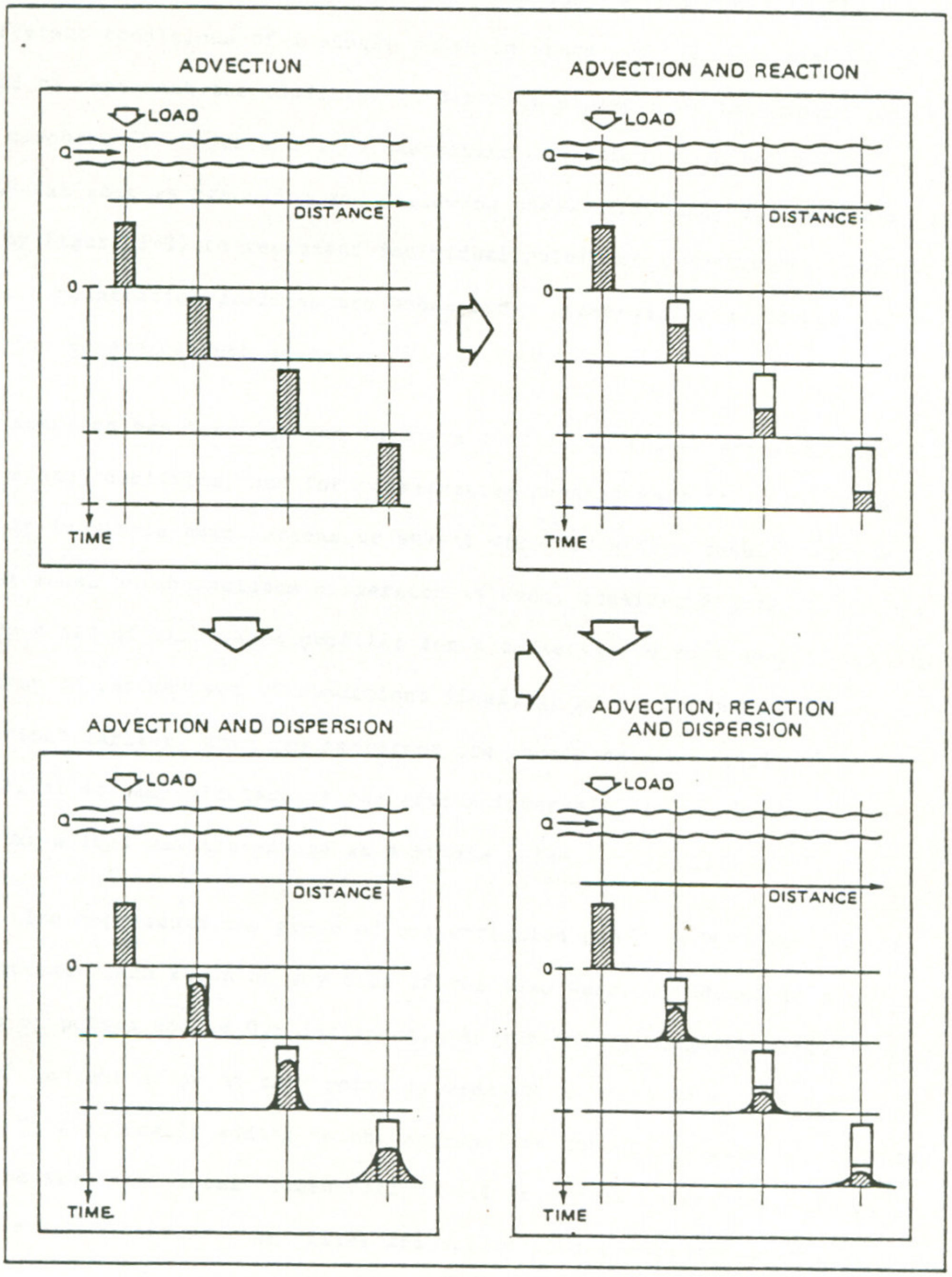


Figure 2: Transport mechanism of waste loads

Wastewater effluents are discharged into streams and rivers so as to minimize any potential adverse effects on river water quality by suitable citing of outfalls. A typical example of meandering given by Boxall et al. (2003) is shown in Figure 3. The cross sectional profile and velocity pattern of flow at different sections of the channel are shown in Figure 4. It can be seen from that figure that the maximum velocity profiles are always on the convex (right) portion of the channel looking at the downstream. When pollutant is discharged at the bottom or on the surface of the different sections, the length of mixing zone varies due to variation in velocity profiles. Also, the location of injection of pollutants (on the surface or at the bottom) changes the mixing phenomena, which can be very well observed in Figure 4.

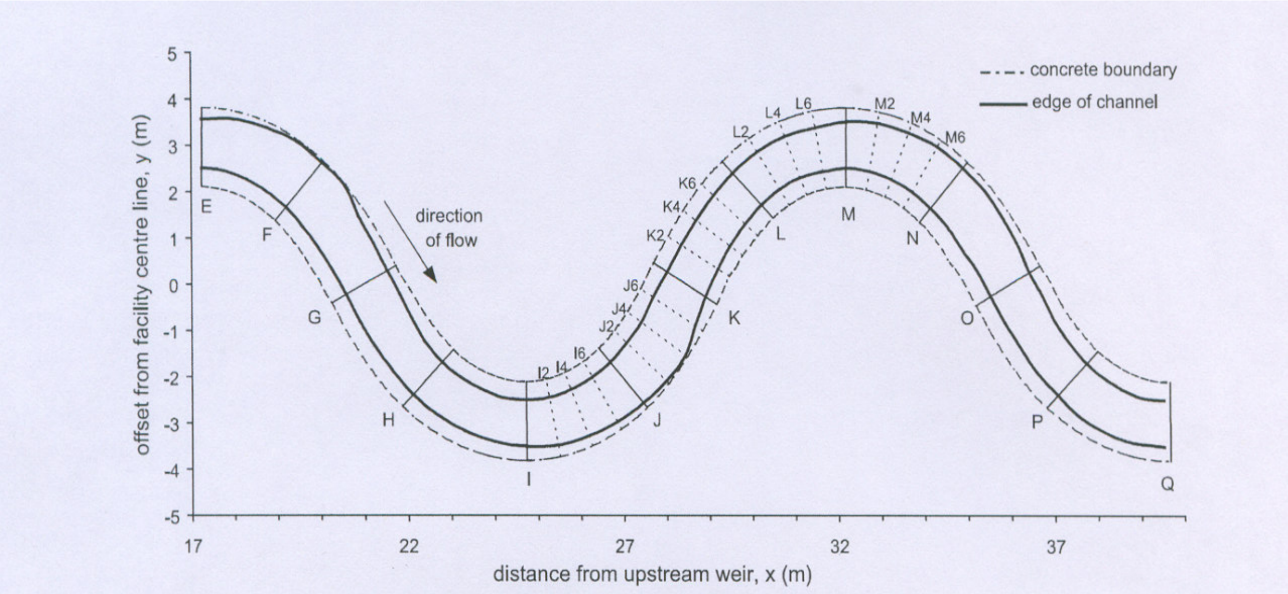


Figure 3: Typical channel geometry and sections numbering

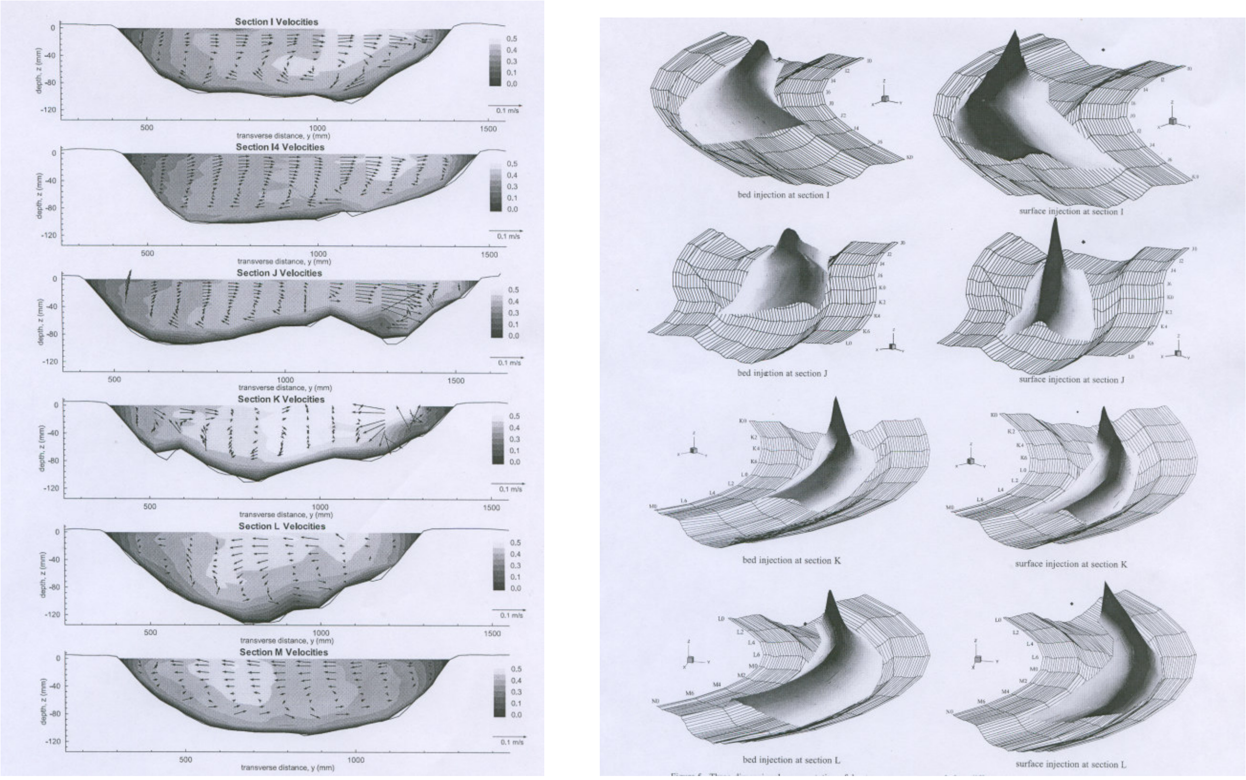


Figure 4: Cross-sectional and velocity profiles

It can be seen from the Figure 4 that the vertical mixing is usually complete in a short distance below the outfall or injection point, whereas lateral spreading is more gradual resulting in lateral concentration gradients. Ultimately, the cross-sectional concentration distribution attains uniformity at some distance below the outfall. Consideration of how to compute the distance from an outfall to compute mixing is a separate more complicated topic. However, the order of magnitude of the distance from a single point source to the zone of complete mixing is obtained from (Yotsukura, 1968):

$$L_m = 2.6U \frac{B^2}{H} \tag{1}$$

for a side bank discharge, and from

$$L_m = 1.3U \frac{B^2}{H} \tag{2}$$

for a midstream discharge. In the above, L_m = distance from the source to the zone where the discharge has been well mixed laterally in ft, U = average stream velocity in fps, B = average stream width in ft, H = average stream depth in ft

1.8 Objectives of the present work

Taladanda Canal in Orissa is off-taking from right side of Mahanadi Barrage. It is used for supply of municipal and industrial water. However, the canal is contaminated by different polluting sources at its off-taking locations. It is important to undertake rigorous approach using a large number of physically based parameters and input data for accurate simulation of water quality variables in the Taladanda canal system with the following objectives:

1. Identification of water quality problems in Taladanda Canal (existing and emerging).
2. Rational planning of pollution control with primary focus on the impact caused by municipal drains (human sewage).
3. Assessment of suitability of water for different purposes and uses.

4. Evaluation of water quality trend under different conditions of canal discharge.
5. Assessment of assimilative capacity of water at different stages and different reaches.
6. Study of ecology and aquatic environment in the canal system.
7. Simulation of water quality variables and water quality management.
8. Generation of scenarios for best water quality management for different purposes.
9. Recommendation of policy action for preventing release of pollutants into the canal.

It is intended that the consultant will assist the surface water wing of Hydrology Project, Orissa to develop mathematical models related to water quality in Taladanda Canal basin on the data available and to be acquired during the process of implementation. Such models must be developed in a manner so as to arrive at standardized methodologies. The type and range of model to be addressed under the study would be proposed in detail by the Consultant as part of his proposed methodology, based on his understanding of the requirements of the assignment. The range would include internationally acceptable guidelines to determine the quality of water in the canal for different uses including determination of uniform procedure to estimate standard water quality parameters and monitoring procedure.

CHAPTER 2

THE STUDY AREA-TALDANDA CANAL

Taladanda Canal in Orissa is off-taking from right side of Mahanadi Barrage (Figure 5). The Taladanda canal system has become more than 140 years old and once it was the life line of people of erstwhile undivided Cuttack district. Parts of the canal were dug up in 1862 by the East India Company for irrigation purposes as well as for using as a waterway. It was later taken over by the British government, which completed it in 1869. It was the longest canal of Orissa. The canal was originally designed to provide irrigation and navigation from Bay of Bengal at Paradeep to Cuttack. Subsequently, there was a need to extend the canal to meet the industrial water requirement of number of large industrial units in Paradeep as well as to meet the municipal requirement of the area.

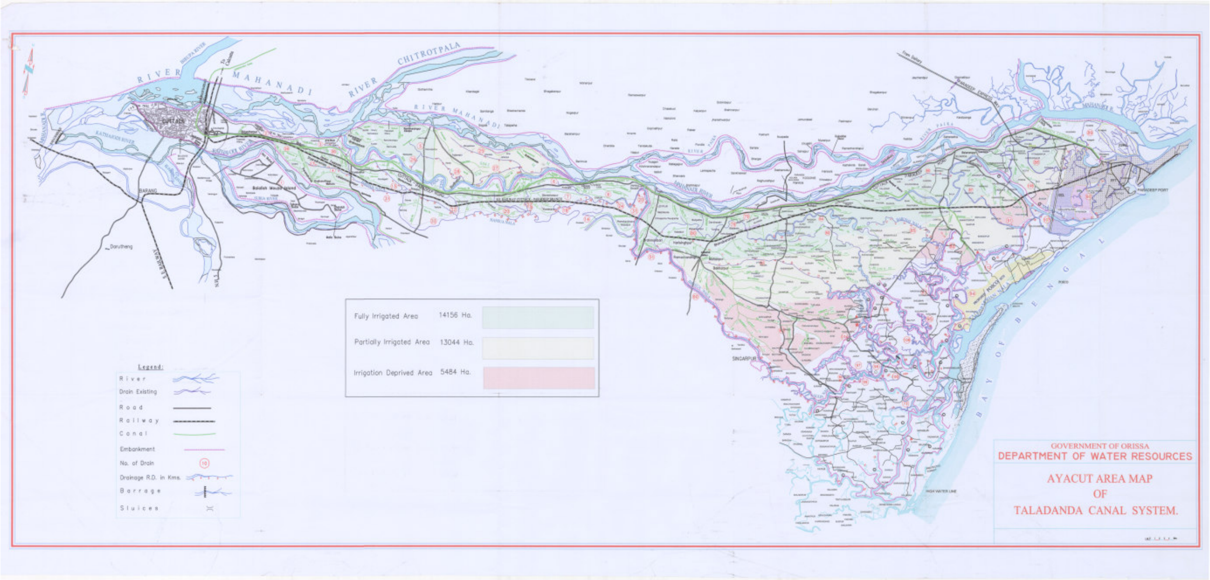


Figure 5: Location map of Taldanda canal

The Taladanda canal was designed to be a source of water for irrigation to six blocks of Cuttack and Jagatsinghpur districts – Sadar Cuttack, Jagatsinghpur, Raghunathpur, Balikuda, Tirtol and Ersama. The canal is commanding an ayacut of 72611 Ha with design discharge of 88.42 cum. The total length of the canal is 83.2 km. The Taladanda canal meanders through the city of Cuttack, starts at Jobra in Cuttack and it passes through Ranihat, Chhatrabazar, Nuabazar of Cuttack city and then enters to Jagatsinghpur district before finally linking the Mahanadi river with the Bay of Bengal at Paradip 83 km away. A flow chart is shown in Figure 6, indicating various weirs and minors in canal.

The area enjoys a subtropical monsoon climate with an average annual rainfall of 1,370 mm and average annual humidity is 76%. The temperature varies from 11.9°C to 44.4°C. There are two major geological formations covering the study area, i.e., Eastern ghat group of crystalline rocks, and Gondwana group of sedimentary rocks. The trend of bedding and foliation is in EW to NW–SE. The water-bearing characteristics of the area however are influenced by the local topography. The area is endowed with good water resources in terms of both groundwater and surface water. The surface water is used for human consumption and industrial consumption as well as for irrigation in the area.

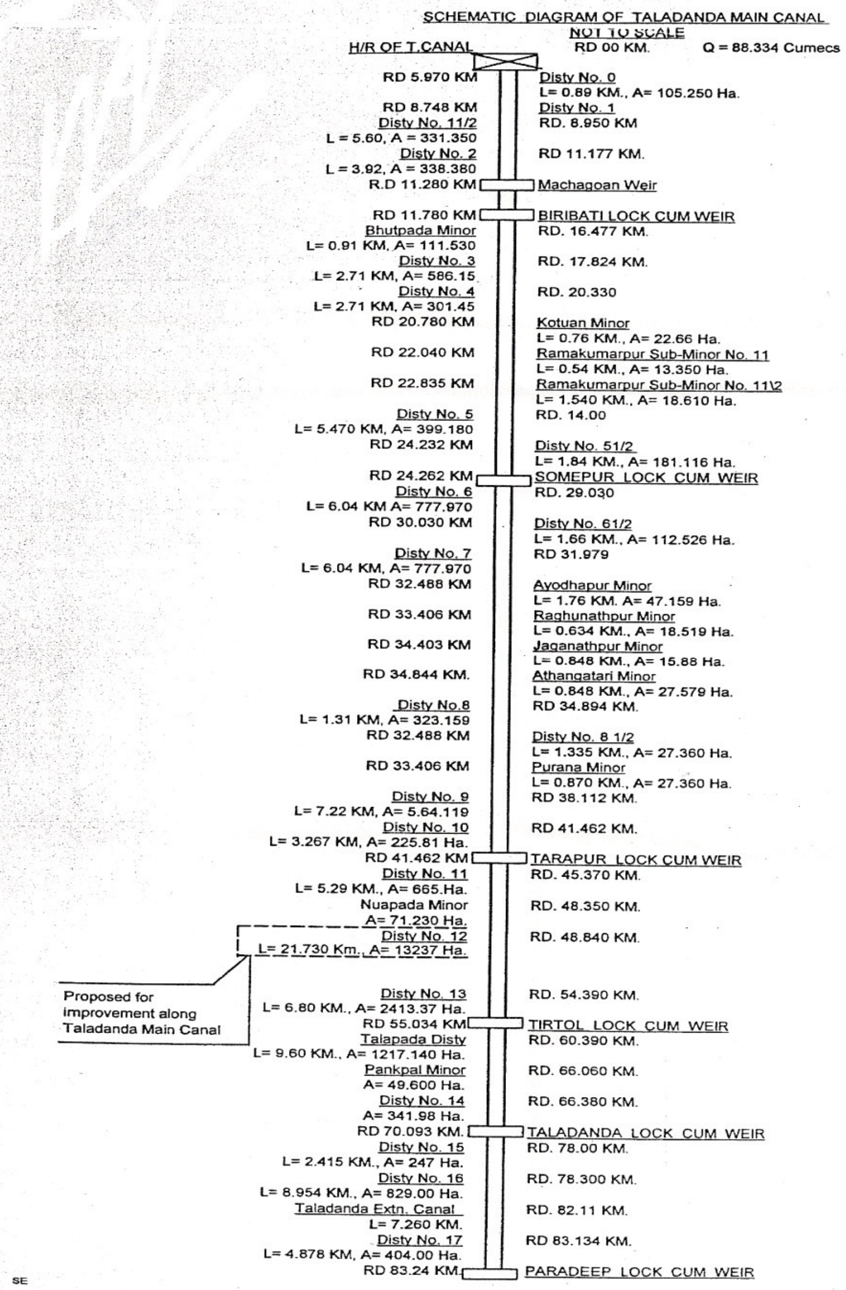


Figure 6: Flow chart of Taldanda Canal

Taldanda canal is used for supply of municipal and industrial water. However, the canal is contaminated by different polluting sources at its off-taking locations. Presently the canal is in a dilapidated condition (Figure 7). The deficiency in carrying capacity in the canal is mainly due to discharge of pollutants from municipal sources, hospitals, industries for which its carrying capacity is not achieved and has become unsuitable for human consumption.

Realising the importance of this problem this study aims to determine the present pollution level of the canal and based on the findings suitable models for prediction of the pollutant behaviour at different locations of Taldanda canal. Figure 7, shows various sites of Taldanda canal having water pollution and algae.

Figure 7: Plates showing water pollution in Taldanda canal

CHAPTER 3

IDENTIFICATION OF WATER QUALITY PROBLEMS AND PLANNING FOR ITS IMPROVEMENT

This section deals with the following objectives:

1. Identification of water quality problems in Taladanda Canal (existing and emerging).
2. Rational planning of pollution control with primary focus on the impact caused by municipal drains (human sewage).
3. Assessment of suitability of water for different purposes and uses.
4. Evaluation of water quality trend under different conditions of canal discharge.
5. Assessment of assimilative capacity of water at different stages and different reaches.
6. Study of ecology and aquatic environment in the canal system.

In Taldanda canal water quality survey was carried out at different sampling locations during the year 2011-2012 by the water resources department and provided to NIT Rourkela for its analysis. In addition, water quality data collected earlier by different research in Taldanada canal has also been studied in the present work. The details are discussed below.

3.1 Water quality data for the year 1996-1997 (Das and Acharya, 2003)

Das and Acharya,(2003) collected a total of 120 water and sewage samples from 20 stations over six consecutive seasons in two years in order to study the possible impact of domestic sewage on the lotic water in and around Cuttack, India. A majority of samples exceeded the maximum permissible limit set by WHO for NH+4 and NO−3 contents. Total viable count (TVC) and *Escherichia coli* (*E. coli*) counts in all the samples were high and the waters were not potable. The nutrient characteristics of the study area exhibited drastic temporal variation indicating highest concentration during the summer season compared to winter and rains. The persistence of dissolved oxygen (DO) deficit and very high biochemical oxygen demands (BOD) all along the water courses suggest that the deoxygenation rate of lotic water was much higher than reoxygenation. Hierarchical cluster analysis of the various physico-chemical and microbial parameters established three different zones and the most contaminated zone was found to be near the domestic sewage mixing points.

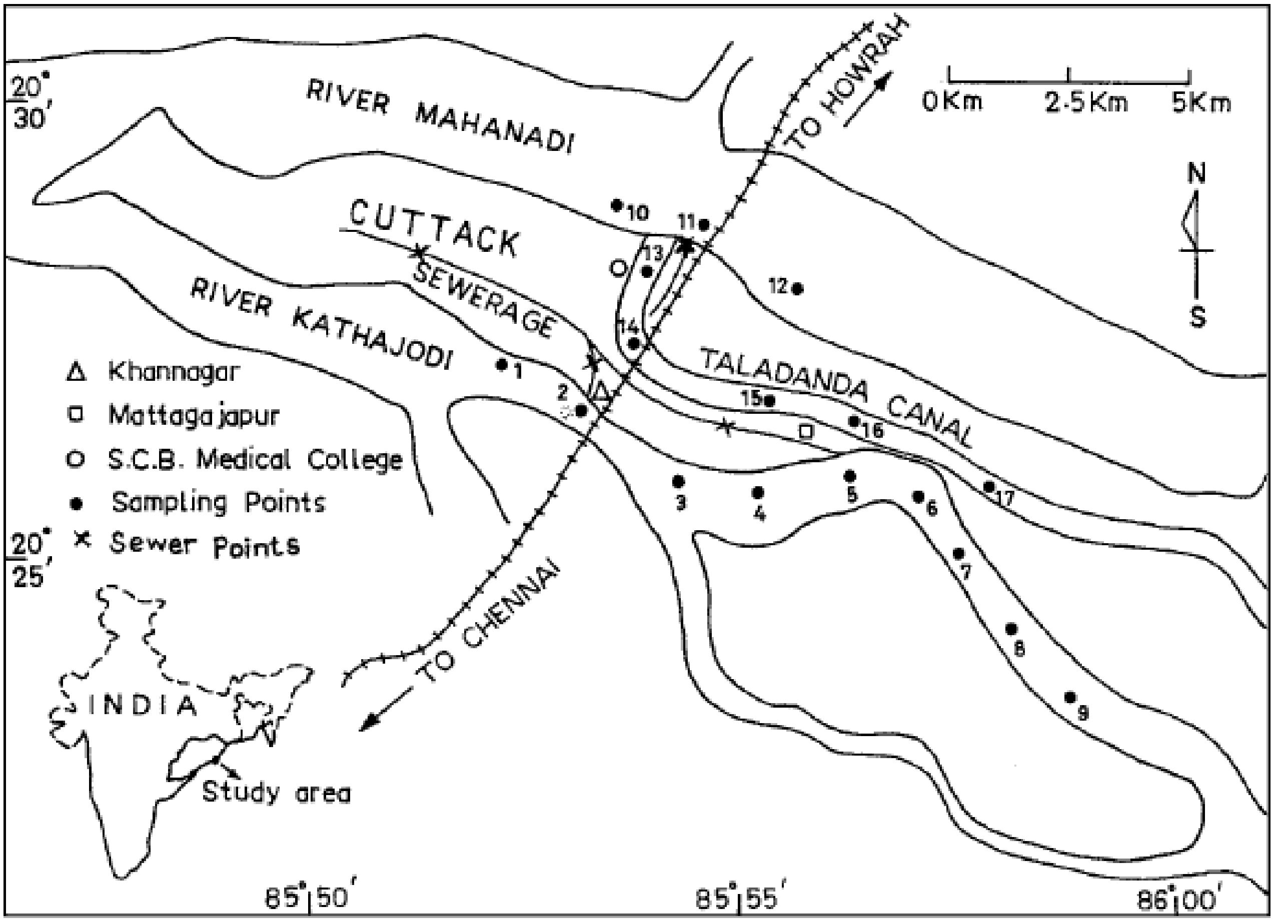


Figure 8: Location of Sampling Sites ((Das and Acharya, 2003)

In Figure 8, the sampling locations 13, 14, 15, 16 and 17 indicates the water quality sampling points of Taldanda canal. The TDS of water samples collected during different seasons varied from 348 to 599 mg L−1, which is well within the permissible limit of WHO. In general, TDS increased from rainy to winter and summer seasons (Figure 9). Station 13 which is apparently free from municipal sewage contamination exhibited lower TDS values compared to stations downstream.

The ammonium concentration ranged from 0.32 to 2.68 mg/l. Higher concentration of the ion was observed in the Taladanda canal at stations 14 to 17 particularly during winter and summer seasons. All the samples collected during rains were well below the maximum permissible limit set by WHO but 59% of samples collected during winter or summer exceeded the WHO limit.

The NO_3 concentration varied from14 to 126 mg/l. Samples collected during rains registered the maximum concentration of the ion. The NO_3 ion is usually derived from anthropogenic sources like agricultural fields, domestic sewage and other waste effluents containing nitrogenous compounds. The concentrations at stations upstream of the sewage discharge points could be related to runoff of large catchment area.

The sulphate content ranged from 21 to 105 mg/l. It increased in water at sewage discharge points and gradually decreased in the downstream stations. The sulphate content also increased at station 14, where hospital wastes are discharged.

Concentration of Cl varied from 22 to 145 mg/l and none of the samples exceeded the WHO permissible limit. Chloride is widely distributed in nature as salts of Na, K, and Ca and enters into the natural water through dissolution of salt deposits. However, concentration of chloride at sewage mixing stations was much higher than the upstream stations which may be due to the influence of domestic sewage and this gradually decreased in the downstream of both rivers and canal.

The DO concentration ranged from 1.35 to 7.60 mg/l. The DO deficit persists all along the water courses of Taladanda canal indicating that the deoxygenation rate due to biological decomposition of organic matter is higher than the reoxygenation from the atmosphere.

A minimum of 12 to a maximum of 242 mg/l of BOD values were observed in the investigated samples. Stations located along the Taladanda canal were also not free from organic load. The problem is acute during summer season as the metabolic activities of various aerobic and anaerobic micro-organisms accelerated with increase in water temperature and there was considerable decrease in the flow of water. But during rains a huge volume of fresh water diluted the organic matter resulting in the decrease in the BOD values (Bagde and Verma, 1985; Palharya and Malvia, 1988). It has been reported that in case of high load of organic matter discharged into lotic water, the oxidation of the same occurs in the downstream.

The total viable count varied from 1 to 8.7 million/100 mL. The TVC were highest in summer followed by rains and winter. The count increased from stations 13 to 17 in the Taladanda canal. These were possibly due to the discharge of untreated domestic sewage. During rains contamination from overflowing sewerage and organic wastes are responsible for the existence of TVC at all the stations.

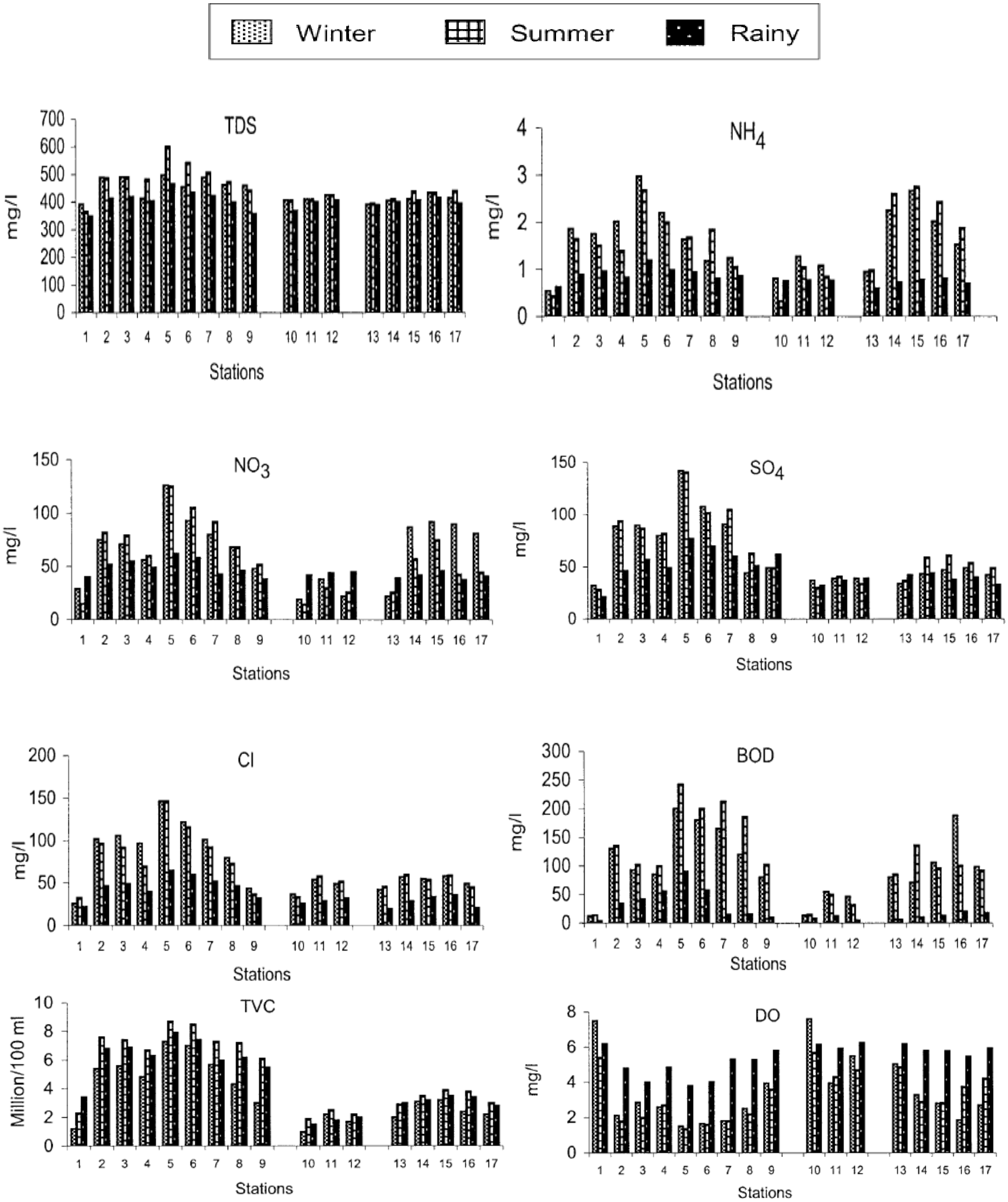


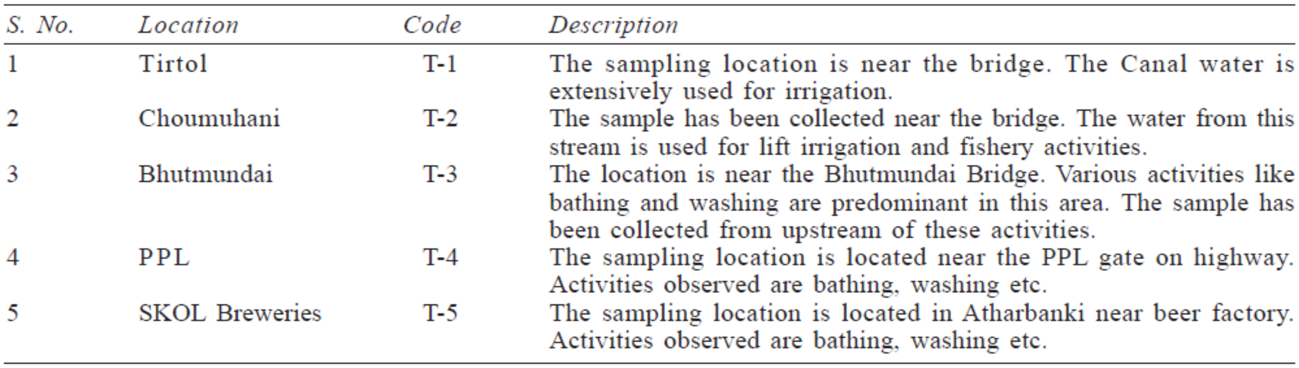
Figure 9: Water quality variables (Das and Acharya, 2003)

The *E. coli* count varied from 350 to 6750/100 mL in the lotic waters. The count was maximal during summer and the minimum coincided with winter season. Like TVC, the *E. coli* count also increased during summer seasons could be related to much decreased water volume and higher temperature.

3.2 Water quality data for the year 2006 (Samantray et al.2009)

Water samples from Taldanda canal were collected from various locations namely Tirtol, Choumuhani, Bhutmundai, PPL, Atharabanki etc. Activities like fishing, bathing, washing and cleaning by inhabitants are observed in this canal. The sampling locations of Taldanda canal are given in Table 1.

Table 1: Sampling locations of Taldanda Canal (Samantray et al.2009)



S. No.	*Location*	*Code*	*Description*
1	Tirtol	T-1	The sampling location is near the bridge. The Canal water is extensively used for irrigation.
2	Choumuhani	T-2	The sample has been collected near the bridge. The water from this stream is used for lift irrigation and fishery activities.
3	Bhutmundai	T-3	The location is near the Bhutmundai Bridge. Various activities like bathing and washing are predominant in this area. The sample has been collected from upstream of these activities.
4	PPL	T-4	The sampling location is located near the PPL gate on highway. Activities observed are bathing, washing etc.
5	SKOL Breweries	T-5	The sampling location is located in Atharbanki near beer factory. Activities observed are bathing, washing etc.

Taldanda canal originates from Mahanadi river at Jobra, Cuttack which is extensively used mainly for irrigation and joins Atharabanki creek at Paradip. The water quality of Taldanda canal during different seasons are presented in Table 2 and highlighted below.

Postmoonson Season: pH varied between 7.18 at Bhutmundai to 7.53 at PPL. BOD of water samples varied between 2.7 mg/l at Tirtol to 4.8 mg/l at Bhutmundai. TDS at Choumuhani varied between 66 mg/l to 184 mg/l at PPL. Fluoride values varied between 0.22 mg/l to 0.33 mg/l. Dissolved Oxygen values varied between 5.8 mg/l to 6.4 mg/l.

Winter Season: pH of water samples varied between 7.0 mg/l at Choumuhani to 7.46 mg/l near PPL. BOD of water samples varied between 2.8 mg/l at Tirtol to 4.9 mg/l at Bhutmundai.

Summer Season*:* pH of water samples varied between 6.85 at Choumuhani to 7.34 near PPL. The water quality of Taldanda canal near Tirtol is fresh water and the physico-chemical parameters are within permissible limits. TDS is about 100 mg/ l and BOD is very less indicating that it is free of contamination. Water samples of Taldanda canal at Choumuhani, Bhutmundai, near PPL and near Atharabanki appear to be fresh water within permissible limits.

Table 2: Water quality during different season in Taldanda Canal

Location	*Season*	*pH*	*Turbidity NTU*	*[TDS] mg/l*	*[TH] mg/l*	*[NO$_3$] mg/l*	*[F] mg/l*	*[BOD] mg/l*	*[DO] mg/l*
T1	Postmonsoon	7.38	5	76	24	8.8	0.32	2.7	6.4
	Winter	7.31	4	81	33	9.9	0.36	2.8	6.2
	Summer	7.16	5	101	48	11.0	0.40	3.0	6.0
T2	Postmonsoon	7.27	3	66	20	4.0	0.22	3.6	6.0
	Winter	7.00	5	85	32	4.5	0.25	3.7	5.8
	Summer	6.85	5	109	46	5.0	0.28	4.0	5.7
T3	Postmonsoon	7.18	4	158	43	3.2	0.32	4.8	5.8
	Winter	7.06	5	167	60	3.6	0.36	4.9	5.6
	Summer	6.92	12	209	87	4.0	0.40	5.0	5.5
T4	Postmonsoon	7.53	4	184	63	5.6	0.24	3.7	6.0
	Winter	7.46	5	194	98	6.3	0.27	3.8	5.8
	Summer	7.31	4	242	140	7.0	0.30	4.0	5.6
T5	Postmonsoon	7.32	4	67	33	12.8	0.33	3.6	5.9
	Winter	7.24	3	88	46	14.4	0.37	3.7	5.7
	Summer	7.09	6	113	67	16.0	0.42	4.0	5.6

3.3 Water quality data for the year 2011 (WRD, Orissa)

In Taldanda canal and Hansua Nala discharge data were monitored along with various water quality variables. Figure 10 (b) illustrates the flow pattern. It is interesting to note that Hansua nala is receiving irrigation return flow from the command area and the discharge at RD 70 km is higher than the discharge at RD 42 km in all the cases. It can be seen from Figure 10 (a) that the discharge is decreasing as we proceed towards Paradeep from Cuttack. The flow is reducing exponentially and upto RD 11.75 km, half of the water is distributed to command areas through canal.

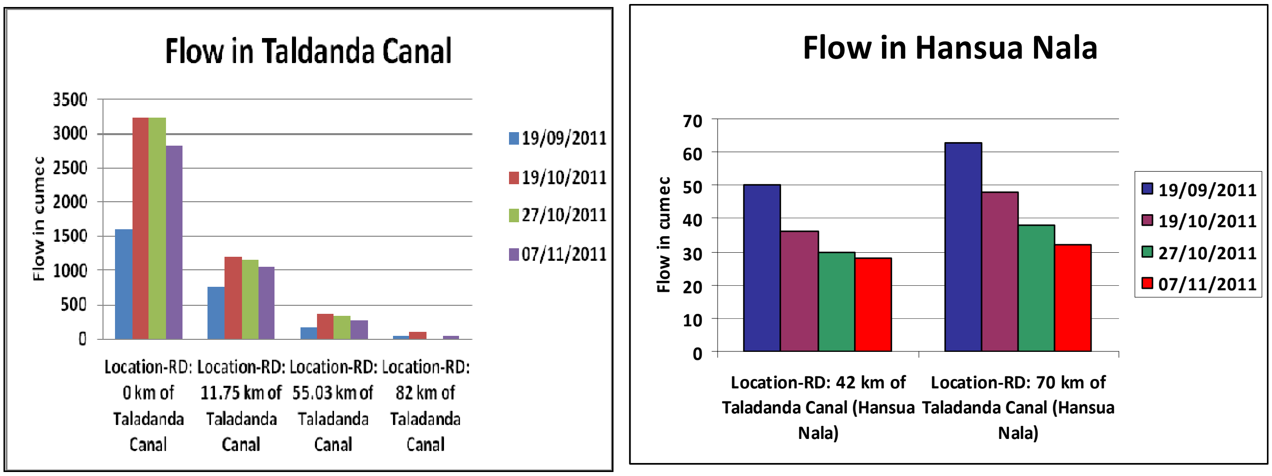


Figure 10: (a) Flow in Taldanda canal, (b) Flow in Hansua nala

Following water quality data were collected during the year 2011 from nine locations of Taldanda canal (RD: 0 km, RD: 1 km, RD: 3.5 km, RD: 1.75 km, RD: 30 km, RD: 41.6 km, RD: 55.03 km, RD: 70 km, RD: 82 km) four drains (RD: Drain at Malgodam; RD: Drain at SCB College; RD: Drain at Naya Bazar ; RD: Drain at Matru Bhawan) and one location of Hansua Nala (RD: 70 km).

Category 1: pH, Temperature, DO, BOD, COD, turbidity, Conductivity, TDS, TSS, Boron, Hardness

Category 2: Total Coliform, Fecal Coliform, E.Coli(MPN), Plankton (phytoplankton and zooplankton), Chlorophyll estimation

Category 3: Sodium, Potassium, Calcium, Magnesium, Nitrate, Phosphates, Sulphate, Chlorides, Total Alkalinity

Category 4: Iron, Fluoride, Zinc, Copper, Cadmium, Cynide, lead, nickel, Chromium, Mercury, Silica, Pesticides

Out of these variable, some water quality variable are not detected and some are found in negligible amount. However, couple of toxic chemicals, metals and bacteriological indicators are found in Taldanda canal. They are discussed in the following section:

It has been found that the Total Dissolved solids (TDS) are less than 150 mg/l in Taldanda canal and Hansua nala, which is showing reduced values in comparison to TDS values observed during the year 1996-97 (das and Acharya, 2003) and 2006 (Samantray et al, 2009) (Figure 11). Total suspended solids (TSS) are found very high during July and then the values were observed less than 200 mg/l. Turbidity values are found to be on higher side with a maximum of 106 mg/l during July 2011. The values obtained are much higher than the values obtained by Samantray et al (2009). Conductivity is found to be more than 100 (µs/cm) all time, which indicates the presence of ionized substances.

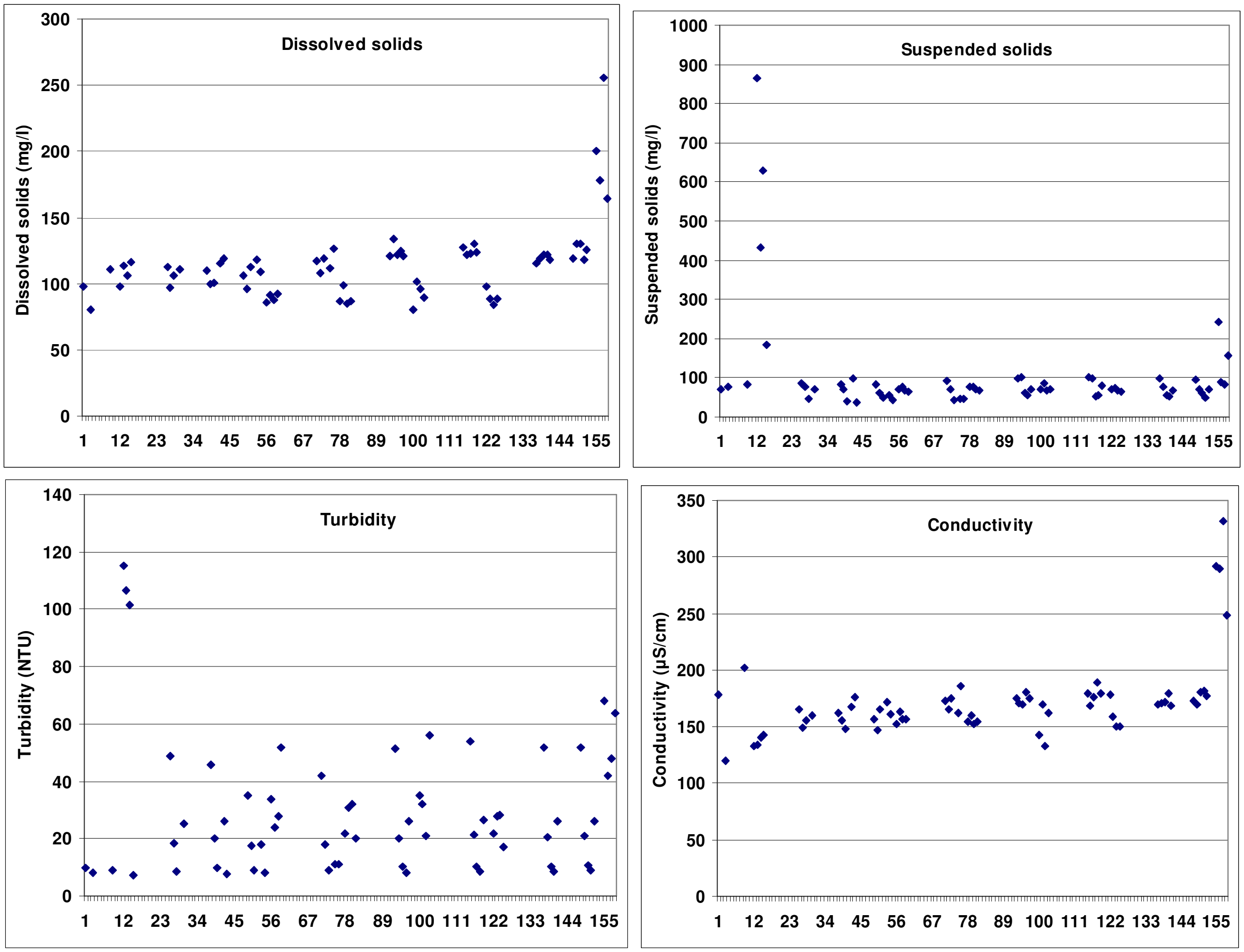


Figure 11: Physical parameters available in Taldanda canal

Biochemical oxygen demand (BOD) values are found to be highest 25 mg/l at RD during November 2011 (Figure 12). However, all the drains discharge very high BOD in Taldanda canal with highest from drain at Malgodam. BOD values obtained by Das and Acharya (2003) are found to be much higher (12-200 mg/l) where as the values obtained by Samantray (2009) are very low (2-7 – 5.0 mg/l). <u>High values of BOD are alarming in Taldanda canal in all the reaches upto Paradeep and also in Hansua nala</u>. Chemical oxygen demand (COD) is found to be in three folds of BOD, indicating presence of chemical in every sampling point in Taldanada canala and Hansua nala. The situation needs to be controlled.

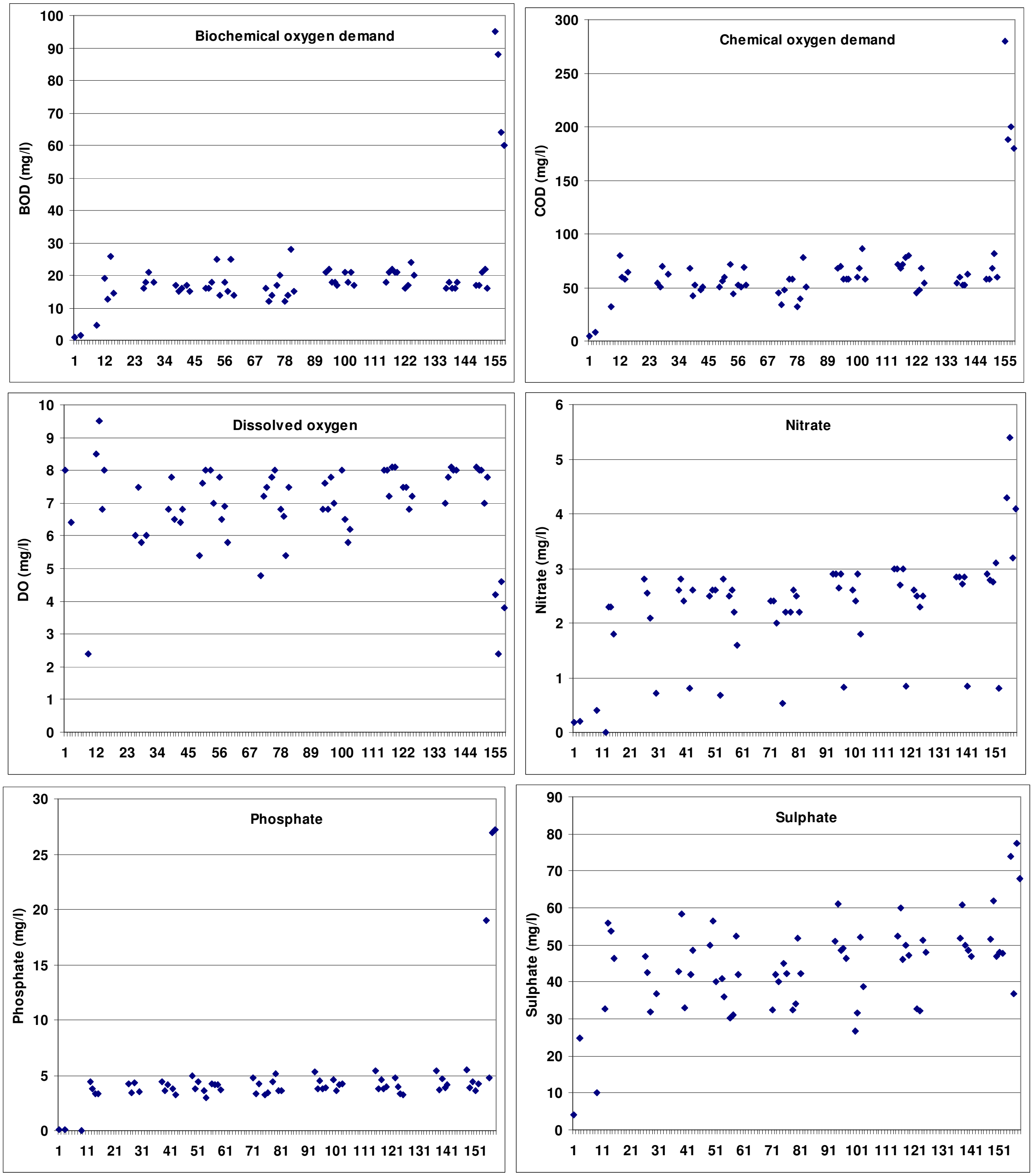


Figure 12: Chemical parameters (organic) available in Taldanda canal

The dissolved oxygen (DO) values are within the permissible range most of the times. Only on few occasions and it has gone below 4. Interestingly, DO values has never been zero in any of the drains, which indicated their interaction to atmosphere due to some turbulence. Das and Acharya (2203 also observed low values of DO (1.7 mg/l) in some of their sampling points.

Nitrate (NO_3) and Phoshpate (PO_4) values are found to be less than 3 mg/l, but significant amount of PO_4 has been observed from all the drains discharging the water to Taldanda canal. NO_3 can be toxic to certain aquatic organisms even at concentration of 1 mg/l whereas PO_4 may cause algal bloom in Taldanda canal.

Sulphate (SO_4) are found to be within the range (Figure 13). They are available in abundance in nature as sodium sulphate and magnesium sulphate. Sodium (Na) is present as common salt, which reacts with water to make sodium hydroxide and hydrogen. In the analysis, it is found to be less than 25 mg/l.

Magnesium (Mg) indicates hardness in the water and its values were found to be fluctuating in different period of sampling.

Potassium are found to be prominent up to RD 11.75 km, but the less than 15 mg/l. Thereafter its values have been reduced.

Calcium is also an indicator for hardness. Its values are found to be below 25 mg/l at every location.

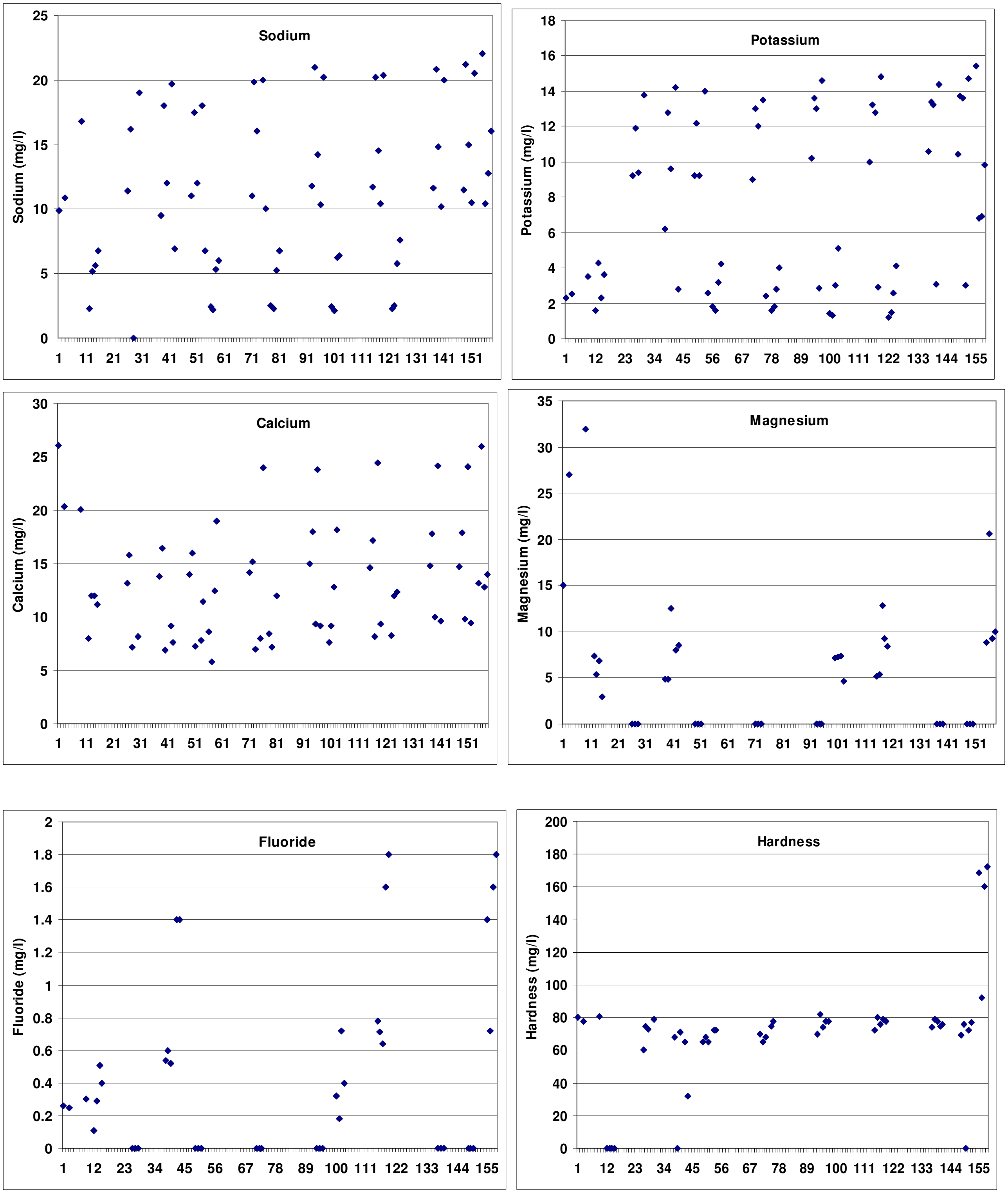


Figure 13: Chemical parameters (inorganic) available in Taldanda canal

Figure 14 illustrate the presence of trace metals in Taldanda canal and Hansua nala. The traceable metals are Iron (Fe), Zinc (Zn), Copper (Cu) and Silica (Si). Other traces metals are found only on one or two occasions during the sampling. Iron content is very high in amount varying between 1-6 mg/l. The maximum permissible range is 0.50 mg/l. High concentration of iron damages liver. Coagulants or Flocculation is essentially needed to remove iron.

Availability of Copper is in high concentration touching the maximum permissible range of 1.5 mg/l. The dissolved copper salts even in low concentrations are poisonous to some biota. It should be less than 0.05 mg/l.

Zinc and Silica are found to be within the range at all the sampling locations of Taldanda canal.

Total Coliform, Fecal Coliform and E-Coli are detected in the water at different sampling locations of Taldanda canal and Hansua nala. The values are significantly high but have not crossed the maximum permissible range.

Traces of phytoplankton, zoo plankton and Chlorophyll are also found in water at water at different sampling locations of Taldanda canal and Hansua nala.

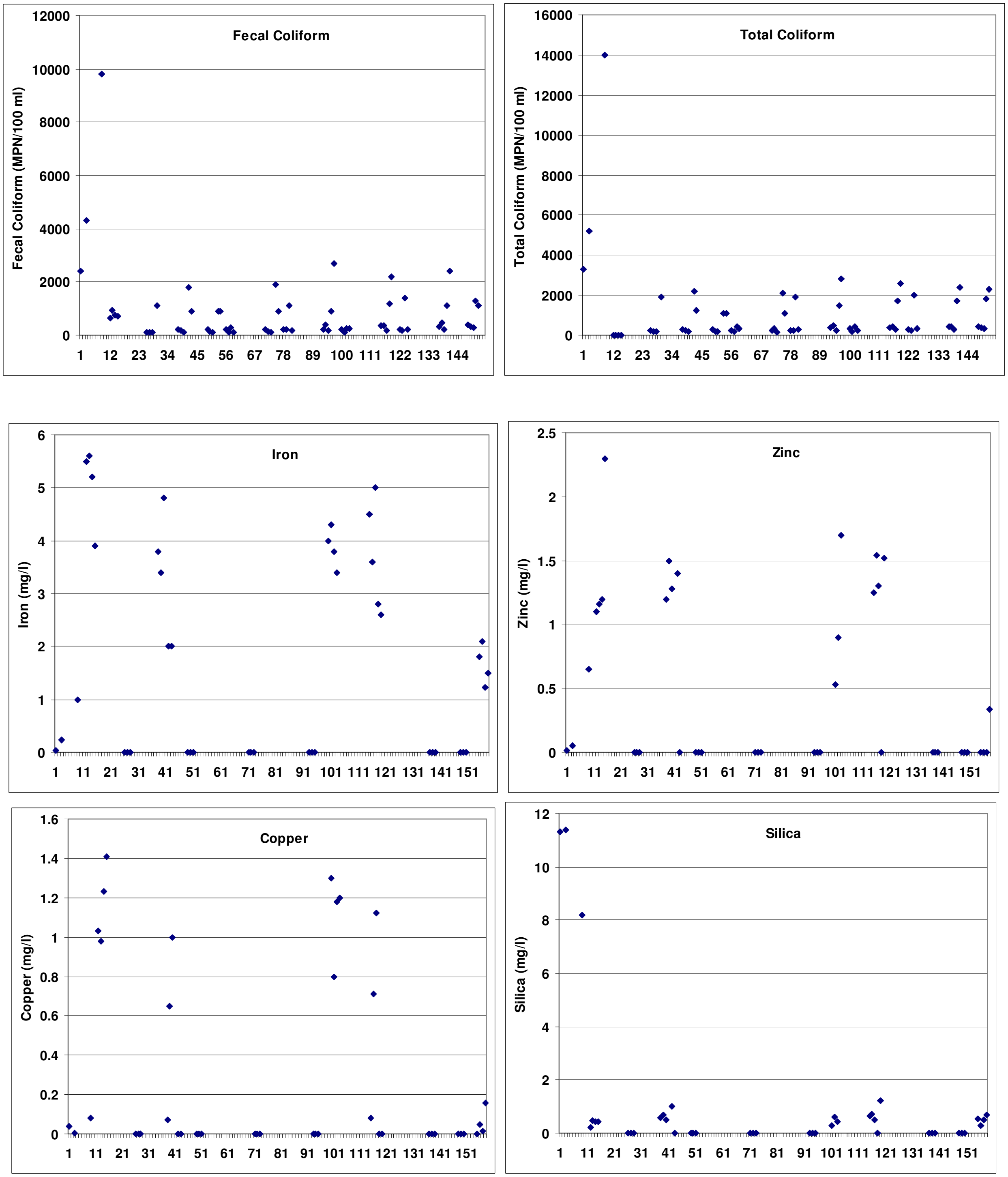


Figure 14: Trace metals available in Taldanda canal

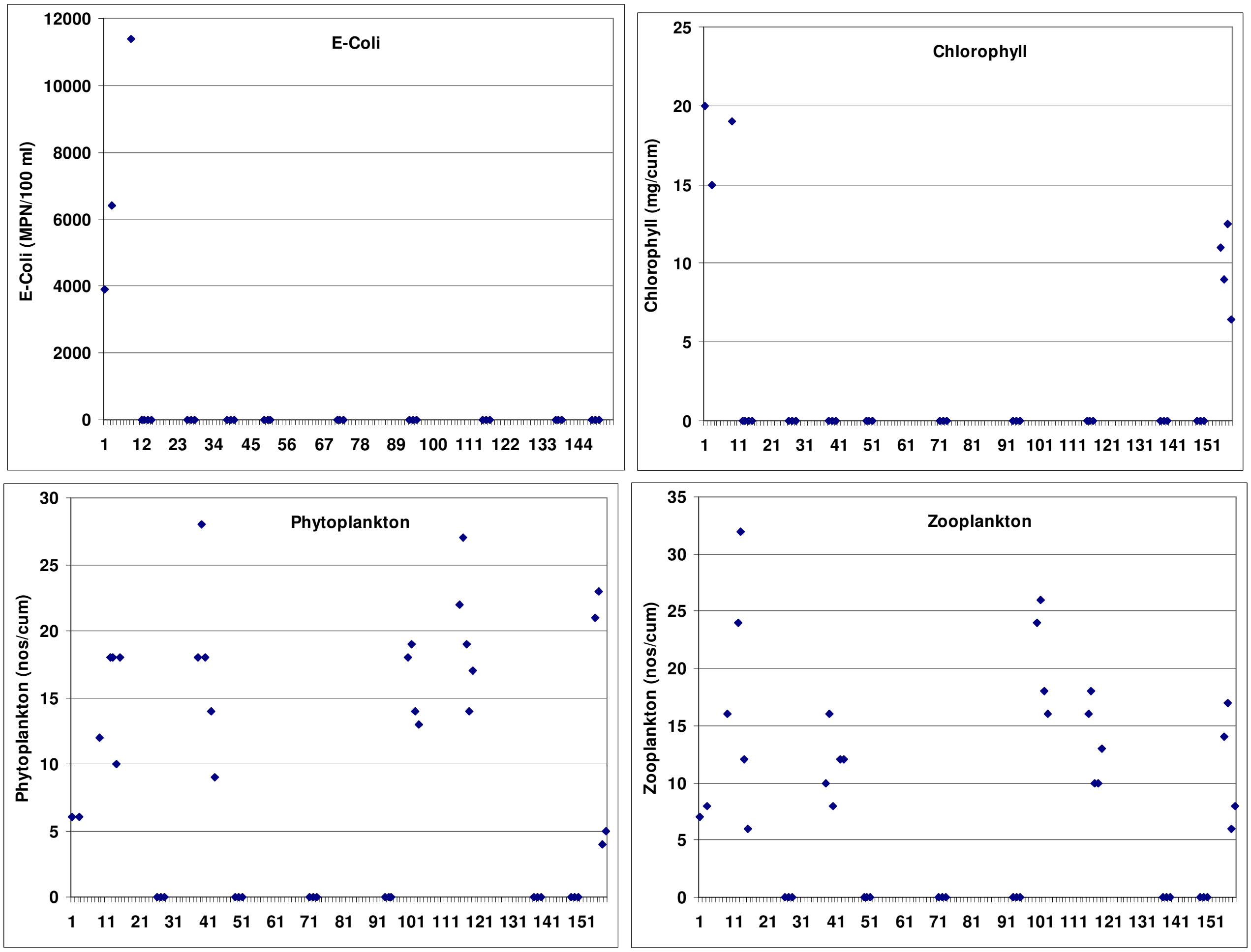


Figure 15: Biological variables available in Taldanda canal

CHAPTER 4

WATER QUALITY MODELLING FOR WASTE LOAD ALLOCATION AND ASSIMILATIVE CAPACITY

This section deals with the following objectives:

1. Simulation of water quality variables and water quality management.
2. Generation of scenarios for best water quality management for different purposes.
3. Recommendation of policy action for preventing release of pollutants into the canal.

4.1 Water Quality Modelling

River water quality modelling has a long history that dates back to the pioneering work of Streeter and Phelps in 1925. Streeter and Phelps described the bacterial decomposition of organic carbon characterised by biochemical oxygen demand (BOD) and its impact on dissolved oxygen conditions. In the course of the next half-century, this simple, first-order kinetics approach was further developed in three major steps. The first was the refinement of the two-state-variable model by introducing the settling rate (of particulate matter) in addition to the decay rate (of dissolved matter) and the so-called sediment oxygen demand (as a parameter). The model was also improved by using research results on the surface reaeration rate. Finally, an extension was made by distinguishing between carbonaceous BOD (CBOD) and nitrogenous BOD (NBOD), which led to a third state variable. The second step was the incorporation of a simplified nitrogen cycle: ammonia, nitrate, and nitrite appeared as new components. This extension appears in QUAL1 (TWDB 1971), the first model of the QUAL family. Ten years later the third step further extended the approach by incorporating phosphorus cycling and algae, which resulted in organic nitrogen, organic phosphorus, dissolved phosphorus, and algae biomass (in terms of chlorophyll a) as additional state variables. This model is known today as QUAL2E and is widely used. It has also been adopted in a practically unchanged form in various simulation software and decision support systems (DSS). A general layout of water quality model is shown in Figure 16.

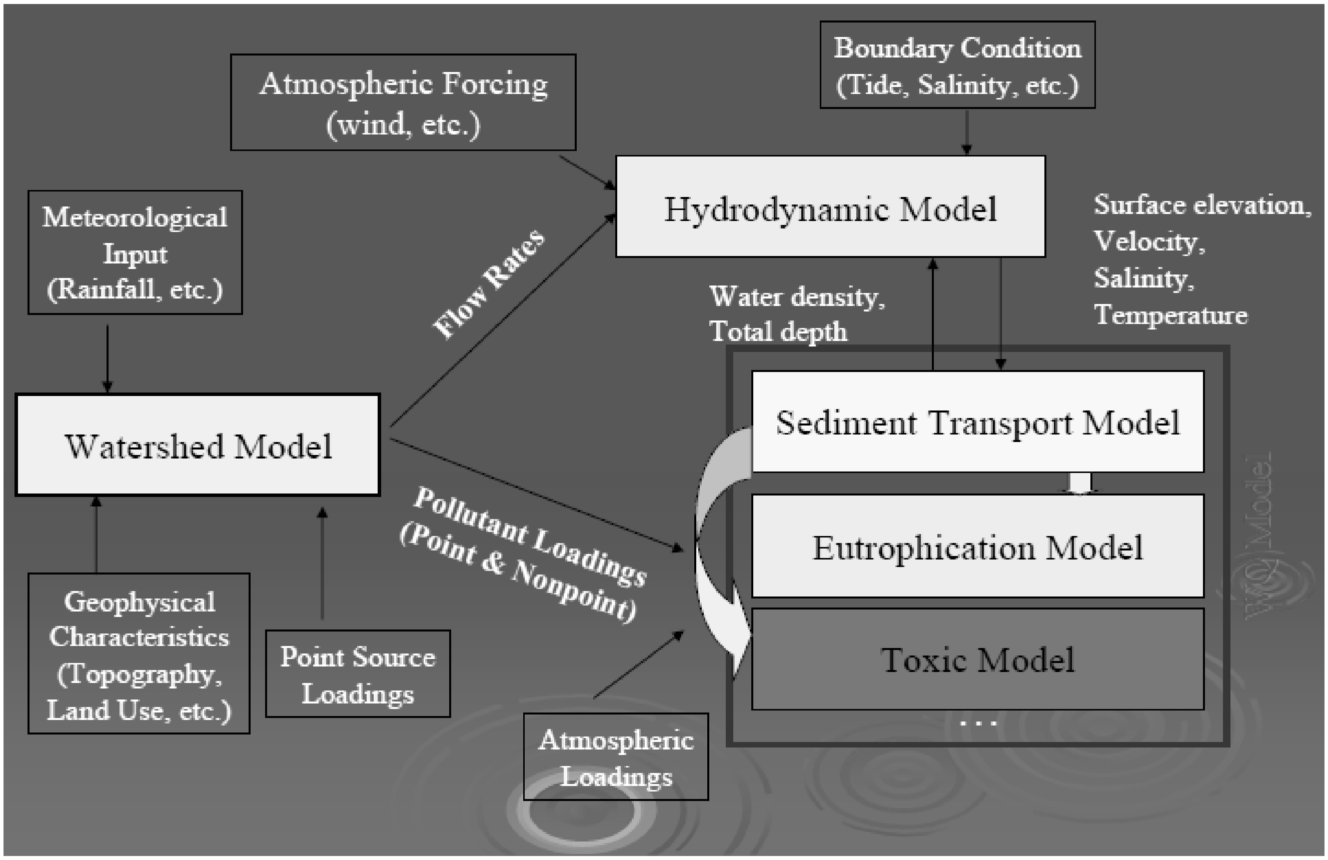


Figure 16: General layout of water quality model

Equation (3) forms the basis of all water quality models. The basic equation describes the variation of the concentration of a quality constituent C with the time and space. Apart from the advective and dispersive transport terms, the internal source/sink term, or internal reaction term, have been included in the equation. They are also called the transformation processes with the meaning that the substance in concern is being transformed by various physical, chemical, biochemical and biological processes resulting in the change of the quantity of the substance in an elemental water body. This change is either a "loss" or sink term caused by processes such as settling, chemical-biochemical decomposition, uptake by living organisms or a "gain", a source term, such as scouring from the stream bed, product of chemical-biochemical reactions, biological growth, that is the "build-up " of the substance in concern on the expense of other substances present in the system. The actual form of these transformation processes will be presented in relation to concrete model equations such as the BOD-DO models, the models of the oxygen household and the plant nutrient (phosphorus) transformation processes of the lake models.

$$\begin{aligned} &\frac{\partial C}{\partial t} + v_x \frac{\partial C}{\partial x} + v_y \frac{\partial C}{\partial y} + v_z \frac{\partial C}{\partial z} = \\ &= \frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y}\left(D_y \frac{\partial C}{\partial y} \right) + \frac{\partial}{\partial z}\left(D_z \frac{\partial C}{\partial z} \right) + S(x, y, z, t) \pm S_{internal} \end{aligned} \tag{3}$$

where,

C- is the concentration, the mass of the quality constituent in a unit volume of water (mass per volume, M L^{-3}); D_x,D_y,D_z - are the coefficients of dispersion in the direction of spatial co-ordinates x, y, and z, (surface area per time, L^2T^{-1}); v_x,v_y,v_z - are the components of the flow velocity in spatial directions x, y, and z, (length per time, L T^{-1}); t - is the time (T); S(x,y,z,t) - denotes external sources and sinks of the substance in concern that may vary in both time and space (mass per volume per time, M L^{-3} T^{-1}); $S_{internal}$- denotes the internal sources and sinks of the substance, (M L^{-3} T^{-1});

Water quality models are used for many different problems and purposes. Existing models address some of these problems better than others. We have named the model presented in this report River Water Quality Model (RIWAQ). applications that RIWAQ is intended to address include:

(1) Conservative pollution (trace metal ions and inorganic components) modeling using mass balance model and generic water quality model.
(2) BOD and DO modeling using dispersion, dilution, diffusion and reaction kinetics.
(3) Nutrient modeling using export function and distributed modeling approach.

4.2 The General Dilution Equation

This is one of the most important tools in water quality "modelling", a simple mass balance equation, which is used when the pollution source is considered as an initial condition. Considering a river and an effluent discharge of steady state conditions (with flows and concentrations not varying in time) and assuming instantaneous full cross-sectional mixing of the sewage water with the river water the initial concentration C_o downstream of an effluent outfall can be calculated by the dilution equation, which stems from the balance equation of in- and out flowing fluxes written for the section of the discharge point (e.g. back-ground river mass flux plus pollutant discharge mass flux equals the combined mass flow downstream of the point of discharge). This equation is used very frequently in simple analytical water quality models for trace metal ions and inorganic components for calculating the initial concentration of pollutants

$$C_0 = \frac{C_s q_s + C_b Q_b}{q_s + Q_b} \qquad (4)$$

where

C_b - background concentration of the polluting substance in concern in the river, (ML^{-3});

C_s - concentration of the pollutant in the waste water, (ML^{-3});

Q_b - discharge (rate of flow) of the river upstream of the effluent outfall, ($L^3 T^{-1}$);

q_s - the effluent discharge, ($L^3 T^{-1}$);

4.3 BOD-DO river models

BOD-DO river models deal with the oxygen household conditions of the river, by considering some of the main processes that affect dissolved oxygen (DO) concentrations of the water. These models are of basic importance since aquatic life, and thus the existence of the aquatic ecosystem, depend on the presence of dissolved oxygen in the water. All river water quality models, and thus the BOD-DO models, can be derived from the general basic water quality model equation (Equation 3). The main process that affect (deplete) the oxygen content of water is the oxygen consumption of micro-organisms, living in the water, while they decompose biodegradable organic matter. This means that the presence of biodegradable organic matter is the one that mostly affect the fate of oxygen in the water. There are internal and external sources of such biodegradable organic matter. Internal sources include organic matter that stem from the decay (death) of living organisms, aquatic plants and animals (also termed "detritus", or dead organic matter). Among external sources anthropogenic ones are of major concern and this includes wastewater (sewage) discharges and runoff induced non-point source or diffuse loads of organic matter.

In the models biodegradable organic matter is taken into consideration by a parameter termed **"Biochemical oxygen demand, BOD"**. BOD is defined as the quantity (mass) of oxygen consumed from a unit volume of water by microorganisms, while they decompose organic matter, during a specified period of time. Thus BOD_5 is the five-day biochemical oxygen demand that is the amount of oxygen that was used up by microorganisms in a unit volume of water during five days "incubation" time in the respective laboratory experiment. Thus the unit of BOD is mass per volume (e.g. gO_2/m^3, which equals mg O_2/litre). Another main process in the oxygen household of streams is **the process of reaeration**, the uptake of oxygen across the water surface due to the turbulent motion of water and to molecular diffusion. This process reduces the "**oxygen deficit"** (D) of water, which is defined as the difference between saturation oxygen content and the actual dissolved oxygen level.

These two counteracting processes are considered in the traditional BOD-DO model (Streeter and Phelps, 1925) in the mathematical form. The value of the reaeration coefficient K_2 depends, eventually, on the hydraulic parameters of the stream and a large number of experimental formulae have been presented in the literature along with reviews of these literature equations (Gromiec, 1983, Jolánkai 1979, 1992, Moog and Jirka, 1998, Jha et al, 2004). These expressions deviate from each other, sometimes substantially. For the estimation of the value of K_1 the Table of Fair (ref. Jolánkai, 1979) can be used, when knowing the value of K_2, can be used. This Table expresses the ratio $f= K_2/K_1$ in function of the verbally described hydraulic condition of the stream as shown in Table 3**.**

Table3: Ratio $f=K_2/K_1$ in function of the verbally described hydraulic condition of the stream

Description of the water body	**range of $f=K_2/K_1$**
Small reservoir or lake	0.5 - 1.0
Slow sluggish stream, large lake	1.0 - 2.0
Large slow river	1.5 - 2.0
Large river of medium flow velocity	2.0 - 3.0
Fast-flowing stream	3.0 - 5.0
Rapids and water falls	5.0 - and above

4.3.1 The BOD decay model

$$\frac{dL}{dt} = - K_1 L \tag{5}$$

$$L = L_0 e^{-K_1 t} \tag{6}$$

in which, L - BOD in the water (g O_2/m^3); L_0 - initial BOD in the stream (below waste water discharge), K_1 - is the rate coefficient of biochemical decomposition of organic matter (T^{-1}, usually day^{-1}); t - is the time, that is the time of travel in the river interpreted as t=x/v, where x is the distance downstream of the point of effluent discharge (T, given usually in days).

4.3.2 The dissolved oxygen model

$$\frac{dD}{dt} = K_1 L - K_2 D \tag{7}$$

where, D - is the oxygen deficit of water (g 0_2/m^3), L - BOD in the water (g O_2/m^3), K_1- is the rate coefficient of biochemical decomposition of organic matter (T^{-1}, usually day^{-1}), K_2 - is the reaeration rate coefficient (T^{-1}), t - is the time, that is the time of travel in the river interpreted as t=x/v, where x is the distance downstream of the point of effluent discharge.

$$D = \frac{K_1 L_0}{K_2 - K_1}\left(e^{-K_1 t} - e^{-K_2 t}\right) + D_0 e^{-K_2 t} \tag{8}$$

Here, D - is the oxygen deficit of water (g 0_2/m^3), D_0-is the initial oxygen deficit in the water (downstream of effluent outfall), L_0-is the initial BOD concentration in the water (g O_2/m^3), (downstream of effluent discharge), K_1- is the rate coefficient of biochemical decomposition of organic matter (T^{-1}, usually day^{-1}), K_2 -is the reaeration rate coefficient (T^{-1}), t -is the time, that is the time of travel in the river interpreted as t=x/v, where x is distance downstream of the point of effluent discharge; and v - is mean flow velocity of the river reach in concern. (L T^{-1})

4.3.3 Expanded and Modified BOD-DO River Models

In addition to the decay of organic matter and the process of reaeration, discussed in the text, there are many other processes in a stream which affect the fate (the sag) of the dissolved oxygen content. These processes are, without claiming completeness, as follows:

Physical processes:

- Effects of dispersion (mixing), spreading, mixing, diluting pollutants, thus reducing BOD (and increasing aeration, a process that is to be included in the reaeration rate coefficient K_2);
- Settling of particulate organic matter, that reduces in-stream BOD values;

Chemical, biological and biochemical processes:

- Effects of benthic deposits of organic matter (e.g. the diffuse source of BOD represented by the decay of organic matter that had settled out earlier onto the channel bottom);
- Sinks and sources of oxygen due to the respiration and photosynthesis of aquatic plants (macrophytes, phytoplankton (algae) and attached benthic algae;
- oxygen consumption by oxidising biochemical processes, such as nitrification.

BOD-DO models (Jha et al. 2006)

$$L = L_0 e^{-(K_1+K_3)t} + \frac{L_d ql\left(1-e^{-(K_1+K_3)t}\right)}{(K_1+K_3)(Q_u+ql)} + \frac{BQ_u\left(1-e^{-(K_1+K_3)t}\right)}{(K_1+K_3)(Q_u+ql)} \tag{9}$$

$$\begin{aligned}D = {} & D_0 e^{-K_2 t} + \frac{K_1 Q_u L_0\left(e^{-(K_1+K_3)t}-e^{-K_2 t}\right)}{(K_2-(K_1+K_3))(Q_u+ql)} + \frac{K_1 Q_u L_d ql\left(1-e^{-K_2 t}\right)}{K_2(K_1+K_3)(Q_u+ql)^2} \\ & + \frac{K_1 Q_u\left(e^{-(K_1+K_3)t}-e^{-K_2 t}\right)L_d ql}{(K_2-(K_1+K_3))(K_1+K_3)(Q_u+ql)^2} + \frac{K_1 Q_u^2 B\left(1-e^{-K_2 t}\right)}{K_2(K_1+K_3)(Q_u+ql)^2} \\ & - \frac{K_1 Q_u^2 B\left(e^{-(K_1+K_3)t}-e^{-K_2 t}\right)}{(K_2-(K_1+K_3))(K_1+K_3)(Q_u+ql)^2} + \frac{D_d ql\left(1-e^{-K_2 t}\right)}{K_2(Q_u+ql)} - \frac{(P-R)Q_u\left(1-e^{-K_2 t}\right)}{K_2(Q_u+ql)}\end{aligned}$$

(10)

4.3.3.1 The initial oxygen deficit equation

This set of equations is used to calculate the initial oxygen deficit of the water downstream of a point source sewage discharge as compared to the saturation dissolved oxygen concentration, which latter is temperature dependent.

$$D_0 = DO_{sat} - DO_0, \quad [\mathrm{mg}\, O_2/\mathrm{litre}] \tag{11}$$

$$DO_{sat} = 14.61996 - 0.4042\,T + 0.00842\,T^2 - 0.00009\,T^3 \tag{12}$$

in which, D_0 - is the initial concentration of dissolved oxygen deficit in the river, downstream of the effluent discharge point (ML^{-3}, e.g. mg O_2/l), DO_0 - is the initial concentration of dissolved oxygen in the river, downstream of the effluent discharge point (ML^{-3}, e.g. mg O_2/l), DO_{sat} - is the saturation oxygen concentration of water, T- is the water temperature (°C)

4.3.3.2 Critical values of the oxygen sag curve

This set of four equations is used to compute the lowest dissolved oxygen concentration (highest oxygen deficit) in the river water downstream of a single source of sewage water along with the corresponding time of travel and downstream distance.

$$t_{crit} = \frac{1}{K_2 - K_1} \ln \frac{K_2}{K_1} \left(1 - \frac{D_0 (K_2 - K_1)}{L_0 K_1} \right) \quad (13)$$

$$x_{crit} = v\, t_{crit} \quad (14)$$

$$D_{crit} = \frac{K_1}{K_2} L_0 e^{-K_1 t_{crit}} \quad (15)$$

$$DO_{crit} = DO_{sat} - D_{crit} \quad (16)$$

where, t_{crit} - the critical time of travel (time during which the water particle arrives to the point of lowest DO concentration in the stream), D_0-is the initial concentration of dissolved oxygen deficit in the river, downstream of the effluent discharge point (ML^{-3}, e.g. mg O_2/l), L_0 - is the initial concentration of BOD in the river, downstream of the effluent discharge point (ML^{-3}, e.g. mg O_2/l), K_1 - is the rate coefficient of biochemical decomposition of organic matter, the BOD decay rate, (T^{-1}, usually day^{-1}), K_2 - is the reaeration rate coefficient, the rate at which oxygen enters the water from the atmosphere, (T^{-1}), x_{crit} -the critical distance downstream of the point of effluent discharge (the point of lowest DO concentration) (L), v - is the average flow velocity of the river reach in concern ($L\,T^{-1}$), D_{crit} - is the critical (highest) oxygen deficit in the water, along the river, (ML^{-3}, e.g. mg O_2/l), $DO_{cri\,t}$- is the critical (lowest) dissolved oxygen concentration of the water (ML^{-3}, e.g. mg O_2/l), DO_{sat} - is the saturation oxygen content of water, see also equation 12.

4.3.3.3 Equations for estimating K_2

Table 4: Developed Predictive Reaeration Equations

S. No.	Investigators	Reaeration equation
1.	O'Connor and Dobbins (1958)	$K_2 = 3.90V^{0.5}H^{-1.5}$
2.	Churchi11 et al. (1962)	$K_2 = 5.010V^{0.969}H^{-1.673}$
3.	Krenkel and Orlob (1962)	$K_2 = 173(SV)^{0.404}H^{-0.66}$

4.	Owens et al. (1964)	$K_2 = 5.35V^{0.67}H^{-1.85}$
5.	Langbein and Durum (1967)	$K_2 = 5.14VH^{-1.33}$
6.	Cadwallader and McDonnell (1969)	$K_2 = 186(SV)^{0.5}H^{-1}$
7.	Thackston and Krenkel (1969)	$K_2 = 24.9(1 + F_r^{0.5})V_*H^{-1}$
8.	Parkhurst and Pomeroy (1972)	$K_2 = 23(1 + 0.17F_r^{2})(SV)^{0.375}H^{-1}$
9.	Tsivoglou and Wallace (1972)	$K_2 = 31200SV$ for $Q < 0.28m^3/\text{sec}$ $K_2 = 15200SV$ for $Q > 0.28m^3/\text{sec}$
10.	Smoot (1988)	$K_2 = 543S^{0.6236}V^{0.5325}H^{-0.7258}$
11.	Moog and Jirka (1998)	$K_2 = 1740V^{0.46}S^{0.79}H^{0.74}$ for $S > 0.00$ $K_2 = 5.59S^{0.16}H^{0.73}$ for $S < 0.00$
12.	Jha et al. (2000)	$K_2 = 5.792V^{0.5}H^{-0.25}$
13.	Jha et al. (2004)	$K_2 = 0.603286V^{0.4}S^{-1.0}H^{0.154}$ for $F_r<1$ $K_2 = 866.307V^{1.393}S^{-0.173}H^{0.8}$ for $F_r<1$

Here, V= velocity of stream water in m/s, H= flow depth in m, S= slope, V_*= friction velocity in m/s, and F_r = Froude number.

4.3.3.4 Temperature correction formula for K_2

This equation is used for the correction of the value of BOD decomposition rate coefficient K_1 in function of the water temperature.

$$K_{1(T)} = K_{1(20^\circ C)} 1.047^{(T-20)} \tag{17}$$

Here, $K_{1(T)}$ -is the value of rate coefficient K_1 at water temperature T °C, $K_{1(20^\circ C)}$ -is the value of rate coefficient K_1 at water temperature T=20 °C

4.4 Nutrient modeling from Non-Point Source Pollution

In India, applications of fertilizers and chemical for different crops are in practice, which in turn, causes non-point source pollution to the surface water and the groundwater of the region. Non-point source pollution enters the receiving surface water diffusely at intermittent intervals. It may generate both conventional and toxic pollutants, just as point sources do. Although non-point sources may contribute many of the same kinds of pollutants, these pollutants are generated in different volumes, combinations, and concentrations. The extents of non-point source pollution are mainly related to infiltration and storage characteristics of the basin, the permeability of soils, geographic, geological, land use/land cover conditions differing greatly in space and other hydrological parameters. The important waste constituent outflows from diffuse sources are suspended solids, nutrients and pesticides.

Numerous studies were conducted globally since early seventies to understand the processes controlling non-point source pollutants in the river systems.

Specific equations for different variables used in NPS estimation and for routing component of NPS assessment are given below in Tables 5 and 6.

Table 5: Specific equations for different variables

Variables	**Author(s)**	**Governing Equation**
Overland flow	Manning's formula	$Q_r = \frac{1}{R_3}(D_1 - D_S)^{5/3} S_1^{1/2} A$
Interflow	Kouwen (1988)	$Q_{\text{int}} = R_{ec}(W_{ac} - R_{et})$
Infiltration and surface detention	Philip (1954) Priestley and Taylor (1972)	$\frac{dF}{df} = k\left[1 + \left(\frac{(m - m_0)(P_{ot} + D_1)}{F}\right)\right]$ $P_{et} = \alpha \frac{s(T_a)}{s(T_a) + \zeta}(K_n + L_n)\frac{1}{\rho\lambda_y}$
Interception	Linsley et al. (1949)	$V = (S_i + C_p E_a t_R)(1 - e^{-kP})$
Surface storage	Kouwen (1988)	$D_S = S_d(1 - e^{-kP_e})$
Evapotranspiration	Hargreaves and Samani (1982)	$P_{et} = 0.0075 R_a C_1 \delta_t^{1/2} T_{avg}$
Transport capacity	Hartley (1987)	$Y_C = 2.65 pcr_f$

Shear stress relationships	Hartley (1987)	$\tau_d = \frac{\beta}{\beta+1}\left(\frac{60}{K_f}\right)\gamma H_L S_o$ $\tau_c = (\sigma-1)\gamma\phi D_{50}$
Rainfall soil detachment	Hartley (1987)	$G_{rf} = E_{rf}(1-GC)CFD$
Runoff soil detachment	Hartley (1987)	$G_{ro} = E_{ro}D$
Potential sediment supply	Hartley (1987)	$Y_S = (G_{rf} + G_{ro})\Delta t$
Soluble nutrient (nitrogen)	Young et al. (1986)	$C_{RON} = \frac{(N_{AVS} - N_{AVR})}{F_{POR}} * \left[e^{(-N_{DMV}I_{EFF})} - e^{(-N_{DMV}I_{EFF} - N_{RMV}R_{OFF})}\right] + \frac{N_{RNC}R_{OFF}}{P_{EFF}}$
Sediment attached Nutrients	Young et al. (1986)	$N_{SED} = N_{SCN}Y_{SED}ER$ $P_{SED} = P_{SCN}Y_{SED}ER$ $ER = aY_{SED}^{b}T_f$

Here, V = interception depth (mm), S_i = storage capacity (mm), C_p = ratio of vegetated surface area, E_a = evaporation rate (mm h^{-1}), t_R = duration of the rainfall (h), k = constant (mm^{-1}), P = precipitation (mm), D_s = depression storage (mm), S_d = surface retention value (mm), P_e = accumulative rainfall excess (mm), F = total depth of infiltrated water (mm), t = time (s), K = saturated conductivity (mm s^{-1}), m = average moisture content of the soil, m_o = initial soil moisture content, P_{ot} = capillary potential (mm), D_1 = detention storage (mm), P_{et} = potential evapotranspiration rate (mm d^{-1}), α = equilibrium factor, s(Ta) = slope of the saturation vapor pressure vs. temperature curve, ξ = psychrometric constant, K_n = short wave radiation, L_n = long wave radiation, ρ = mass density of water, λ_y = latent heat of vaporization, R_a = total incoming solar radiation (mm), C_t = temperature reduction coefficient, δ_t = temperature difference (^{o}F⇐^{o}C), T_{avg} = mean temperature (^{o}F⇐^{o}C), Q_{int} =

interflow (m^3 s^{-1}), R_{ec} = coefficient representing depletion, W_{ac} = water accumulation in the upper zone storage (mm), R_{et} = retained storage (mm), Q_r = channel inflow (m^3 s^{-1}), D_1 - D_s = runoff depth above ponding, R_3 = combined roughness and channel-length parameter optimized for each land class, S_1= average overland slope, A= area of the element (m^2), Y_C = sediment transport capacity (kg m^{-2}), c = volumetric sediment concentration ratio = $A\left(\frac{\tau_d}{\tau_c}\right)^B$, A=0.00066, B= 1.61, r_f = runoff (mm), τ_d = dominant flow shear stress, τ_c = critical stress, β = discharge parameter (=5/3), γ = water specific weight (kg m^{-2} s^2), H_L = average runoff depth (mm), S_o = average overland slope, K_f = overland flow friction = $60 + 3140GC^{1.65}$, GC = ground cover factor, D_{50} = median size of soil particles (mm), σ = specific weight of sediment, ϕ Shields entrainment function = $\frac{0.11}{R^*} + 0.0211\log_{10} R^*$, R^* = Reynolds number = $\frac{\sqrt{\tau_d \gamma D_{50}}}{\nu}$, ν = kinematic viscosity of water ($m^3 s^{-1}$), G_{rf} = rate of soil detachment due to rainfall (kg m^{-2} h), CF = canopy factor, D = soil erodibility factor (gJ^{-1}), E_{rf} = rate of rainfall energy (Jm^{-2} h)= $i(11.9 + 8.7\log_{10} i)$, i = rainfall intensity (mm h^{-1}), G_{ro} = rate of soil detachment due to runoff (kg m^{-2} h), E_{ro} = rate of energy input to the soil by the flow ($Jm^{-2}h$) = $\left(\frac{60}{K_f}\right)\gamma\frac{Q_L}{2}S_o$, Q_L = unit flow discharge (m^2 h^{-1}), S_o = element slope, Δt = time increment (h), C_{RON} = soluble nitrogen concentration in rumoff (kg ha^{-1}), N_{AVS} = available nitrogen content in the surface (kg ha^{-1}), N_{AVR} = available nitrogen in rainfall (kg ha^{-1}), N_{DMV} = rate of downward movement of nitrogen into soil, N_{RMV} = rate of nitrogen movement into runoff, I_{EFF} = effective infiltration (mm), R_{OFF} = total runoff (mm), F_{POR} = porosity factor, N_{RNC} = nitrogen contribution due to rain (kg ha^{-1}), P_{EFF} = effective precipitation (mm), N_{SED} = overland nitrogen transported by the sediment (kg ha^{-1}), N_{SCN} = soil nitrogen concentration (.001gNg^{-1}soil), ER = nutrient enrichment ratio (a=7.4, b= -0.2), T_f = correction factor for soil texture (0.85 for sand, 1.0 for silt, 1.15 for clay and 1.50 for peat).

Table 6: Specific equations for routing component of NPS assessment

Variables	Authors	Governing Equation
Grid or cell for sediment	Frere et al. (1980)	$Y_{SEDout} = 1000[(1 - S_{Dep})(Y_{SEDab} + Y_{SED}$
Grid or cell for nutrients	Frere et al. (1980)	$CC_{RONout} = \frac{100}{R_{OFF}}[(1 - N_{Dec})(C_{RONab} +$

Here the subscripts 1 and 2 indicate the beginning and end of the time step, $I_{1,2}$ = inflow to the reach (m^3s^{-1}) consisting of overland flow, interflow base flow and channel flow from all contributing upstream basin elements, $O_{1,2}$ = outflow from the reach (m^3s^{-1}), $S_{1,2}$ = storage in the reach (m^3), Δt = time step of the routing (s), R_2 = channel roughness parameter, A_x = channel cross-section area (m^2), S_o = channel slope, Y_{SEDout} = sediment leaving the cell (ppm), S_{Dep} = deposition fraction, Y_{SEDab} = sum of all the sediment entering the cell (kg ha^{-1}), Y_{SEDin} = sediment generated within the element, CC_{RONout} = soluble nutrients concentration in runoff leaving the cell (ppm), N_{Dec} = nutrients decay fraction, CC_{RONab} = sum of all the nutrient entering the cell (kg ha^{-1}), CC_{RONin} = nutrient generated within the element

4.4.1 Non-point source equations proposed by Jha et al. (2005)

$$TOTAL - LOAD = Q_u C_u e^{-kt} + C_{npx}\left[\frac{(Q_d - Q_u)}{l}x\right]e^{-kt_{npx}} + C_{np2x}\left[\frac{(Q_d - Q_u)}{l}x\right]e^{-kt_{np2x}} \quad (17)$$

$$+ - - - - - - - - - - + C_{np(l-x)}\left[\frac{(Q_d - Q_u)}{l}x\right]e^{-kt_{np(l-x)}} + C_{npl}\left[\frac{(Q_d - Q_u)}{l}x\right]$$

$$TOTAL - LOAD = \frac{C_{npx}l(Q_d - Q_u)}{kt}\left(1 - \frac{1}{kt} + \frac{e^{-kt}}{kt}\right) + Q_u C_u e^{-kt} \quad (18)$$

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Flow measurements in Taldanda Canal and Hansua Nala and their models

Flow data collected from Taldanda canal have been analysed and it has been observed that there is an exponential reduction in the flow of Taldana canal in the downstream direction due to supply of water to the command area for irrigation purposes (Figure 17). The exponential model developed for flow reduction is shown in equation (19), which is used to estimate the mean flow at any location of the Taldanda canal.

$$y = 2354.2e^{-0.044x} \qquad (r^2=0.97) \qquad (19)$$

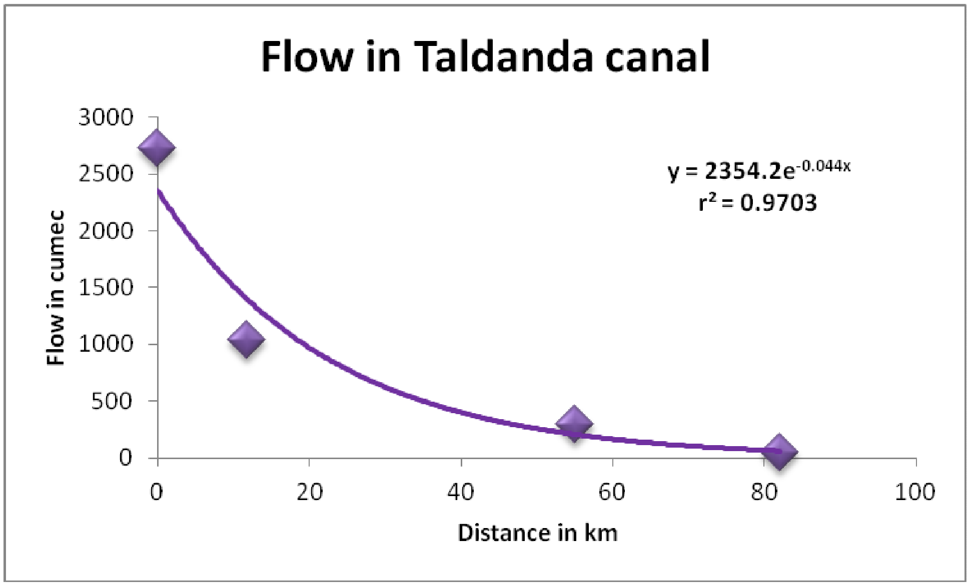


Figure 17: Flow variation in Taldanda canal

Flow data collected from Hansua Nala have been analysed and it has been observed that there is an increase in the flow of Hansua Nala in the downstream direction due to supply of water from the command area used for irrigation purposes from Taldanda canal. The power function model developed for flow reduction is shown in equation (20), which is used to estimate the mean flow at any location of the Hansua Nala.

$$y = 0.1198x^{1.7043} \qquad (r^2=1.00) \qquad (20)$$

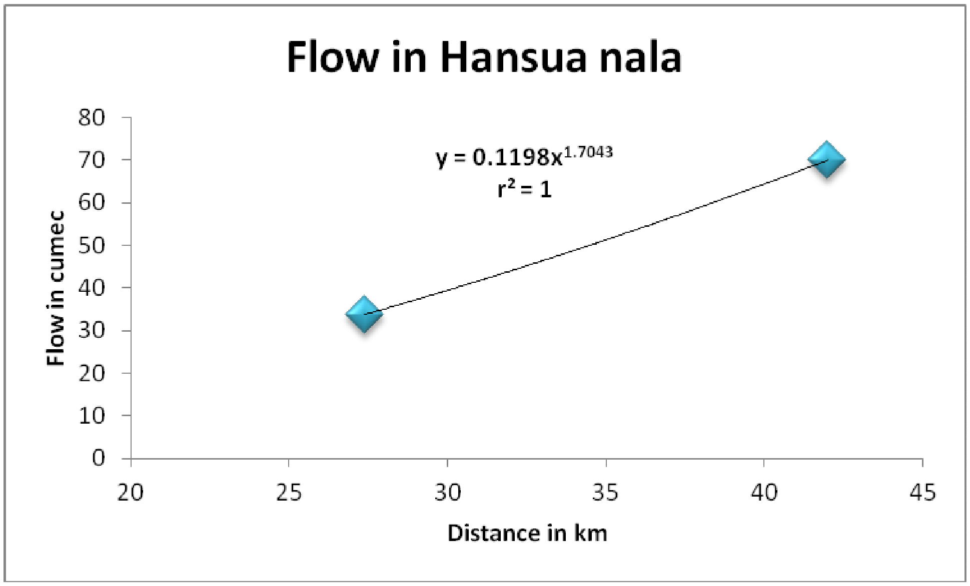


Figure 18: Flow variation in Hansua Nala

5.2 Physical parameter analysis

Conductivity is found to be increasing continuously in Taldanda canal. After analysis it has been found that the conductivity is well represented by linear, exponential and polynomial models. However, the second order polynomial equations provided best results as shown in Figure 19. Similarly, Dissolved solids are increasing in Taldanda canal and the polynomial equations developed are found to provide most suitable results (Figure 20). Ttotal solds are changing abruptly and do not follow any trend (Figure 21). None of the model is found suitable for estimating total solids available in Taldanda canal.

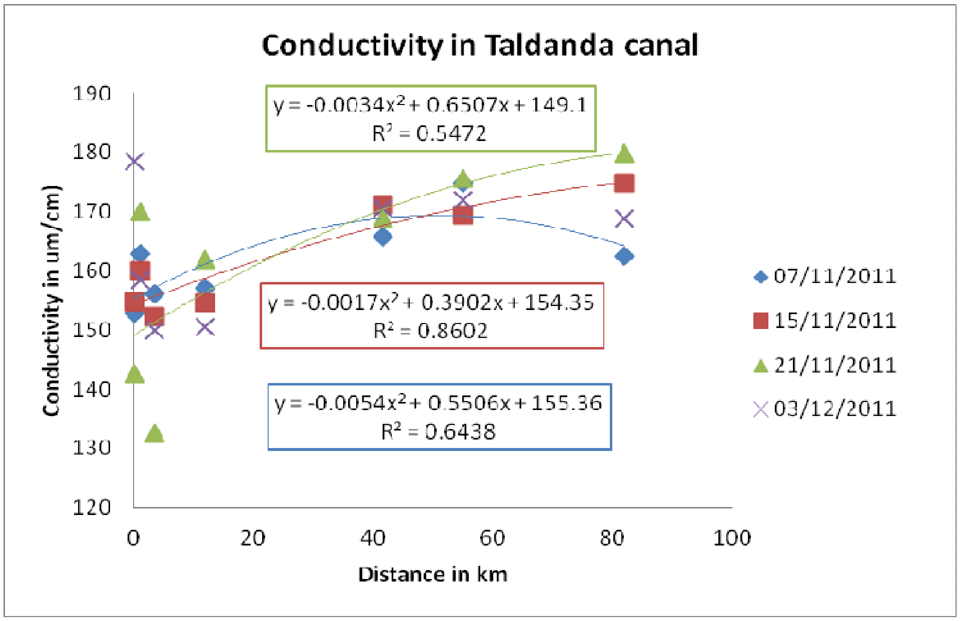


Figure 19: Conductivity showing good reslts with polynomial equations

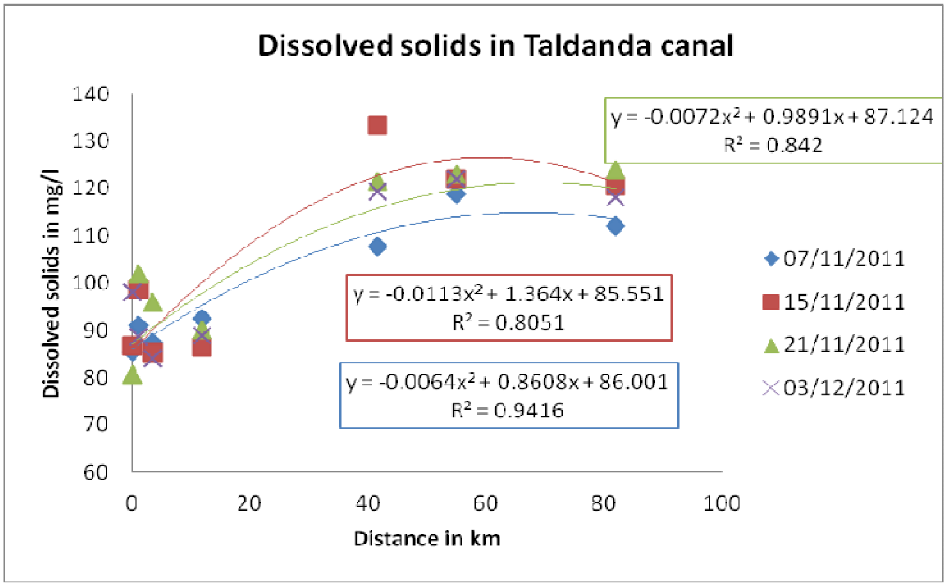


Figure 20: Dissolved solids showing good reslts with polynomial equations

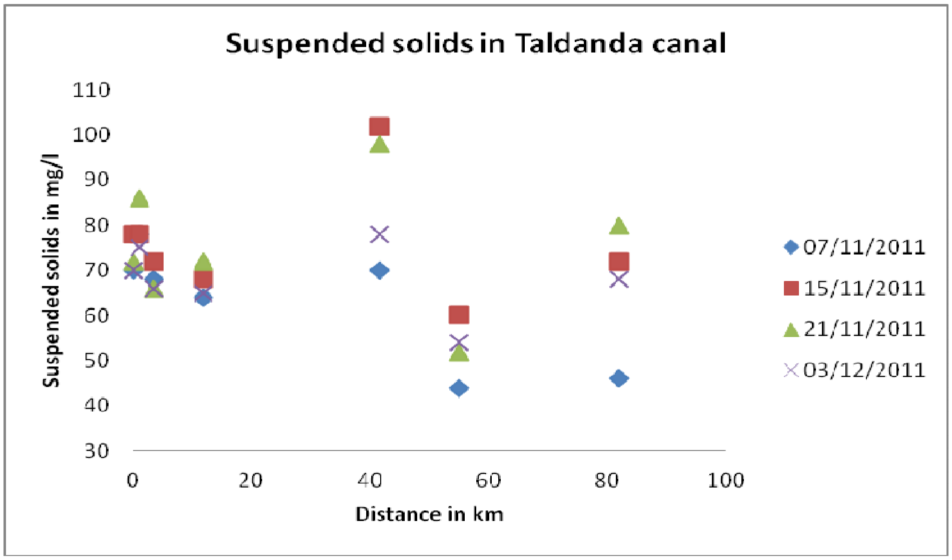


Figure 21: Total solids showing abrupt values without any trend

5.3 BOD and DO analysis

For water quality modeling, various hydraulic, hydrologic and river data have been collected from Water Resources Department, Government of Odisha. These data sets are given below in Tables 7, 8 and 9.

Table 7: BOD input values for the model

Location	**Date**	**BOD load**	**Date**	**BOD load**	**Date**	**BOD load**	**Date**	**BOD load**
		kg/day		**kg/day**		**kg/day**		**kg/day**
RD: 0 km	**07/11/2011**	4233254	**15/11/2011**	2822170	**21/11/2011**	4938797	**28/11/2011**	3762893
RD: 11.75 km	**07/11/2011**	1254355	**15/11/2011**	1343952	**21/11/2011**	1523146	**28/11/2011**	1791936
RD: 55.03 km	**11/11/2011**	350784	**18/11/2011**	451008	**26/11/2011**	551232	**03/12/2011**	400896
RD: 82 km	**11/11/2011**	76377.6	**18/11/2011**	76377.6	**26/11/2011**	94348.8	**03/12/2011**	80870.4

Table 8: DO input values for the model

Location	Date	DO deficit load	Date	DO deficit load	Date	DO deficit load	Date	DO deficit load
		kg/day						
RD: 0 km	**07/11/2011**	325480.8	**15/11/2011**	560661.6	**21/11/2011**	278444.7	**28/11/2011**	396035.1
RD: 11.75 km	**07/11/2011**	795842.4	**15/11/2011**	396035.1	**21/11/2011**	701770.1	**28/11/2011**	466589.3
RD: 55.03 km	**11/11/2011**	396035.1	**18/11/2011**	560661.6	**26/11/2011**	466589.3	**03/12/2011**	254926.6
RD: 82 km	**11/11/2011**	325480.8	**18/11/2011**	513625.5	**26/11/2011**	254926.6	**03/12/2011**	278444.7

Table 9: Different input data established for both BOD-DO models

Location	width (m)	depth (m)	Cross-section area (sqm)	Distance (km)	Travel time (day)	velocity (m/s)	Mean Flow (cumec)
RD: 0 km	50	36.3	1814.667	0		1.5	2722
RD: 11.75 km	50	20.7	1037	11.75	0.11	1	1037
RD: 55.03 km	50	5.8	290	43.28	0.5	1	290
RD: 82 km	50	1	52	26.97	0.31	1	52
Location	**Temperature**	**DO saturation**	**K1(1/day)**	**K2(1/day)**			
RD: 0 km	20	14.62					
RD: 11.75 km	20	14.62	8	30			
RD: 55.03 km	20	14.62	2.5	2			
RD: 82 km	20	14.62	5	2.5			

From observed data, BOD and DO plots were made (Figures 22 and 23). IT has been observed that at distance 3.5 km, BOD values are increasing significantly and DO is reducing. In genral, BOD values are much higher than the desired limit of 2 mg/l in Taldanda canal.

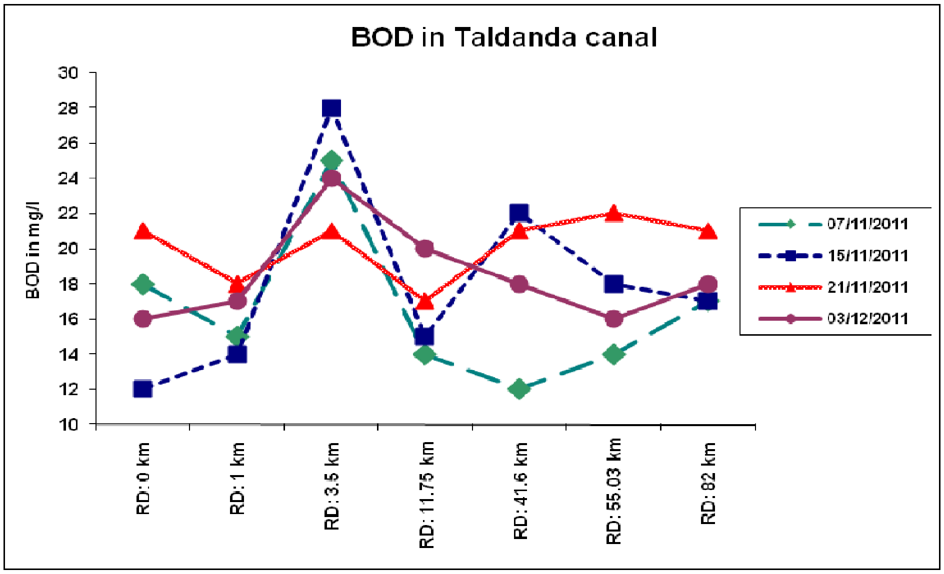


Figure 21: BOD values along Taldanda canal

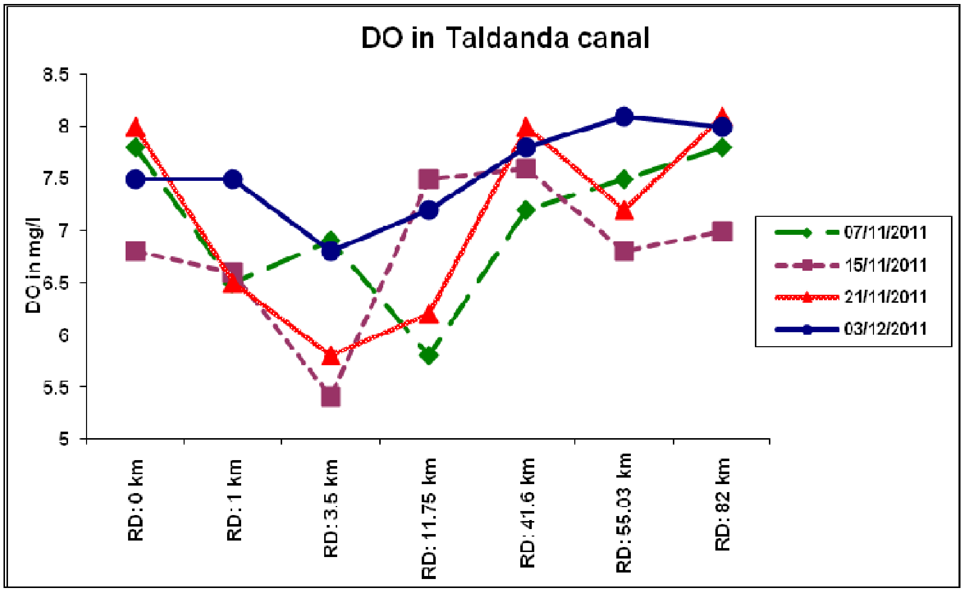


Figure 22: DO values along Taldanda canal

Once the data were observed, BOD and DO loads in kg/day were computed by multiplying BOD and DO concentrations with their respective discharges. For BOD modeling, it is essential to estimate the deoxygenation rate coefficients (K_1, 1/day) in equation (6). These values were established and finally K_1=8.0, 2.5 and 5.0 are found to be suitable for distance from 0.0- 11.75 km, 11.75- 55.03 km and 55.03-82 km stretch. The values are found to be very high during the distance between 0.0 and 11.75 km due to withdrawal of water for command area and high turbulence in the region. The results obtained using BOD model are found excellent and most suitable for different regions, if these values of K_1 are used for estimating BOD at any location. The results are shown in Figure 23 with the equation (21) having r^2 value equal to 0.897.

$$y = 1.07065x - 365.73 \qquad (r^2 = 0.897) \qquad (21)$$

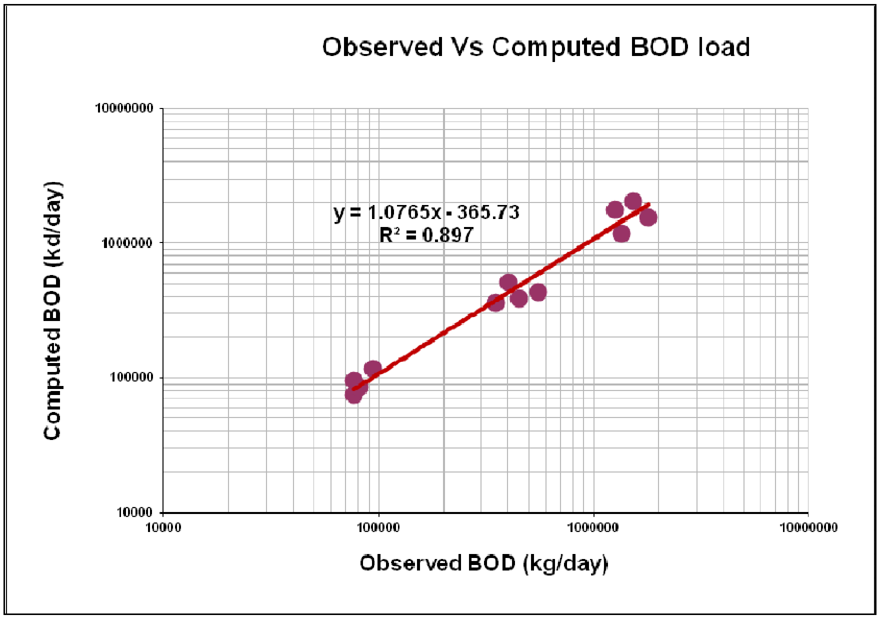


Figure 23: Results obtained using BOD model

For DO modeling, it is essential to estimate the reaeration rate coefficient (K_2, 1/day) keeping the deoxygenation rate coefficients (K_1, 1/day) same as obtained in BOD modelling. There are many empirical equations to obtain reaeration rate coefficient. In the present case, K_2 values were obtained using mass balance approach (Equation 8). These values were established and finally K_2=30.0, 2.5 and 3.0 are found to be suitable for distance from 0.0- 11.75 km, 11.75- 55.03 km and 55.03-82 km stretch. Again, the values are found to be very high during the distance between 0.0 and 11.75 km due to withdrawal of water for command area and high turbulence in the region. The results obtained using Do model are found excellent and most suitable for different regions, if these values of K_2 are used for estimating DO at any location. The results are shown in Figure 24 with the equation (22) having r^2 value equal to 0.897.

$$y = 0.6726x + 179959 \qquad (r^2 = 0.7263) \qquad (22)$$

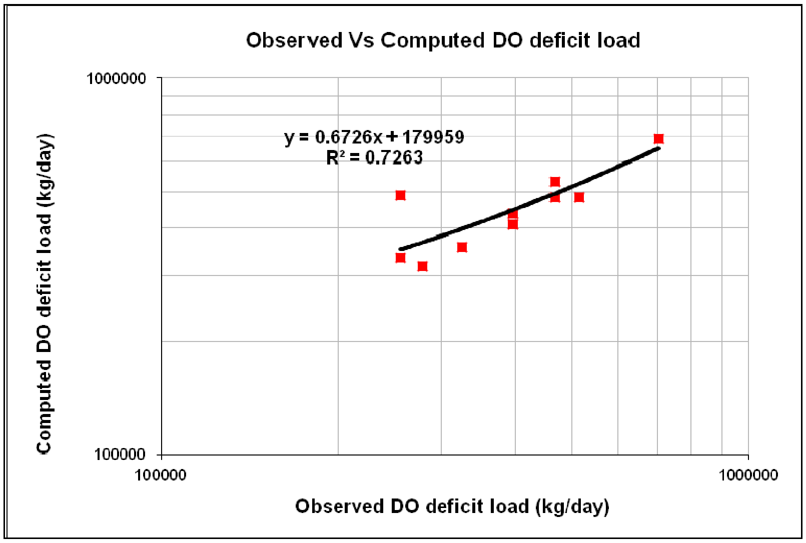


Figure 24: Results obtained using DO model

For computing reaeration rate coefficient (K_2), the equation (23) developed by Jha et al. (2001) provided very good results. This equation can be directly used for obtaining reaeration coefficients, specifically in the reaches below 11.75 km, as lots of turbulence and water withdrawal has been obtained in upper reaches.

$$K_2 = 5.792V^{0.5}H^{-0.25} \tag{23}$$

5.4 Mass balance and Exponential models for chemical parameters

Figure 25 indicates the Calcium, Sodium and sulphate values, which are found to be prominent in Taldanda canal. Their vales are increasing initially and following the chemical mass balance equation (4) shown in previous chapter and thereafter, the values are reducing. In fact, concentration is only the indication of presence of chemical in Taldanda canal.

To study the trend, it is found essential to estimate the loads of different ionic elements present prominently in Taldanda canal. For this total load of Calcium, Sodium and sulphate at different sampling stations were collected and studied.

It has been observed that the load is reducing exponentially for all chemicals (Figure 26). The exponential models developed in each case is given by equations (24), (25) and (26) for Calcium, Sodium and sulphate respectively

$y = 2E + 06e^{-0.044x}$ ($r^2 = 0.9792$) (24)

$y = 693125e^{-0.021x}$ ($r^2 = 0.8241$) (25)

$y = 7E + 06e^{-0.04x}$ ($r^2 = 0.9627$) (26)

5.5 Heavy metal trend

Two types of heavy metals Copper (Cu) and Iron (Fe) are found in alarming situations. Bothe the metal areat par with their permissible limits (Figur 27). The results indicate that their concentration is reducing in the Taldanda canal towards downstream direction slightly. However, the total load in the Canal is reducing exponentially. The equations (27) and (28) demonstrates the method for estimating heavy metals at downstream locations.

$y = 816227\ e^{-0.0468x}$ $r2 = 0.9165$ (27)

$y = 259980e^{-0.0471x}$ $r^2 = 0.9692$ (28)

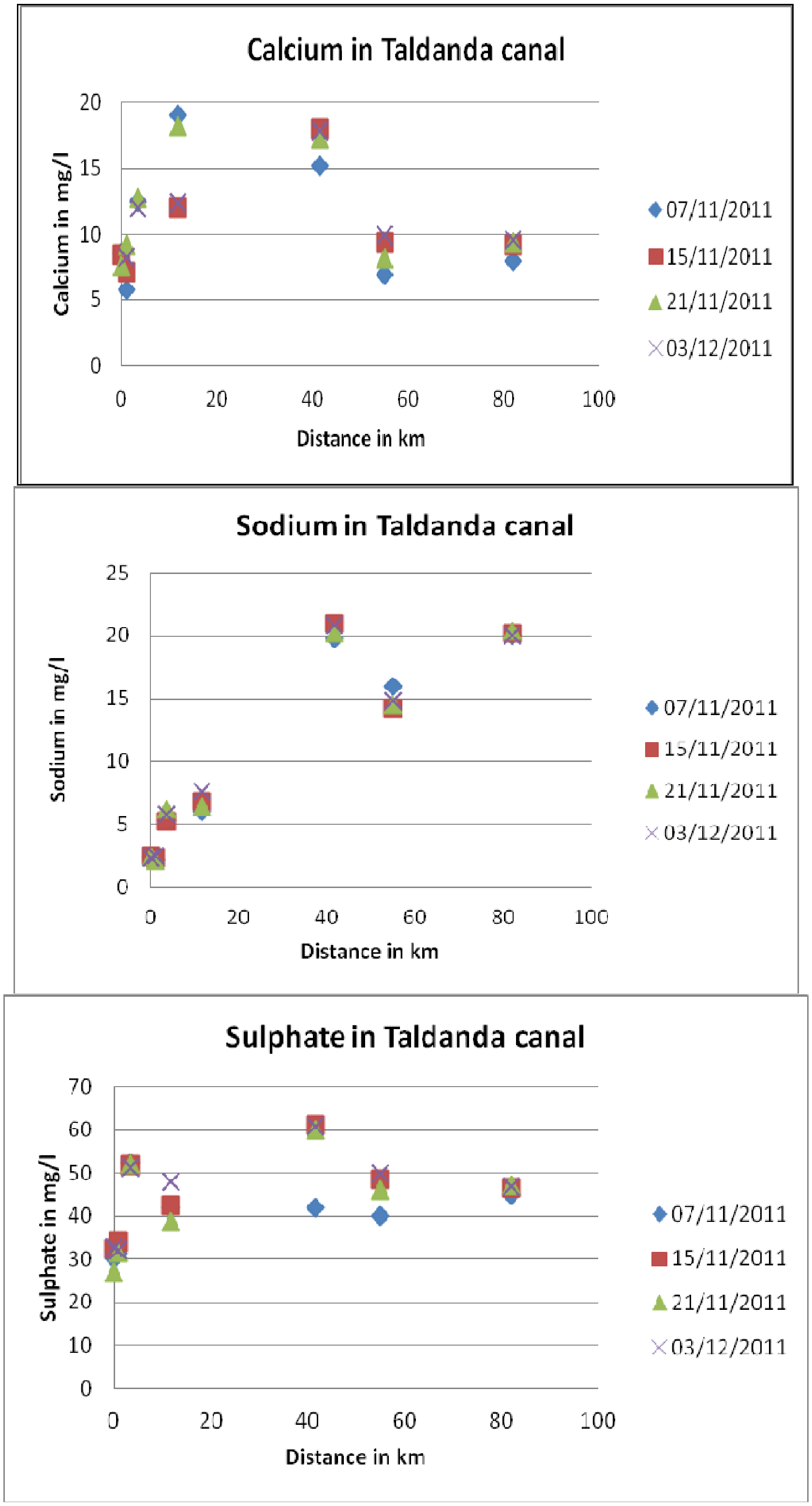


Figure 25: Concentration of various chemical in Taldanda canal

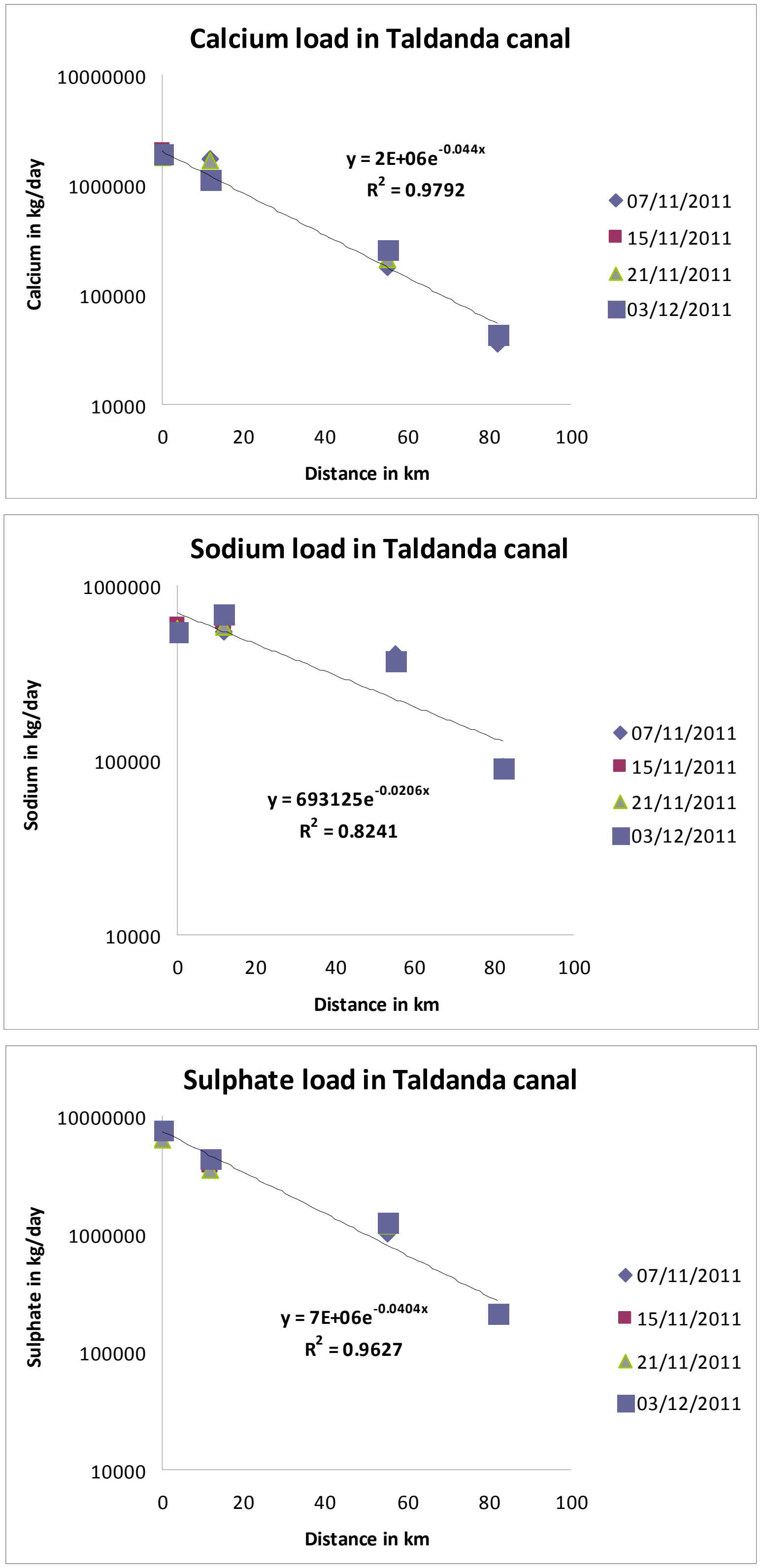


Figure 26: Exponential models for various chemical loads in Taldanda canal

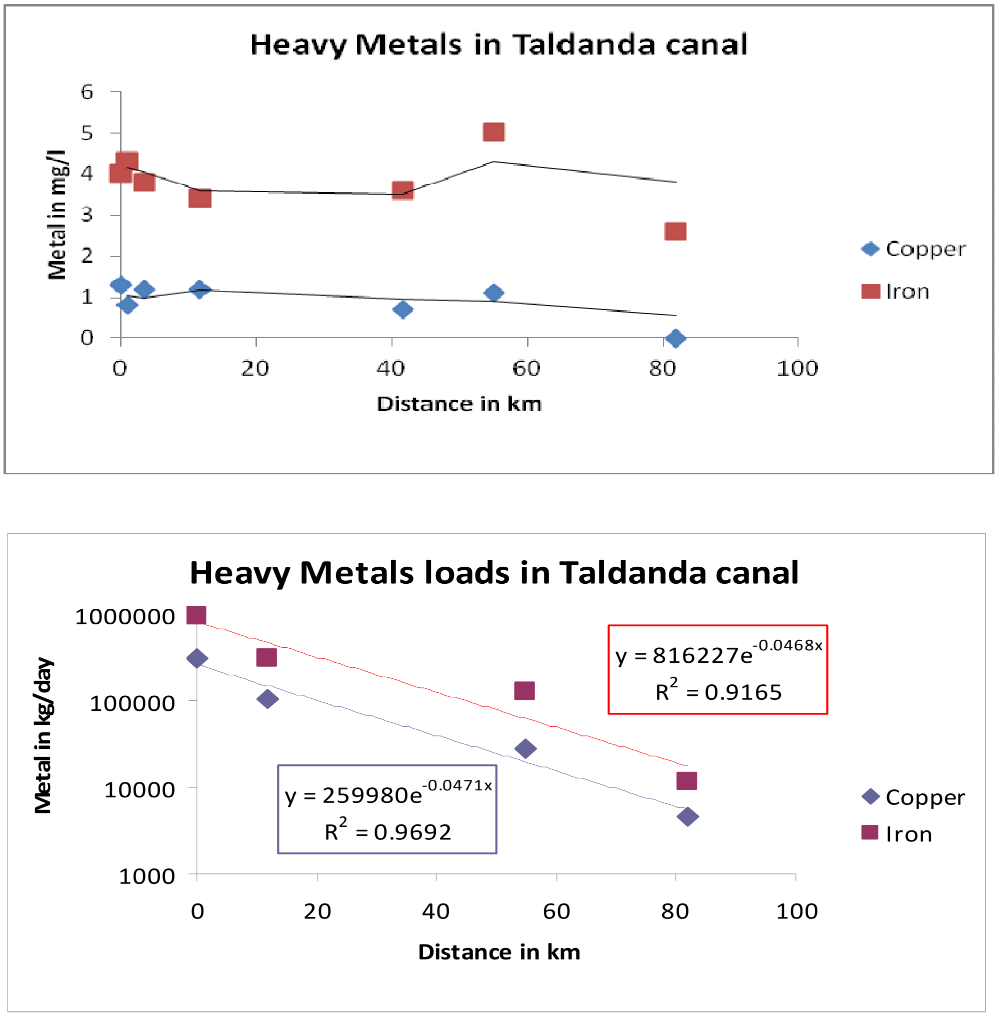


Figure 27: Heavy metals in Taldanda canal

5.6 Biological indicators modeling

Fecal coliform and Total coliform are in very high numbers in Taldanda canal and Hansual nala. They are increasing in down stream direction and may cause serious health problems. Figure 28, shows in increasing trend of both the biological indicators. A second order polynomial equation has been developed for Fecal and Total coliform separately denoted by equations (29) and (30).

$$y = 0.6374x2 - 33.585x + 292.76 \qquad r^2 = 0.9395 \qquad (29)$$

$$y = 0.7675x2 - 37.608x + 414.34 \qquad r^2 = 0.9309 \qquad (30)$$

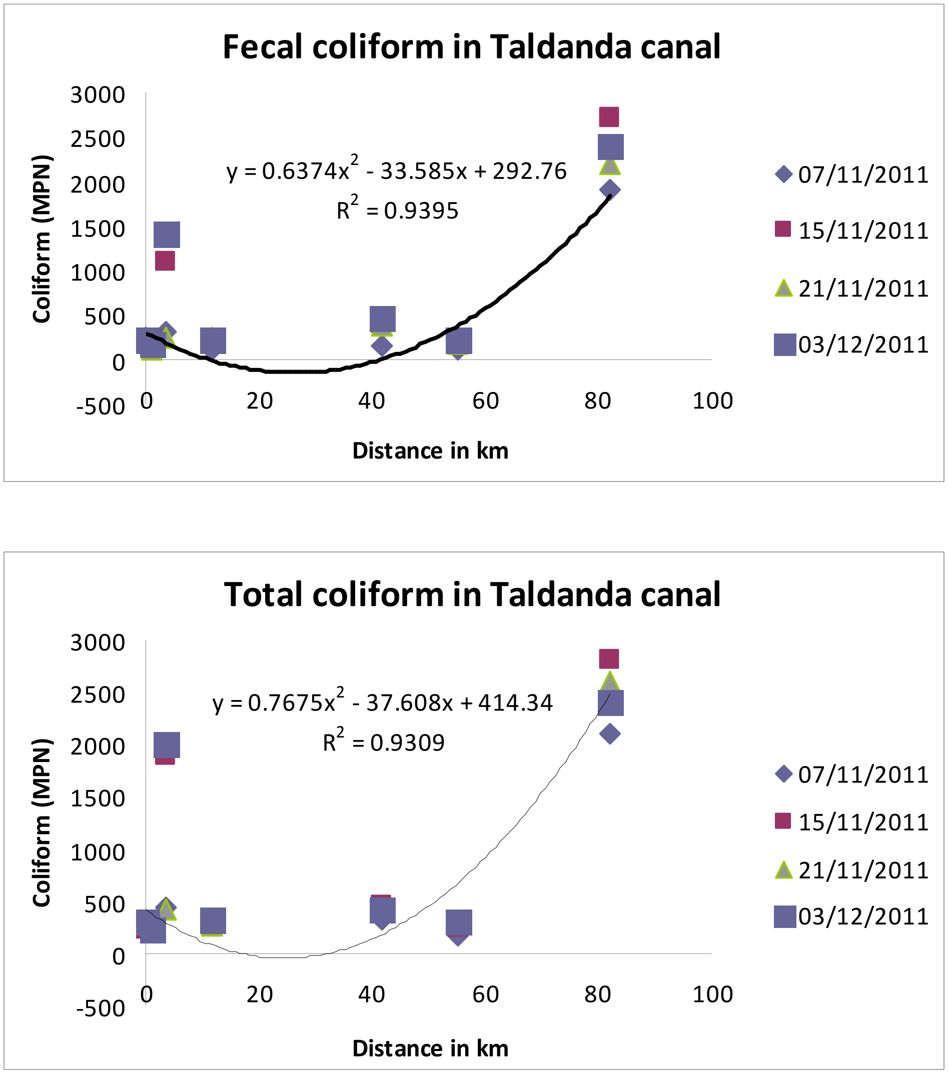


Figure 28: Fecal amd Total Coliform represented by polynomial equations

5.7 Nutrient modeling

Nitrate, Phosphate and Potassium concentrations are found in small quantity in Taldanda canal and Hansua nala, in which the potassium is found to be increasing continuously in downstream sampling points (Figure 29). Due to reduced flow, the total load of nutrients is reducing exponentially in Taldanda canal (Figure 30) and the euqations developed to demonstrate these models are shown in equations (31), (32) and (33) for Nitrate, Phosphate and Potassium respectively.

$y = 495003e^{-0.0583x}$ $r^2 = 0.9098$ (31)

$y = 834914e^{-0.0463x}$ $r^2 = 0.9521$ (32)

$y = 501370e^{-0.0207x}$ $r^2 = 0.7577$ (33)

The nutrient flow has been increasing in Hansua nala due to influx of non-point source pollution. It is governed by the model developed by Jha et al. ((2005), given below in equations (34) and (35) with the value of k=0.15. The non-point load comes out to be 900 kg/day.

$$\begin{aligned} TOTAL-LOAD \; &= Q_u C_u e^{-kt} + C_{npx}\left[\frac{(Q_d - Q_u)}{l}x\right]e^{-kt_{npx}} + C_{np2x}\left[\frac{(Q_d - Q_u)}{l}x\right]e^{-kt_{np2x}} \\ &+ - - - - - - - - - - + C_{np(l-x)}\left[\frac{(Q_d - Q_u)}{l}x\right]e^{-kt_{np(l-x)}} + C_{npl}\left[\frac{(Q_d - Q_u)}{l}x\right] \end{aligned} \qquad (34)$$

$$TOTAL - LOAD = \frac{C_{npx}l(Q_d - Q_u)}{kt}\left(1 - \frac{1}{kt} + \frac{e^{-kt}}{kt}\right) + Q_u C_u e^{-kt} \qquad (35)$$

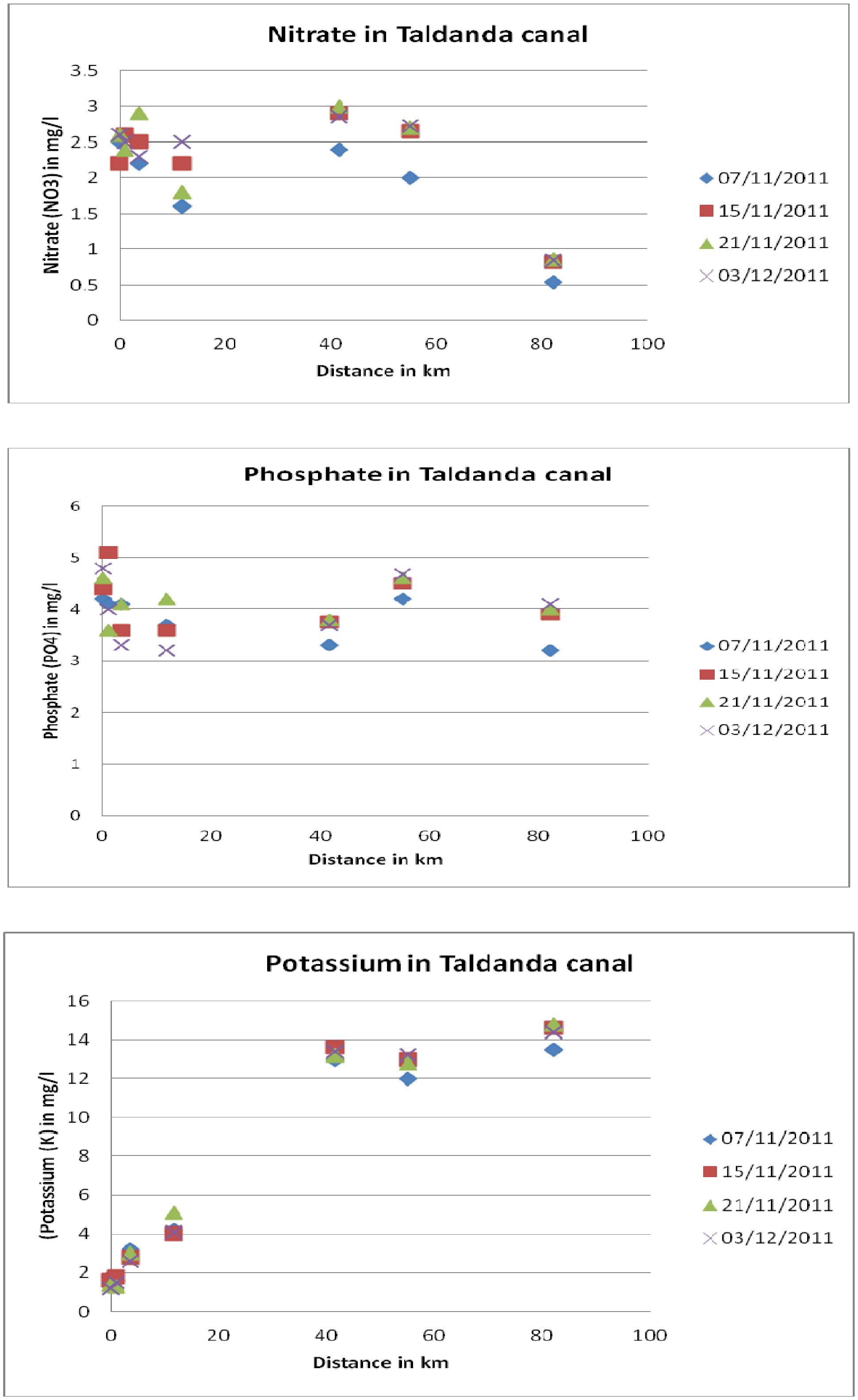


Figure 29: Nutrient concetration in Taldanda canal

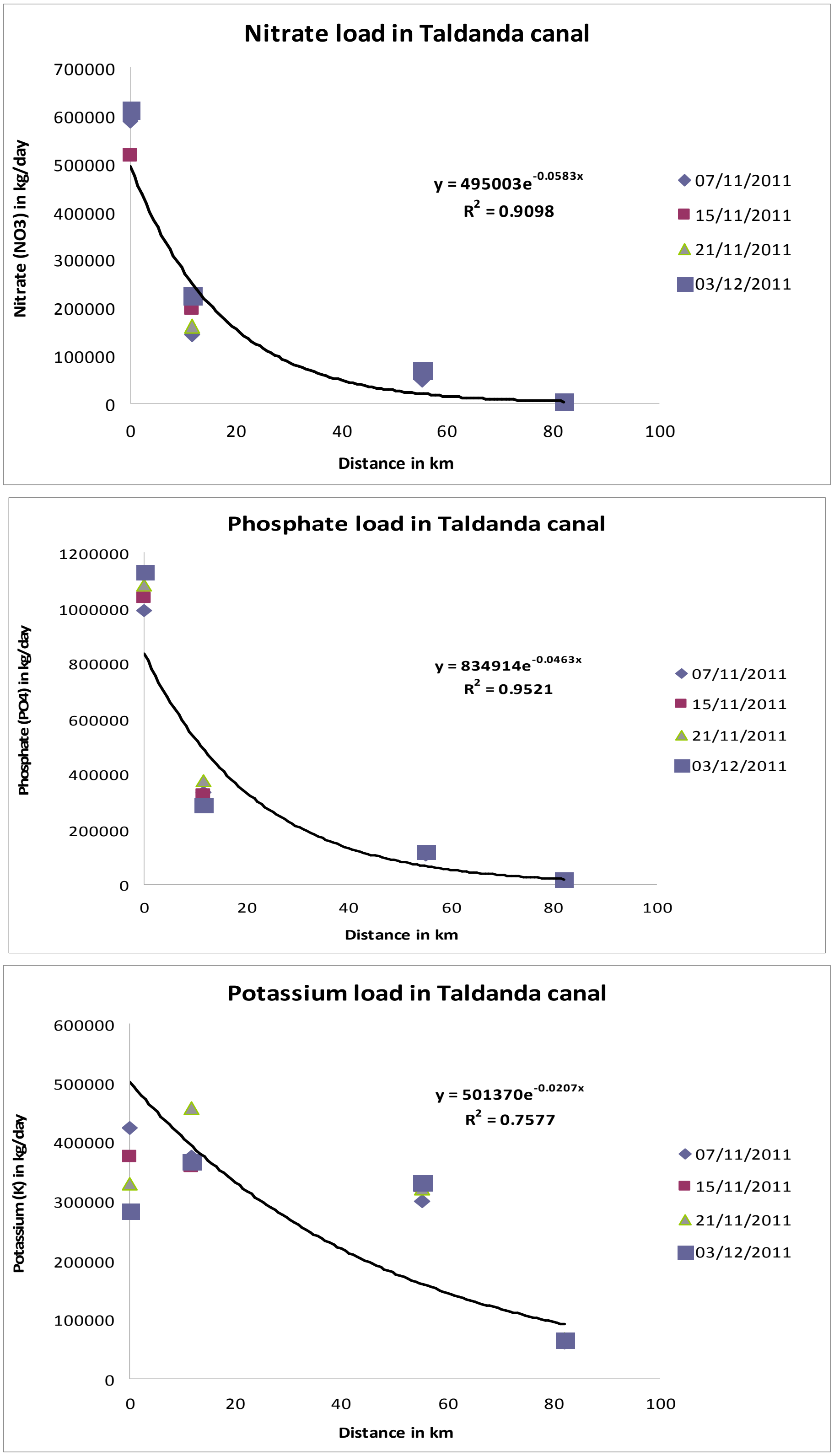


Figure 30: Nutrient load and exponential model in Taldanda canal

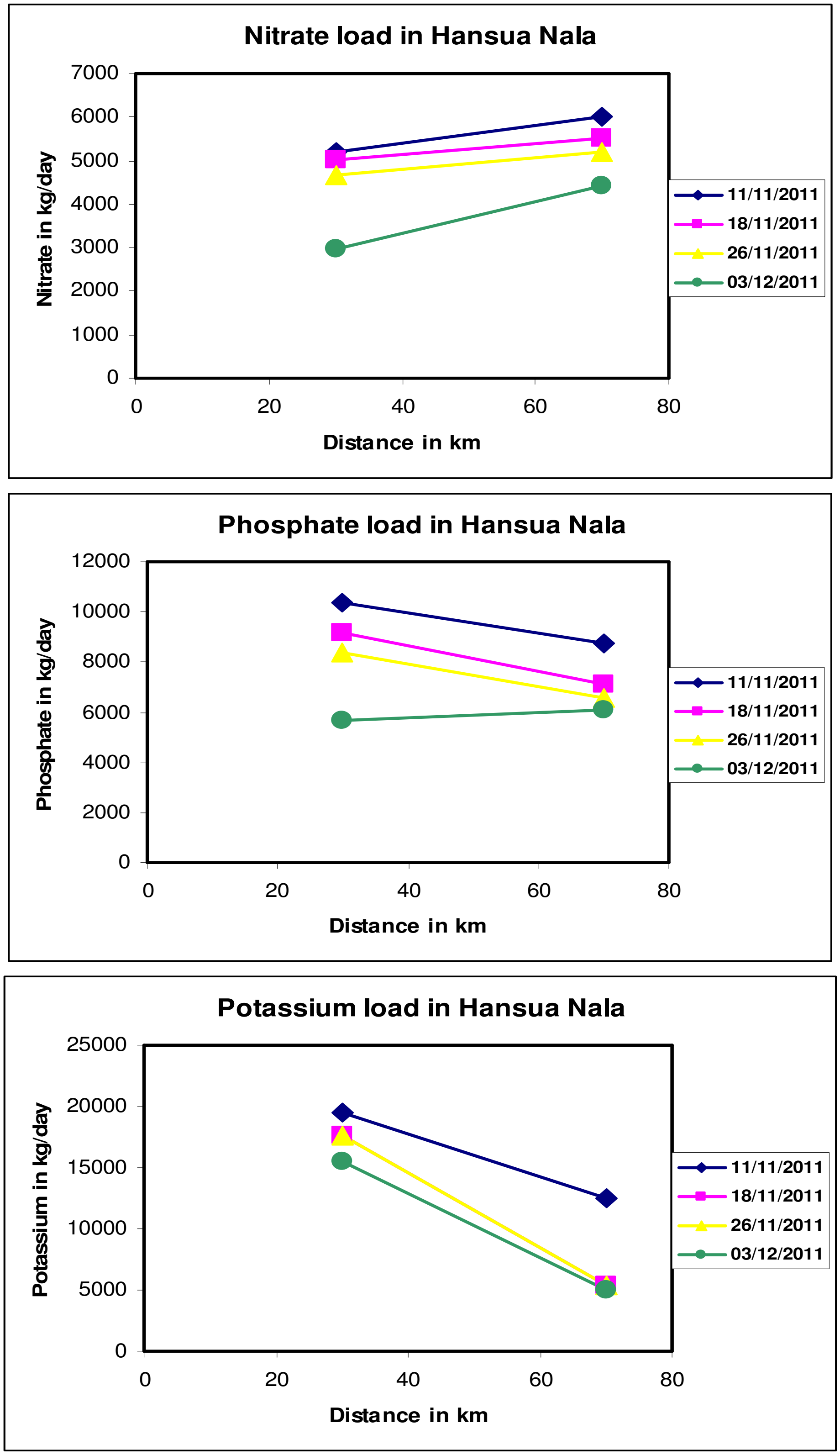


Figure 30: Nutrient load in Hansua nala

6.0 RECOMMENDATIONS FOR REMOVAL OF POLLUTION FROM TALDANDA CANAL

1. BOD and COD values are very high. This can be removed by using hydrogen peroxide or oxidation using aerators or coagulants.
2. For BOD and DO simulation at different location, proper water quality modeling approach needs to be applied to find the assimilative capacity and most suitable site for waste disposal with their appropriate quantity.
3. Iron and Copper are present in high amount, which needs to be controlled by effluent management and suitable removal techniques including oxidation, activated carbon, ion exchange, chemical treatment, membrane or adsorption techniques.
4. Biological variables (Total coliform, Fecal coliform and E-coli are available significantly), which may cause serious health problem to the people drinking the canal water and using it for drinking purposes. Chlorination, UV technique, membrane techniques are mainly required for pathogen removal. However, Total organic carbon should be checked before injecting chlorine to avoid formation of disinfection byproducts which causes cancer.
5. Turbidity is high, which needs to be reduced to improve the water quality ionic components by chemical treatment, and ion exchange techniques.

6. Some trace metals such as Zinc, lead, Chromium, Cadmium, Cobalt, and Boron have been detected, which may be a alarming signal for future water management. Chemical treatment, activated carbon, coagulation, ion exchange, and membrane techniques should be applied.
7. Non-point source pollution is entering in Hanusa nala as return flow. Nitrate is increasing in the downstream. It needs to be removed by chemical treatment to avoid diseases like "blue baby".
8. Regular monitoring of highly toxic variables needs to be done and water quality management should be applied properly.
9. Water quality models developed in the present work are very useful to estimate chemicals, heavy metals, coliform, physical parameters, nutrients, organic matter, etc. at downstream station with high accuracy and correlation statistics.

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