HYDROCHEMICAL STUDIES IN UPPER HINDON BASIN, DISTT. SAHARANPUR, U.P., INDIA

A THESIS

submitted in fulfilment of the
requirements for the award of the degree
of
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in
APPLIED GEOLOGY

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A.K.Seth

(ASHOK KUMAR SETH)

SYNOPSIS

There is an increasing awareness for the maintenance of water quality especially in urban areas, while attempting to locate new and sizeable sources of water. The quality of natural waters has been affected by man through various activities like channelization, deforestation, industrialization, urbanization as well as agriculture.

The present work was taken up with the aim of studying the chemical characteristics of surface and ground waters of the upper part of Hindon river basin (latitude $29^{\circ}55'$ and $30^{\circ}0'$ N; longitude $77^{\circ}30'$ and $77^{\circ}40'$E) with the following objectives:

- To evaluate the chemical characteristics of surface water of the Hindon river system and of ground water in the basin by using appropriate methods of representing water quality data with the view of assessing the synoptic quality for various specified uses. This also includes the study of the temporal variations in chemical characters of natural waters.
- To identify the major point sources of pollutants and to study their salient quality characteristics.
- To ascertain the impact of biodegradable organics on water quality and the associated DO-BOD relationship.
- To study the adsorption of selected toxic metals on the sediments of the area.

The area of study is a part of Indogangetic plain and is located in Saharanpur district, Uttar Pradesh, India. The Hindon river is the main stream which is fed by several rivulets (popularly known as nalas) viz. Nagdeo nala & Dhamola nala. The Hindon river is of perennial nature, only in parts, downstream of its confluence with the Nagdeo nala. It meets the river Yamuna near Okhla in Delhi.

In the vicinity of Saharanpur town, various industries have come up such as those related to the cardboard, paper, dairy products, rubber, steel rolling, electroplating etc. which release effluents into the riverine system. The main effluent discharges are from the Star Paper Mill and the Foremost Dairies which are reported to be about 37,950 KLPD and 2000 KLPD respectively. The chemical analyses of waste effluents of Star Paper Mill and Foremost Dairies show that these wastes are rich in organic substances as reflected by high BOD and COD.

In the course of field monitoring, fourteen sets of surface water and ground water samples were collected from various locations during April,1985 to November,1987. The chemical data of ground water and surface water have been represented on maps by the Stiff's diagram.

The Piper Trilinear diagrams for ground water indicate the dominance of excessive noncarbonate hardness or the carbonate hardness. In ground water and surface water selected trace metals (like Cd^{++}, Pb^{++} and total chromium) show high concentration (0.19

mg/l, 1.96 mg/l and 0.32 mg/l respectively) and thus render the water unfit for drinking purposes at various locations.

An attempt has been made to work out water quality indices for surface water of the area using Horton based procedures. A rating scale has been defined in the range of 100 to 400. The weights were assigned to various water quality parameters in the range of 1 to 5 according to their relative importance; a rating value for each parameter was computed from developed equations. Using the rating value and weight factor for the respective parameters, water quality indices were obtained by taking weighted arithmetic mean.

An ambient water quality index, modified after Inhaber (1975) has also been calculated, for trace metals using subindices for toxic metals, DO, BOD and ammonical nitrogen. The data indicate that the ambient water quality index is in the range of 1.075 to 115.360.

The water quality index profiles along the Hindon-Nagdeo streams indicate that the quality of surface water deteriorates considerably downstream of the outfall of the Dairy waste and Paper Mill waste. In the intermediate stretches, the water quality shows a steady improvement due to reoxygenation. Also, the quality of surface water improves considerably downstream of the confluence of the Dhamola nala with the Hindon river indicating an overall better quality of water in Dhamola nala. Generally, in summer months (May, 1985 and May, 1986) water quality index of surface water is relatively higher than the monsoon months

(August, 1985 and August, 1986) indicating the dilution effects due to rainfall.

The ambient water quality index profiles along the Hindon river and its tributaries are generally similar in nature as the quality profiles based on Horton indices.

The dissolved oxygen sag curves were computed for the surface waters for four periods between September, 1986 - October, 1986 and November, 1987 using DOSAG-I water quality routing model given by the Texas Water Development Board, USA. The computation of BOD and DO involved evaluation of reaeration constant (K_2') from a discretized form of Streeter - Phelps (1925) equation. The values of deoxygenation coefficient (K_1') were calculated from the equation based on the Streeter - Phelps equation and the approach based on Bhargava (1986) which takes into consideration the phenomenon of bioflocculation and sedimentation.

The DO sag curves developed by using K_2' values calculated from Streeter - Phelps based equations show a noticeable disagreement between observed and computed DO curves at some places. In the approach suggested by Bhargava (1986), the computed and observed DO curves exhibit fairly close agreement at most of the locations. The Root Mean Square error between observed and computed DO values in the first approach is also somewhat higher than calculated for DO sag curves computed by the Bhargava's approach.

The DO sag curves for Dhamola stream show higher DO levels as compared to Hindon - Nagdeo stretches indicating thereby better organic quality of the Dhamola waters. This fact is also corroborated by the continuing rise in dissolved oxygen downstream of confluence of Dhamola with the Hindon river.

An attempt has also been made to study the distribution of heavy metals (viz. lead, zinc and manganese) in the river bed sediments for determining the sorption behaviour of freshly deposited sediments. The sediment samples were collected close to the waste outfall locations. A background sample was also collected from the nearby place for comparision purposes. Batch studies were performed for the determination of optimum pH and sediment dose for the adsorption of metal ions. Adsorption experiments with varying adsorbate concentration were run to study the behaviour of isotherm by applying Langmuir and Freundlich models.

The various parameters, for the three metal ions as obtained from Langmuir and Freundlich models, do not show any particular gradation. The maximum adsorption values obtained in the laboratory are quite different from those calculated on the basis of above models. These models do not hold true for the entire concentration range of the adsorbates studied, which may be a reason for the above mentioned disparity.

The analytical data of two metal ions (Pb^{++} and Zn^{++}) in water and sediment show good correlation, both being in relatively high concentrations.

It appears that metal content of the aqueous discharge is taken up by the sediment and presently the chances of the reverse process seem to be remote. In terms of pollution, the risk from the discharged water is much less in comparison to the sediments which in course of time may start transporting the toxic metals to nearby areas.

The present study has brought out the quality characteristics of the surface water and ground water in the upper Hindon basin in terms of the conservative and degradable constituents. The spatial and temporal variations in water quality due to waste outfalls from dairy and paper industries on the stream water have also been highlighted.

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CHAPTER-1

INTRODUCTION

There is now an increasing concern for the maintenance of water quality while attempting to locate newer and larger sources of water. The quality of natural waters has been affected by man through damming, channelization, addition of various inorganic and organic chemicals and other activities.

The lotic and lentic waters may acquire in space and time respectively, certain quality characteristics due to natural or man made interaction. These acquired quality characteristics may render the water unfit for a particular use. It is not possible to keep the water bodies in pristine or at even an uniform quality throughout the entire stretch of lotic waters body. However, it is necessary that the various stretches of water bodies are maintained at the characteristic quality level which will sustain the respective uses of the stretches. It is possible to accomplish the above objective by controlling pollution caused by human activities. In order to identify the areas requiring such control, the traditional organised uses of the various stretches and status of water quality are required to be known.

Urban settlement and growing industrial production, combined with rapidly increasing demand for water, are causing water management problems. One of the most important of these is the contamination of surface water with solid and liquid wastes, and with waste water and sludge where domestic sewage consisting of organic components is mixed with different types of liquid industrial waste with a variety of origins (UNESCO, 1974).

Ninety six percent of water pollution problems in India are due to indiscriminate discharge of municipal wastes (Chaudhary, 1981). These wastes being biodegradable produce a series of directional but predictable changes in water bodies. Industrial effluents are responsible for pollution to a lesser extent but the effects produced by them may be more serious as nature is often unable to assimilate them.

Agriculture, can also be responsible for degrading the surface water bodies by generating runoff from animal husbandry units which contain predominantly organic components from the use of mineral fertilizers and chemical pesticides.

The upper part of the Hindon river basin in Saharanpur District, Uttar Pradesh, India, has a number of industries related to paper, milk products, distillery and many small scale cottage industries related to electroplating, paper board, chemicals and rubber etc. The waste effluents generated from these industries are released on the lowlands and tributaries of the Hindon river system passing through the area. Much of these wastes apparently contaminate the receiving waters as can be felt from the foul smell and unaesthetic colour especially in the stretches to the downstream of the outfalls of waste effluents.

The modern practice of waste disposal by sanitary landfills has not yet gained necessary momentum in the developing countries like India. Thus, the leachate resulting from the wastes and the effluents may find their way into the subsurface formations, thus contaminating the ground water. Also, due to the visible deterioration in the quality of the surface waters in the Hindon basin, it is suspected that various influent streams might also contaminate the ground water in their vicinity.

In view of the above observations, it is of interest to study the pollutional characteristics of the major waste effluents in Hindon river basin, and their impact on the quality characteristics of the surface water and ground water in the area. As Saharanpur is one of the major town in the upper part of the Hindon basin, it may be rather easy to compare the effects of the contamination of natural waters in the area with that of the background pollution, if any, from induced or geological factors.

1.1 THE STUDY AREA

The area under study is a part of the Indogangetic plain and lies in the upper part of Hindon basin, bounded between latitude $29^{\circ} 55'$ and $30^{\circ}0'$ N and longitude $77^{\circ}30'$ and $77^{\circ}40'$ E (Fig. 1.1). The area is located within Saharanpur district of Uttar Pradesh (India) and is included in the Survey of India topographic sheets $53\frac{G}{g}$ and $53\frac{G}{10}$ on the scale of 1:50,000. The investigated area is about 510 sq.km. The study is confined to a stretch of Hindon river system in between Gagalheri and Maheshpur villages (Fig. 1.1).

The climate in the Hindon basin is of moderate to subtropical monsoon type. Thus, there exists a well marked seasonal variation in precipiation, temperature, and relative humidity. The average annual monsoon rainfall in Saharanpur town is 886 mm and the temperature variation is from 8°C in winter to 40°C in summer. The drainage of the area comprises of the Hindon river which is an ephemeral river flowing towards south. The river finally meets the Yamuna river (a tributary of the river Ganges) near Ghaziabad (Latitude 28° $28'$ N) outside the study area. In the area of study, the Hindon river has two perennial tributaries viz. Nagdeo nala* and Dhamola nala which join the Hindon near Ghogreki and Sadauli Haria villages respectively (Fig. 1.1).

The soil is of alluvial type deposited by Hindon river system. Lithologically it consists mainly of clay, silt and fine to coarse sand. The soils are very fertile for growing wheat, sugar cane and vegetables. However, along the sandy river course, fruit orchards are also common.

1.1.1 Regional Geology

The area under study is a part of the Gangetic plain, which has been divided into the following three belts (Taylor, 1959; Krishnan, 1967).

1) Bhabhar belt
2) Terai belt
3) Alluvial plain.

The geological succession of the region with their sub-surface lithology is given in Table 1.1.

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* A 'nala' is a vernacular word meaning a rivulet, which may be tributary to a stream or river.

Table 1.1: Geological Succession in Ganges Plain (After Taylor, 1959)

	Plain and foot hills of area	Lithology
Recent	Bhabhar deposit	Alluvial fan deposit, essentially consisting of sand and gravel-beds with cobbles and boulders.
	Terai deposit	Clay, sandy clay, and sand with gravels and pebbles.
	Gangetic alluvium	Sand, silt, clay and Kankar with gravel beds.

i) Bhabhar Formation

In the foot hill region of the Himalaya, the hills are fringed towards the south by talus fans. The upper portion of talus fans is composed of rock fragments, gravel and soil, which support thick forests. This zone known as the Bhabhar, has a thickness of about 200 m. The Bhabhar formation is chiefly made up of unconsolidated boulders. The zone is characterised by steep ground slope and deep water table lying between 5 to 37 m depth below the ground surface. The southern limit of the Bhabhar generally forms a spring line which also defines the northern limit of the Terai tract (Taylor, 1959).

ii) Terai Formation

The Terai tract lies immediately south of the Bhabhar zone. It is a transition zone between the Bhabhar and the Alluvial plain. It is composed of alternate layers of clay and sand often having marshy conditions covered with grass and thick forest.

In the Terai, ground slope varies from mild to steep and the water table is at very shallow depth. The width of the belt varies from 5.5 to 8 km.

iii) Alluvial Plain

Barring a northern peripheral zone, the study area lies in the alluvial plain, which is almost a level country with gentle slope from NW to SE. Lithologically, the Gangetic plain has thick alluvial deposits consisting of unconsolidated deposits of sands, clay and Kankar.

1.2 PREVIOUS WORK

Little published work is available about surface water and ground water quality and evaluation of pollutional characteristics of wastes released in Hindon Basin close to Saharanpur area.

An early work on the geohydrological studies of Saharanpur area was done by Rao (1965). Verma and Mathur (1971) conducted studies on characteristics and pollutional effects of paper mill wastes on the Hindon river. A significant amount of work has been done on the pollution of Hindon river in relation to fish and fisheries by Verma et al., (1980). They concluded that quality wise, the water of Hindon is not suitable for propagation of fish culture and related aquatic life. Goel (1983) has studied the pollutional effect of cadmium on natural waters in parts of Uttar Pradesh. He has reported cadmium concentration of 1 μg/lit in river Yamuna around Saharanpur area. Handa (1983) has studied pollution of natural waters by industrial waste effluent in some parts close to Hindon river where high values of lithium, strontium, zinc and cadmium have been reported. Kumar (1983) has estimated the pollutional effects of lead on natural waters of Uttar Pradesh. He has reported a concentration of 15 ug/lit (0.015 mg/l) in Saharanpur area. Patel (1985) has carried out hydrochemical studies of natural waters with reference to the waste effluent disposal in the upper part of Hindon basin in Saharanpur area.

A review of the previous literature related to the upper Hindon basin indicates that systematic and integrated hydrochemical studies of surface water and ground water in the area have not been attempted. The effect of biodegradable organics on the waters of the above river system is also not described in the published work. As such, comprehensive idea about the quality and chemical character of natural waters in the area is not available.

1.3 NATURE AND SCOPE OF PRESENT STUDY

The present work aims at evaluating the chemical characteristics of surface water of Hindon river system and ground water with the following objectives:

- To ascertain the chemical character of surface water and ground water of Hindon river system by using appropriate methods for representing water quality data with the purpose of assessing the synoptic quality for various specified uses. This also includes study of the temporal variation in chemical character of the natural waters.

- To identify and report the major point sources of pollutants and to study their salient quality characteristics.
- To ascertain the impact of biodegradable organics on water quality, and DO-BOD relationship.
- Adsorption study of selected toxic metals like lead, zinc and manganese on the sediments of the area.

In Chapter 2, major point sources of waste effluents in the area have been studied and their salient degradable and nondegradable constituents monitored. These have given a comprehensive idea of pollutant loads in the surface water. For the sake of comparison, background values of the chemical constituents were also considered.

In Chapter 3, the procedures for hydrological and chemical monitoring of surface water and ground water at the prespecified sample locations have been outlined. The existing methods of chemical analysis have also been briefly reviewed.

In Chapter 4 entitled 'Representation of Water Quality Data & Interpretation' the results of chemical analysis for conservative and non-conservative constituents including selected toxic elements have been given. The spatial and temporal variations of these characteristics have also been discussed. The methodology for the development of water quality indices with the aim of an overall assessment of water quality has been outlined. An attempt has also been made to develop the water quality indices for surface water of the study area.

In Chapter 5 entitled 'DO-Sag modelling', an attempt has been made to examine the relationship between the dissolved oxygen and biochemical oxygen demand of surface waters of a part of the Hindon river. The relationship between BOD and COD of these waters wherever polluted by different kinds of waste effluents has also been evaluated. An attempt has also been made to compute the DO levels of river waters by using experimental values of deoxygenation and reaeration coefficients and the BOD data.

In Chapter 6, the results of metal sorption study of sediment in the vicinity of Hindon river, at selected locations for Pb^{++}, Zn^{++} and Mn^{++} have been described. Different parameters which influence the sorption of these metals in sediments have also been evaluated.

Chapter 7 gives a summary of the major findings and important conclusions and recommendations for further work.

CHAPTER-2

CHARACTERISTICS OF INDUSTRIAL WASTES

2.1 INTRODUCTION

The human activities combined with changes in land use like urbanisation, deforestation, agriculture and mining practices greatly influence the quality of natural waters. The influence of urbanisation on the water quality depends mainly on the nature of generated industrial effluents, domestic sewage, contamination of rainfall due to air pollution in cities, and the pollution of surface runoff from the urban areas. Hall (1984) suggested that more marked changes in water quality may occur within the land phase of the hydrological cycle. Lazaro (1979) opined that in addition to the background pollution derived from natural and geological origin, the sources of pollution may be classified into: Non-point sources and Point sources: Point sources enter the stream at discrete and identifiable locations. They usually can be directly measured and their impact can be assessed. The non-point (Diffuse) sources of pollution cannot be pin pointed and are often in the form of release of wastes through overland runoff resulting from rainfall. Major point sources include effluents from industries and municipal waste water discharges. The examples of non-point sources are sediments or acid mine drainage or urban runoff (Whipple, 1976).

As major industries in the study area are concerned with paper and pulp, dairy products, distilleries and others, it is necessary to review the existing literature on characteristics of the related waste effluents.

2.2 CHARACTERISTICS OF WASTE EFFLUENTS FROM DAIRIES, PAPER AND PULP MILLS AND DISTILLERIES

Waste waters in dairy industry originate from equipment washing, product spillage and losses. The dairy waste is a dilute solution or suspension of decomposable organic matter. The wastes include buttermilk and milk plant washings containing constituents of milk such as protein, lactose, a small quantity of fat plus mineral constituents of milk, and traces of sanitizers and detergents used for cleaning and sanitization of dairy plant equipment. The general range of BOD in dairy wastes is 500mg/kg to 1680 mg/kg (Eckenfelder, 1970). Nemerow (1971) reported that milk plant wastes are generally high in dissolved organic matter, contain around 1000 mg/l BOD, and are nearly neutral in pH. Since these wastes are mainly composed of soluble organic materials, they tend, if stored, to ferment and become anaerobic and emit odour.

The high concentration of organic matter especially of the carbohydrate, lactose and the temperature ideally suited for the bacteria make the dairy waste a heavy burden on the DO balance of most streams and even on sewage treatment plants (Raoand Subrahmanyam, 1972). Rajgopalan (1972) pointed out that in dairies which produce a variety of milk products such as butter, cheese, milk powder, condensed milk and casein etc. the waste-waters are relatively more concentrated and contain high amounts of organic matter (BOD), suspended solids and fat. The dairy wastes also contain sodium as predominant inorganic constituent which is derived from common salt and alkaline cleansing agents used in dairies. Vandamme and Waes (1980) studied chemical characteristics of dairy plant waste-water and related it to the milk quantity, milk loss, and water consumption. It was concluded that dairy wastes are rapidly and easily treated biologically because the BOD:COD ratio was found to be 0.63 and the BOD:N:P ratio 100:5.4:0.9.

The characteristics of paper and pulp wastes depend on the type of pulping process used. The U.S. Public Health Service (1943) has given typical analyses of all types of pulp and paper wastes. Gehm (1953) presented general characteristics of wood wastes and the chemical effluent from modern Kraft (sulphate) mills. Moggio (1954) stated that present day Kraft mills, if efficiently operated, discharge an effluent containing no more than 100 pounds of Na_2SO_4 equivalent of the cooking liquor per ton of pulp. The effluent characteristic varies somewhat, depending on the bleaching practices; suspended solids range from 20 to 50 ppm and are primarily fibers (about 0.5 percent of the total product);dissolved solid concentrations range from 1000 to 1500 ppm of which about 60% is ash. The BOD values range from 100 to 200 ppm. Dhaneshwar et al. (1970) studied the characteristics of effluents from pulp and paper mill located on the Hooghly river in West Bengal (India). The composite effluents being disposed from the mills were found to contain high BOD,COD and lignin. Pollutional characteristics of the composite effluents from these mills included depletion of dissolved oxygen, objectionable odour and colour due to lignin, the formation of bottom deposits and formation of slime and foam. Hutchins (1979) reviewed the literature relative to toxicity of pulp and paper mill effluents. Although untreated effluents may be toxic to aquatic life in low concentrations, treatment can reduce or eliminate toxicity.

Rajaman and Oblisami (1979) have studied the environmental pollution due to paper industry in the rural areas of Tamil nadu, India. The nature of the combined effluent samples being disposed off from the factories were alkaline and contained large amount of suspended and dissolved solids resulting in the high concentration of BOD and COD. The contents of carbonates were high in one paper mill effluent whereas the calcium, magnesium and chloride concentrations were high in the other paper and board mill effluents. Gosh and Konar (1980) mentioned that the important chemicals used by most of the paper and pulp mills are sodium sulphate, sodium hydroxide, sodium sulphide, sodium carbonate, calcium hypochlorite and magnesium bisulphite. Obviously, waste waters which contain various amounts of these chemicals may be hazardous to aquatic life. Claeys et al. (1980) summarized the chemical characteristics of untreated bleach plant effluent and some of the biological effects in aquatic environment caused by bleach plant effluents that have not received biological treatment. Studies conducted with fish in manmade streams receiving high concentrations of treated bleached paper mill effluent have not yielded measurable adverse effects. Rao and Rao (1985) described the chemical characteristics of effluents in

Bhadrachalam area of Andhra Pradesh and reported high values of sodium concentration in these paper and pulp mill wastes.

Nemerow (1971) pointed out that the effluents from distilleries contain large amount of decomposed dissolved organic matter. The matter is decomposed by biological action. Rao and Viraraghavan (1985) reported that the effluents from distilleries are characterized by high BOD (40,000 to 50,000 mg/l), low pH (3.5 to 4.5), high dissolved solids (70,000 to 80,000 mg/l), high levels of sulphates (4000 to 8000 mg/l) and considerable amount of potassium (8000 to 12000 mg/l). Thus, distillery effluent resulting from cane molasses based alcohol industry is one of the highly polluting industrial effluents.

The character and nature of wastes from electroplating industries vary considerably,depending on plating requirements and type of rinsing used. The total plant waste may be either acidic or alkaline, depending on the type and quantity of bath used (Nemerow, 1971).

2.3 CHARACTERISTICS OF WASTE EFFLUENTS IN STUDY AREA

The notable industries in the Upper Hindon basin may be categorised as under:

Major Industries:	Foremost Dairies, Star Paper Mill, Co-operative Company Ltd. (Distillery)
Small Scale Industries	Paper Board, Steel Rolling, Rubber, Chemicals and Electroplating

A list of notable industries with nature and characteristics of effluents released from them is given in Table 2.1.

Table 2.1 : List of Industries

Location on Map	Name of Industrial works	Name of the Drain in which Effluents are being Discharged Directly or Indirectly	Distance (approx.) between industry location to stream	Product from Industry	Nature of Raw Material Used & Processed	Nature of Effluent Waste/ Amount of Discharge	Colour and Appearance of Effluent	Whether Effluent Pretreated
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	Foremost Dairies Ltd., Kailashpur, Saharanpur	Nagdeo Nala	1.25 km	Ghee, Milkpowder Spices	Milk	Acidic/2000 KLPD	Milky	Out of 10 drains only one drain is partly treated
2	Jamuna Rubber Industries Kailashpur Saharanpur	Nagdeo Nala	1.25 km	Rubber Belt and Chappals	Raw Rubber (Sulphur, Iodine, Zinc-Oxide etc.	25 lit/hr.	Brownish Black	No
3	Anand Drinks(P)Ltd., Kailashpur, Saharanpur	Nagdeo Nala	1.5 km	Campa Cola	-	-	-	No
4	Gambhir Paper & Board Mill, D.Dun Road, Saharanpur	Nagdeo Nala	1.5 km	Gatta (Rough, Paper)	Waste Paper (KOH,NaOH)	Alkaline	Light Brown	No
5	Kristan Engg.(P) Ltd., D.Dun Road, Saharanpur	Nagdeo Nala	750 m	Steel Tanker	Scrap Iron	No Liquid Discharge (Solid Waste)	-	No
6	Saharanpur Leather Board & Tannery(P) Ltd., Saharanpur	Nagdeo Nala	500 m	Leather Sheets	Waste Leather, KOH, Oil, Latix	30 lit/hr.	Whitish	No
7	Rana Steel Rolling Mills, Saharanpur	Nagdeo Nala	400 m	M.S.Rod C.T.D.Bar	M.S.Ingot, Coal, Black Crude, Oil (Rerolling)	No Liquid Discharge	-	No
8	Dainy Dairy & Food Engineers(P)Ltd., Saharanpur	Nagdeo Nala	400 m	Steel Tanker	-	-	-	No
9	Sidh Solvent Extraction(P).Ltd., Saharanpur	Nagdeo Nala	200 m	Various Oils & Extracts	Rich Bram Mahua Cake Neem Cake (KOH, NOH, Soda & Tri-Sodium Phos-Phate)	25 lit/hr.	Oily Brown	Treatment through Dilution Process (Septic tank)
10	Kamdhenu Paper & Board Mill(P)Ltd., Saharanpur	Nagdeo Nala	100 m	Gatta	Waste Paper	Alkaline 35 lit/hr.	Light Brown	No

(Contd......)

(Contd....) Table 2.1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
11	Shakti Straw Board Mill, Saharanpur	Padli Nala	100 m	Gatta	Wheat Husk & Paper Waste	Alkaline 60-70 lit/hr.	Light Brown	No
12	Bhagwati Paper & Board Mill, Saharanpur	Padli Nala	150 m	Gatta	Waste Paper	Alkaline 30-40 lit/hr.	Light Brown	No
13	Kamdhenu Feeds (Cattle & Polutry Feeds) Saharanpur	Padli Nala	300 m	-	-	-	-	No
14	Saharanpur Iron, Indu., Saharanpur	Padli Nala	2 km	Steel Product	Scrap Iron	Only Solid Waste Produced	-	No
15	Rakesh Chemical Pvt., Ltd., Saharanpur	Dhamola Nala	3 km	Calcium Carbonate	Marble Stones	150 lit/hr.	Brown	No
16	Co-operative Co., Ltd., Distilleries Nawabganj, Saharanpur	Dhamola Nala (through Municipal drain)	1 km	Country Liquor	Molasses (Fermentation Process)	Alkaline 140 KLPD BOD=40,000	Light Brown	Spent wash is diluted with water after treatment BOD = 14,000 mg/l
17	Mahendra Board & Paper Mill, Jawaher Park, Saharanpur	Pandhoi Nala	100 m	Gatta	Waste Paper	Alkaline 100 lit/hr.	Light Brown	No
18	Talwar Tyres Near Dhobi Ghat ,Saharanpur	Pandhoi Nala	200 m	Cycle Tyres	Raw Rubber, Calcium Carbonate, Black Chine Clay, Zinc, Oxide Stearic Acid, Sulphur etc.	500 lit/hr.	Brown Black	No
19	Diamond Rubber Industries, Delhi Road Saharanpur	Dhamola Nala P.W.D.Drains	4 km	Rubber Belts	Raw Rubber (Auto-oxidant Peptinzing derivatives of $CaCO_3$)	500 lit/hr.	Light Brown	No
20	Star Paper Mills Saharanpur	Hindon Nala	2½ km	Paper	Wood Pulp, Jute Sticks	Alkaline 3,50,000 gallons/day	Brown	Partly treated

Verma et al. (1980) have listed the amounts of daily pollutional load disposed off in the Hindon river from various wastes effluents, including dairy and paper-pulp wastes.

2.4 FOREMOST DAIRIES

The effluent from the foremost dairies is milky white in colour. The amount of discharge is reported to be about 2000 KLPD,(Kilo litre per day). The discharge from the factory is released into nearby Nagdeo nala at a distance of 1.25 km through covered pipes. The results of the laboratory analysis of waste water (before treatment) indicate that these waste waters have high organic content in the form of BOD and total suspended solids. In addition, the waste water also exhibits high content of phosphorus, oil and grease. (Verma et al., 1980).

Partly treated waste effluent from this factory has been analysed in the present study for the period of May,1985 to Nov.,1987 and the salient characteristics are given in Table 2.2.

From this table it is observed that BOD values of the effluent range from 35.2 mg/l to 228.5 mg/l whereas the COD values are in the range of 34 mg/l to 680 mg/l. The DO is in the range of 0.0 to 0.9 mg/l, indicating low DO levels.

The pH of the dairy effluents lies between 7.1 to 9.1 indicating its alkaline nature. The TDS has a range of 288 mg/l to 800 mg/l. The maximum value of ammonical nitrogen 1.2 mg/l in summer and zero in winter was recorded in the dairy wastes. The high values of this constituent are indicative of recent

Table: 2·2 : Chemical Characteristics of Effluent from Foremost Dairies (May, 1985 to November, 1987)

Periods	pH	T.D.S.	Total Alkalinity	Ammonical Nitrogen	BOD	COD	DO	S^{--}	SO_3^{--}	Trace Elements			Na^{++}	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	K^+
										Cd^{++}	Pb^{++}	Total chromium						
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
May '85	7.1	358	272	1.2	51.3	180	1.4	N.D	N.D	0.000	N.D	0.000	19.20	116.00	9.36	60	271.7	4.2
Oct. '85	7.5	288	146	0.0	36.0	133	0.3	N.D	N.D	0.004	0.00	0.040	13.70	35.30	38.50	16	145.7	3.7
Jan. '86	7.4	470	404	1.0	41.0	131	1.8	N.D	N.D	0.003	0.29	0.142	36.00	46.24	86.94	20	403.0	5.0
March '86	7.2	546	220	0.5	60.0	222	0.0	N.D	N.D	0.000	0.00	N.D	25.00	40.00	36.00	16	219.5	5.0
May '86	8.3	418	120	0.01	35.2	34.0	2.9	2.4	22.12	0.000	0.16	N.D	49.77	45.36	18.12	22	117.7	6.7
Aug. '86	7.7	526	120	0.03	74.3	102	0.9	3.2	26.86	0.007	0.11	N.D	25.98	36.96	16.42	112	119.4	1.7
Nov. '87	9.1	800	152	1.0	228.5	680	0.0	3.2	37.92	0.026	0.18	N.D	29.15	59.00	6.07	20	135.9	2.9

pollution of the surface waters (Sawyer and McCarty, 1977). The sulphide and sulphite content varies from 2.4 mg/l to 3.2 mg/l and 122.12 mg/l to 37.92 mg/l respectively. Some of the trace elements like Cd^{++}, $Pb^{++}$and total chromium are higher than the safe prescribed limits for release of effluents into surface drainage (ISI, 1981). The values of Na^{+} + K^{+} lie between 13.70 mg/l to 49.77 mg/l.

2.5 STAR PAPER MILL

The effluents from the Star Paper Mill, utilising Kraft process, are dark to light brown, green or yellow in colour and have pungent or irritating smell depending upon the nature of washing. They are highly alkaline in nature. The dissolved solids are higher than suspended solids. The BOD and COD is high and contains enough amount of lignin. The effluents are discharged through a covered drain into the Hindon river. The effluent discharge from the mill amounts to 37, 950, KLPD(kilo litre per day) as per Verma et al. (1980) who also gave data on the physico-chemical characteristics of the combined wastes from the Star Paper Mill. They found the waste to be having high total alkalinity, suspended solids, TDS, BOD and COD .

In the present study, it has been observed that the effluents from the Paper mill have high concentration of organic matter and dissolved solids resulting in high BOD and COD and low value of dissolved oxygen but the total alkalinity is not that high. The results of the laboratory analyses of the Star Paper Mill effluent for Oct.1985 to Nov.1987 are given in Table 2.3.

Table: 2·3: Chemical Characteristics of Effluent from the Star Paper Mill (October, 1985 to November, 1987)

Periods	pH	T.D.S.	Total Alkalinity	Ammonical Nitrogen	BOD	COD	DO	S^{--}	SO_3^{-}	Trace Elements			Na^{++}	Ca^{++}	Mg^{++}	Cl^{-}	HCO_3^{-}	K^{+}
										Cd^{++}	Pb^{++}	Total chromium						
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Oct. '85	7.4	282	261	1.0	320	1360	1.5	N.D	N.D	0.000	0.42	0.109	33.40	28.60	82.60	120	260.4	3.40
March '86	7.1	1248	330	0.3	80	470	0.0	N.D	N.D	0.015	0.20	N.D	70.00	32.00	31.00	104	329.6	20.00
May '86	9.1	1052	233	0.3	105	424	0.0	2.4	39.50	0.076	0.58	N.D	49.12	62.16	37.56	155	208.3	16.72
Aug. '86	7.2	746	100	0.3	44	235	0.6	2.4	30.02	0.000	0.00	N.D	49.91	79.80	43.86	80	99.7	7.51
Nov. '87	8.0	515	388	0.2	109	480	0.0	1.6	72.68	0.034	0.64	N.D	65.60	144.50	15.25	168	384.3	5.00

Lately, occasional pretreatment of disposed effluents from the Paper mill is reported to have commenced, thus reflecting variation in its composition.

As can be seen from the above table, the BOD of the Paper Mill effluent varies from 43.8 mg/l to 320 mg/l and COD from 235.2 to 1360 mg/l. The DO is in the range of 0.0 mg/l to 1.5 mg/l. The maximum value of DO (1.5 mg/l) was in Oct. 1985 and minimum (0.0 mg/l) in May 1986, August 86 and Nov, 1987 thus indicating the severe depletion in DO levels. The value of pH varying from 7.1 to 9.1 indicates that the effluent is alkaline. The TDS is high in the month of March, 1986, with its range varying from 282 mg/l to 1248 mg/l. The range of the ammonical nitrogen is 0.3 to 2.0 mg/l, sulphide and sulphite are found in the range of 1.6 mg/l to 2.4 mg/l and 30.0 mg/l to 72.7 mg/l respectively in paper mill effluents. The amount of $Na^+ + K^+$ lies between 33.4 mg/l to 70.0 mg/l. The sources for these substances seem to be the chemicals used in the pulp and paper manufacture, viz., sodium sulphate, sodium sulphite, sodium sulphide, sodium carbonate, calcium hypochlorite and magnesium bisulphate etc. As seen from table 2.3, the value of lead is higher than the prescribed safe limits for release of effluents (ISI : 2490, 1981).

2.6 DISTILLERY

The effluents from distillery units which contain large amounts of dissolved solids, organic matter, are decomposed by biological action and are discharged into the Dhamola nala through covered municipal drains. As the effluents are disposed through covered drains, it has not been possible to collect the samples at disposal points.

2.7 ELECTROPLATING UNITS

There are several small scale electroplating units in the study area. In electroplating, the metal acts as the cathode while the plating metal in solution serves as the anode. The total liquid wastes are not voluminous but are extremely dangerous because of their toxic contents. The most important contaminants are acids, metals such as Cr, Cd, Pb, Ni, Sn, and Cyanides. Alkaline cleaners, oil and grease are also found in these wastes. The wastes generated by these units are directly disposed into nearby drains which carry the pollutant directly into the Hindon river system.

CHAPTER-3

MONITORING OF WATER QUALITY

3.1 INTRODUCTION

Water quality monitoring is a process to obtain quantitative information on the physical, chemical and biological characteristics of water through statistical sampling (Sanders et al., 1983). The types of information depend upon the objectives of the monitoring which range from detecting extreme values of chemical constituents in water to determine temporal water quality trends. Currently, water quality monitoring refers to most types of water quality sampling or measurement.

The quality of natural waters in an environment is a result of two primary causal mechanisms :

(1) the activities of society, and

(2) the natural hydrologic cycle.

Therefore, water quality management in any society must deal with both the events though it attempts to control only one i.e. the activities of the society (Sanders et.al., 1983). Two major aspects should be considered in quality monitoring:

1) monitoring purpose,

2) monitoring activity.

An overall perspective of the system must be kept in mind in order to integrate the new purposes and activities into the existing monitoring framework and develop an efficient and effective monitoring system.

There are many ways by which monitoring activities could be categorized. The approach chosen can be to broadly divide the activities into 'Data Acquisition and Data Utilisation'. Both of these are important for the effectiveness of a total monitoring system.

3.2 SAMPLING IN RECEIVING WATER BODIES - A REVIEW

Sampling is the first of a series of steps leading to the generation of water quality data (Wilson,1982). For a programme of this type, careful selection of sampling locations is required. Quality varies from place to place within most, if not all,water systems, so that any one sampling location is not representative of the appropriate system.Therefore, locations appropriate to the information needs of a particular programme must be selected. Clark et al. (1977) have described the different types of samples viz.

1) Representative samples,
2) Grab samples,
3) Composite samples,
4) Integrated samples.

Montgomery and Hart (1974) have suggested that samples should whenever possible, be collected from a position at least 30 cm above the bottom of the stream, and a similar distance below the surface will usually be satisfactory. An alternative approach is to sample continuously while the intake of the sampling device is moved from near the surface to near the bottom of the river and back again (Welborn and Skinner, 1968).

The factors involved in proper selection of sampling sites are : objective of the study, accessibility, flow, mixing and other physical characteristics of the water body, chemical source locations and logistic facilities available to conduct the study. Velz (1970) pointed out that the major factors influencing the location of sampling station are the relative position of waste effluent outfall, the channel characteristics, river developments, and self purification character of the river. Nemerow (1963) recommended that sampling stations for collection of water samples in stream should include the following:

(a) upstream site where water is clean,

(b) stream just below the source of pollution or dilution

(c) stream at worst condition due to a specific source of pollution.

Florcyk (1971) and ORSANCO (1976) selected sampling points for their studies by locating points along the length of a stream at which relevant quality parameters were found by experience to be considered along the cross-sections. Ward and Vanderholm (1973) located sampling stations at critical quality points in reference to each source of pollution. Velz (1950) indicated that samples should be taken at some distance downstream where dispersion throughout the section has been reasonably complete. The problem of sampling position can arise in many types of water systems particulary those in which water is flowing in a channel or pipe. The problem is often acute when receiving water bodies (river etc.) are to be sampled. The lateral and vertical mixing of an effluent or tributary with main river can be rather slow particularly if the two waters being mixed differ appreciably in temperature. Thus, a uniform cross sectional distribution of quality may be obtained only after a considerable distance downstream of the confluence (Wilson, 1982).

The choice of sampling frequency seems often to be based on either subjective considerations or the amount of effort available for sampling and analysis. Nemerow (1963) pointed out that the samples should be collected frequently as is necessary to provide a well composite total sample. Eckenfelder (1970) suggested low flow period as the suitable season for sampling for the purpose of D.O. Sag water quality routing.

Nemerow (1974) has outlined the various aspects related to stream sampling, viz. location, number and intensity of sampling, sampling in relation to source of pollution and tributaries, sampling in relation to physical characteristics and river developments and sampling in relation to waste discharge practices. He has also discussed the influence of unusual and discontinuous stream condition and number of samples to be collected.

A network of monitoring stations is necessary to identify stretches where existing water quality is at variance with water quality criteria required for the perpetuation of the designated best use. Water quality data help to ascertain the extent of the requirement of pollution control measures. When such control measures are in implementation and effectively maintained, water quality data also indicate the progressive improvement in water quality status along the reach of water bodies (Chaudhary, 1981).

3.3 SAMPLING PROCEDURES

The term sampling procedure often refers to a routine technique that is used to obtain water sample of interest. For many applications concerned with natural waters, no special sampling system is required. It is often sufficient simply to immerse a container so that it fills with water, which may then be poured into appropriate sample containers.

When it is required to sample from depth that prevent the use of this simple technique, special containers are available for lowering into the water and obtaining a sealed sample from a chosen depth (AWWA 1974; Golterman, 1969). Mancy and Weber (1971) have discussed certain aspects of sampling systems for industrial waste water. Sampling system for natural waters such as river must be carefully selected and installed to avoid blockage of the inlet by debris in water. When sampling from treatment plant and distribution systems and for certain applications for industrial waters, a pipe or tube is inserted into the water of interest so that a stream of sample can be obtained when and where required (British Standard Institution, 1969).

A number of commerically available devices allow a series of samples to be collected automatically (Wilson, 1982). Golterman et al. (1978) have described different types of automatic samplers. Automatic samplers are often easily portable and may be used for any type of water, but they find greatest application in effluent analysis; for example, it is common practice in some countries to collect 24 effluent samples within a period of 24 hours and to prepare one composite sample for analysis.

The desirable practices in sample handling and preservation are given in AWWA (1974).

3.4 ANALYTICAL METHODS

Various methods of analysis of water and waste water for the determination of conservative and non-conservative chemical constituents have been suggested by AWWA (1974). The instrumental methods offer direct yet precise approach for determination of concentrations of various substances in waters. The electrial conductance of waters may be readily estimated from a conductivity meter. There are two methods which are generally used for the determination of pH of the solutions, viz., Methods of pH indicator and Potentiometric. The Atomic Absorption Spectrophotometer (AAS) used for the analysis of metallic elements is very sensitive and accurate than many other analytical procedures used for similar determination. Flame photometry, coupled with simple read out devices also provide high sensitivity and high reliability for the determination of Na^+, K^+, other alkalies and alkaline earths.

3.5 WATER QUALITY MONITORING IN THE PRESENT STUDY

The sampling programme for natural waters in the present study was devised keeping in view the different aspects of various sampling techniques, purpose of sampling, types of samples, site selection, and frequency of sampling. The sampling sites were selected considering the geometry and configuration of the Hindon river and its tributaries and entry points of waste effluents. At places where junction of tributaries (rivulets) of the Hindon river are found, it became necessary to locate sampling points both in the upstream and downstream parts of such confluences, because such an approach would enable to verify the mass relationships with respect to the conservative chemical constitutents present in waters. In view of relatively small depth and width of the river in most stretches and reasonably good mixing, there seemed to be enough justification to resort to Grab sampling technique for the purpose of representativeness. However, in the vicinity of effluent discharges, it was necessary to consider a minimum distance for mixing. At such locations, wherever necessary, Composite sampling along the width of the river was resorted to yield a representative sample of the water.

The total stretch of the study area was sampled in a maximum period of 2 days for one set, with a total of 12 sets of surface water and 6 sets of ground water samples. The periodwise details of sample collection are given Table 3.1 Along with the water sampling programme, stream discharges were also measured in the vicinity of all sampling locations by Area-Velocity Method. The stream velocity was recorded by Float method occasionally cross checked by digital current meter. The locations of 26 sampling sites for surface waters in the study area are shown in Fig. 1.1. For ground water monitoring, the well locations were selected in the vicinity of surface water sampling locations. The ground water samples were collected by Dip sampling method. Samples were

Table : 3.1 Details of Procurement of Surface and Ground Water Samples in the Present Study

Sl. No.	Surface Water Sampling Period	Sl. No.	Ground Water Sampling Period
1.	May - 1985	1.	April - 1985
2.	August - 1985	2.	June - 1985
3.	October - 1985	3.	September - 1985
4.	January - 1986	4.	November - 1985
5.	March - 1986	5.	May - 1986
6.	May - 1986	6.	August - 1986
7.	August - 1986		
8.	November - 1987		
9.	September* - 1986		
10.	January* - 1987		
11.	July* - 1987		
12.	November* - 1987		

* Sampling for
DO - Sag Modelling

collected manually from open wells and were stored in clean plastic bottles fitted. Each surface water sample was collected in five litre polyethylene containers duly sealed for preventing contamination from external sources. In addition, for BOD and DO determination, bottles of 300 ml capacity which can be sealed with long stopcocks were utilised in order to prevent escape of dissolved oxygen and entry of atmospheric gases. For determination of toxic metals (Cd^{++}, Pb^{++} and total chromium), water samples were collected in plastic bottles which were previously soaked and washed with 10% HNO_3 and rinsed finally with double distilled water as recommended in AWWA, (1974).

The water quality monitoring programme was planned in phases depending upon the chemical constituents to be analysed. The procurement of samples was accordingly carried out for determination of parameters as given in Table 3.2. In addition, as seen from Table 3.1, from Sept. 1986 to Nov., 1987 four sets of surface water samples were also collected with a view to develop DO-BOD relationships along the Nagdeo-Hindon and Dhamola streams. For this purpose, only degradable parameters (BOD, DO and COD) were estimated, in addition to the physical parameters like pH and temperature of the water. At selected points of observations along the river course viz. at the confluence of two or more streams, and at major waste outfalls, larger volume of water samples were collected enabling BOD determinations for a period of 2,4,5,8,12,16 and 20 days in order to estimate rate coefficient of deoxygenation (K_1') and ultimate BOD (L_0).

TABLE: 3·2 : QUALITY PARAMETERS MONITORED FOR GROUNDWATER AND SURFACEWATER

PARAMETERS	UNIT
PHYSICAL :	
Temperature (water)	°C
pH	-
Conductivity	micromhos/cm
Total Dissolved solid	mg/l
CHEMICAL :	
Dissolved oxygen*	mg/l
Biochemical oxygen demand*	mg/l
Chemical oxygen demand*	mg/l
Total Hardness (as $CaCO_3$)	mg/l
Calcium (Ca^{++})	mg/l
Magnesium (Mg^{++})	mg/l
Sodium (Na^{+})	mg/l
Potassium (K^{+})	mg/l
Amm. Nitrogen (as N)	mg/l
Nitrate (as N)	mg/l
Alkalinity (as $CaCO_3$)	mg/l
Biocarbonate (as $CaCO_3$)	mg/l
Cadmium (as Cd)	mg/l
Lead (as Pb)	mg/l
Total Chromium (as Cr)	mg/l
Zinc (as Zn)	mg/l
Chloride (as Cl^{-})	mg/l
Sulphide (S^{--})	mg/l
Sulphite (SO^{--})	mg/l
Sulphate (as SO_4^{--})	mg/l

3.6 PRETREATMENT AND CHEMICAL ANALYSIS

It was planned in the present study to carry out most of the chemical analysis in laboratory except few parameters viz. pH, temperature, and electrical conductivity which were determined on the spot in the field. Accordingly, it became necessary to pretreat the water samples with suitable chemical reagents for the purpose of fixation of Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD). For such a fixation, reagents (Viz. Sodium Azide and Manganous Sulphate), as recommeded in AWWA (1974), were utilised.

For the determination of toxic metals, the collected water samples were acidified with concentrated HNO_3 (5 ml per litre of water) to reduce the pH of the sample below 2. Subsequently, each 100 ml of water samples was concentrated by evaporation and digested with concentrated HNO_3. After cooling, it was filtered through 0.63 μm filter paper into 50 ml volumetric flask and the volume was made up by adding double distilled water. It was again transferred to 50 ml. polyethylene bottle and utilised for the determination of heavy metals by Atomic Absorption Spectrophotometer, Model IL 751.

The sequence of planning the monitoring programme, pretreatment and chemical analysis for the present study has been diagrammatically depicted in a flow chart (Fig.3.1). Table 3.3 gives the summary details of the procedures used in chemical analysis of the water samples in the study.

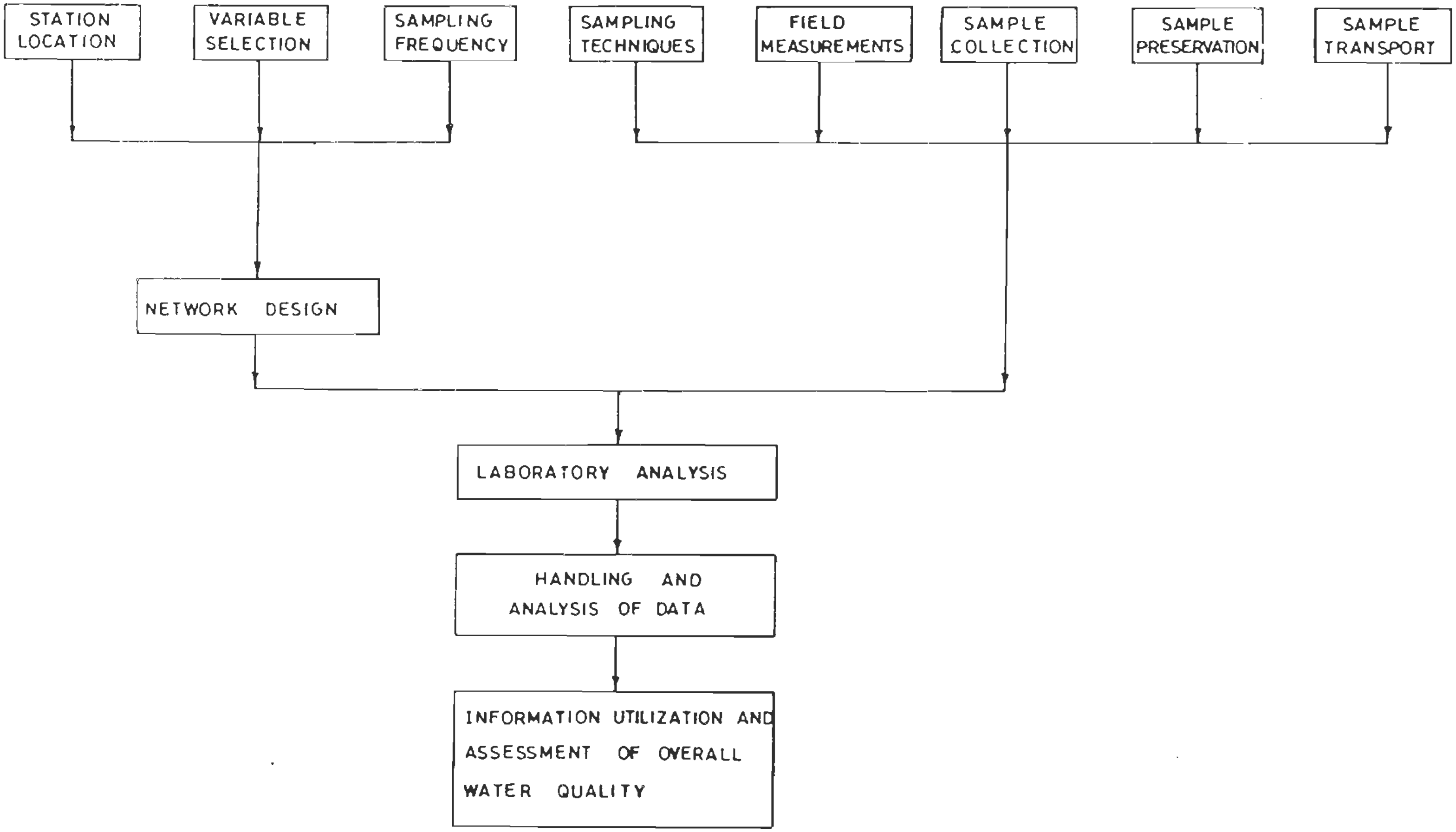

FIG. 3.1 FLOW CHART OF WATER QUALITY MONITORING

Table : 3.3 Procedures of Chemical Analysis and Related Equipment (AWWA, 1974).

Sl.No.	Parameters	Methods	Technique(s) of Analysis
1	2	3	4
PHYSICAL :			
1.	Temperature	Thermometric	Thermometer
2.	pH	pH Meter	Electrometric - Use of Electrodes.
3.	Total Dissolved Solids	Gravimetric	Evaporation of Filtrate at 180°C
4.	Electrical Conductivity	Wheat Stone Bridge	Conductivity Meter
CHEMICAL :			
5.	Dissolved Oxygen(DO)	Titrimetric	Winkler's Method
6.	Bio-Chemical Oxygen Demand (BOD)	Titrimetric	Winkler's Method incubation period 5 days at 20°C
7.	Chemical Oxygen Demand (COD)	Titrimetric	Reflux Method
8.	Total Hardness	Titrimetric	Compleximetric Titration with EDTA (Erichrome black T used as indicator)
9.	Chloride (Cl^-)	Titrimetric	Argentometric Method
10.	Sulphate (SO_4^{--})	Gravimetric	Precipitation by $BaCl_2$ Soln. Ignition of the precipitate at 800°C
11.	Sulfide (S^{--})	Titrimetric	Iodometric Method Titration with 0.025N $Na_2S_2O_3$ using starch indicator

1	2	3	4
12.	Sulphite (SO_3^{--})	Titrimetric	Iodometric Method Titration with $KI-KIO_3$ using starch indicator
13.	Calcium (Ca^{++})	Titrimetric	Titration with EDTA soln. using Mureoxide indicator
14.	Sodium (Na^{+})	Flame Emission	Flame Photometer
15.	Potassium (K^{+})	Flame Emission	Flame Photometer
16.	Alkalinity	Titrimetric	Titration with 0.02N H_2SO_4. Methyl Orange indicator to a pH of 4.5
17.	Amm. Nitrogen	Colorimetric	Nesslerization (Spectrophotometer)
18.	Nitrate Nitrogen	Colorimetric	Phenol Disulfonic Method (Spectrophotometer)
19.	Cadmium (Cd^{++})	Atomic Absorption	Atomic Absorption Spectrophotometer (Using Specific Cathode Lamp)
20.	Lead (Pb^{++})	Atomic Absorption	Atomic Absorption Spectrophotometer (Using Specific Cathode Lamp)
21.	Total Chromium	Atomic Absorption	Atomic Absorption Spectrophotometer (Using Specific Cathode Lamp)

CHAPTER-4

REPRESENTATION OF WATER QUALITY DATA AND INTERPRETATION

4.1 INTRODUCTION

There is now a greater awareness of the overall water quality and various individual parameters comprising it. However, it becomes often difficult for a common man to understand the actual level of water quality as it is expressed in terms of many parameters. It is even more difficult for an environmentalist to express the water quality in simple terms with so many parameters and various modes in which they are present so as to enable a user to understand them easily. It is also difficult to comprehend the analytical data expressed in tabular form, due to its voluminous nature and large number of parameters involved. Therefore, it is necessary to adopt suitable methods for representing the water quality data, especially in cases, when large number of samples and chemical parameters are involved.

The main purpose of presentation of chemical analysis data of water samples is to compare and evaluate different analyses. Several methods have been proposed to represent the analytical data of water quality for evaluation of chemical similarities and dissimilarities and the concentration of different constituents. These methods include several graphical techniques (pictorial), areal variations in parameters (Quality Contour maps etc.), and various other computational techniques.

Matthess (1982) has classified the methods of representation of chemical analysis data into the following three groups.

- Pictorial diagrams in which the quantitative analyses of water sample are represented (e.g. bar diagram,circular diagram etc.).
- Multivariate diagrams, in which several analyses can be directly and quickly compared.
- Diagrams combined with maps or cross sections.

The diagrams can be classified as trilinear, square, rectangular, combination and parallel scale diagrams. The concentration of ions in percentage milli-equivalents (meq %) can be illustrated in trilinear diagrams which give the relative concentration of various cations and anions within a single triangle or in two separate triangles, and,if necessary in combination of triangles to make rhombohedral, rectangular, or triangular fields to record the analysis of water samples (Piper 1944,1953; Freeze and Cherry, 1979; Lloyd and Heathcote, 1985). These diagrams are useful in indicating differences or similarities among waters. They also show the effect of mixing between waters. The hardness triangle devised by Schwille (1957) is a special construction that compares total hardness, carbonate hardness, and non-carbonate hardness.

In the two coordinate diagrams, the relationships between two variables are illustrated, for example, the relationship between electrical conductivity (E.C) and bicarbonate (Hem, 1985), the total dissolved solids and chloride content (Davis and DeWiest,

1967) or that of alkalies/alkaline earth ratio as function of depth. The parallel scale diagrams have limited application as, by the use of linear scales for the axes (which are used to plot anions and cations and the residue after evaporation), it is difficult and often impossible to represent on one diagram very different concentrations in water samples. In such cases, percentage values, or logarithmic scale may have to be preferred. The horizontal scale diagrams include a series of horizontal bars, plots of analysis along three or four horizontal axes (Stiff, 1951). In case of Stiff's diagrams, joining the points on the three horizontal axes produces a polygon with a shape which is characteristic of the particular water. The adaptability of this diagram is great because of the several possibilities, including its spatial representation on maps. Out of several forms of vertical scale diagrams in use, only semilogarithmic diagrams of Schoeller (1959) are widely used. Hem (1985) proposed shifting of the scales for the individual ions opposite the base line for the appropriate equivalent weight, so that the weights can be plotted directly in mg/l.

Davis and DeWiest (1967) and Matthess (1982) pointed out that the data of water quality can also be plotted in a map by lines of equal concentrations (isocone) or equal ionic ratios. However, the simplest form of a water quality map is representation of individual values or analysis with the help of the diagrams described above.

4.2 CLASSIFICATION OF NATURAL WATERS

Most of the work on chemical classification of waters has been restricted to ground water while the surface water has been excluded from such groupings. For surface water, different systems of water quality indices have been in vogue, probably because these may often be of mixed origins and sources including waste waters. Matthess (1982) considered genetic, chemical and hydrological view points as the basis for classification of ground water.

4.2.1 Chemical Classification of Water

Most of the work on chemical classification of waters use either percentage fraction of dissolved ions reported in mg % or in meq%. Piper (1953) developed a form of trilinear diagram which is an effective tool in analysing chemical data for critical study with respect to classification of water into different chemical types.

The concept of the hydrochemical facies was developed by Back (1960), Morgan and Winner (1962), Seaber (1962) and Lloyd and Heathcote (1985). This is considered applicable to ground water only. Hydrochemical facies reflect effect of chemical processes in the lithological environment and prevailing ground water flow patterns. Two main types, i.e.,cation facies and anion facies were suggested which together reflect the overall chemical characteristics of water. The designation of a composition category is commonly based on sub divisions of the trilinear diagram in the manner suggested by Back (1960) and Back & Hanshaw

(1965). In the classification scheme for the designation of hydrochemical facies, it is often appropriate, using maps, cross-section, or fence diagrams to show the regional distribution of facies. Fence diagrams also show the generalized direction of ground water flow.

4.2.2 Classification on the Basis of Potential Uses

Ground water can also be classified with respect to their suitability for domestic, industrial, agricultural and for recreational purposes (Matthess, 1982).

4.2.3 Suitability of Waters for Drinking and Other Uses

To ascertain the suitability of natural water for drinking purposes, the standard given by World Health Organisation (1984) are often adopted. The quality standards are also laid down by US Public Health Service (1962), US Environmental Protection Agency (1974), Indian Standard Institution (1983) and Indian Council of Medical Research (1975). Table 4.1 shows the standards for drinking water recommended by WHO (1984).

Table 4.1: WHO International Standards for Drinking Water (1984)

Substance or characteristic	Highest desirable level	Maximum permissible level
1	2	3
Substance causing discoloration	5 units (Platinum)	50 units
Substance causing odours	Unobjectionable	Unobjectionable
Substance causing tastes	Unobjectionable	Unobjectionable

1	2	3
Suspended matter	5 units (of turbidity)	25 units
Total Dissloved Solids	500 mg/l	above 1200 mg/l
pH range	6.5 to 8.5	6.5 to 9.2
Ammonia detergents	0.2 mg/l	1.0 mg/l
Total hardness	100 mg/l $CaCo_3$	500 mg/l
Calcium (as Ca)	75 mg/l	200 mg/l
Chloride (as Cl)	250 mg/l	600 mg/l
Copper (as Cu)	0.05 mg/l	1.5 mg/l
Iron (Total as Fe)	0.3 mg/l	1.0 mg/l
Magnesium (as Mg)	Not more than 30 mg/l if there is 250 mg/l of sulfate, if there is less sulfate, magnesium upto 150 mg/l may be allowed.	150 mg/l
Sulfate (as SO_4)	200 mg/l	400 mg/l
Zinc (as Zn)	5.0 mg/l	15 mg/l

The Indian council of Medical Research (ICMR, 1975) has given quality standards for drinking water supplies (Table 4.2). Subsequently, Indian Standards Institution (1983) revised these Standards (Table 4.3). In addition, the Central Board for the Prevention and Control of Water Pollution (CBPCWP, 1980) has laid down Indian Standards for drinking water from surface source, based on total coliforms, pH, dissolved oxygen and BOD whereas ISI

Table 4·2: Indian Standards for Drinking Water (ICMR, 1975)

Sr. No.	Substance or Characteristic	Requirement (Desirable Limit)	Undesirable Effects Outside the Desirable Limit	Desirable/ Essential	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
i)	Colour, Hazen units, Max	10	Above 10, consumer acceptance decreases	Essential	May be extended to 50 only if toxic substances are not suspected, in absence of alternate sources
ii)	Odour	Unobjectionable	-	Essential	a) Test cold and when heated b) Test at several dilutions
iii)	Taste	Agreeable	-	Essential	Test to be conducted only after safety has been established
iv)	Turbidity, NTU, Max.	10	Above 10, consumer acceptance decreases	Essential	May be extended upto 25, in absence of alternate sources
v)	Dissolved solids, mg/l, Max.	500	Beyond this palatability decreases and may cause gastro intestinal irritation	Desirable	May be extended upto 3000, in the absence of alternate sources
vi)	pH value	6.5-8.5	Beyond this range the water will affect the mucous membrane and/or water supply system	Essential	May be relaxed upto 9.2, in absence of alternate sources
vii)	Total hardness as $CaCO_3$ (mg/l), Max	300	Encrustation in water supply structure and adverse effects on domestic use	Essential	May be extended upto 600, in the absence of other sources
viii)	Calcium (as Ca) mg/l, Max	75	Encrustation in water supply structure and adverse effects on domestic use	Desirable	May be extended upto 200, in the absence of other sources
ix)	Magnesium (as Mg) mg/l, Max	30	Encrustation in water supply structure and adverse effects on domestic use	Desirable	May be extended upto 100, in the absence of other sources
x)	Copper (as Cu) mg/l, Max	0.05	Astringent taste, discoloration and corrosion af pipes, fittings and untensils will be caused beyond this	Desirable	May be relaxed upto 1.5
xi)	Iron (as Fe) mg/l, Max	0.3	Beyond this limit taste/appearance are affected, has adverse effect on domestic uses and water supply structures, and promote iron bacteria	Essential	May be extended upto 1.0, in absence of alternate sources

(Contd........)

(Contd......)

(1)	(2)	(3)	(4)	(5)	(6)
xii)	Manganese (as Mn) mg/l, Max	0.1	Beyond this limit taste/appearance are effected, has adverse-effect on domestic uses and water supply structures	Desirable	May be extended upto 0.5, where alternate source is not available
xiii)	Chlorides (as Cl) mg/l, Max	250	Beyond this limit, taste, corrosion and palatibility are affected	Essential	May be extended upto 1000, in the absence of other alternate sources
xiv)	Sulphate (as SO_4) mg/l, Max	150	Beyond this causes gastro intenstinal irritation when magnesium or sodium are present	Desirable	May be extended upto 400 provided magnesium (as Mg) does not exceed 30
xv)	Nitrate (as NO_3) mg/l, Max	45	Beyond this methnaemoglobinemia takes place	Desirable	Not relaxation
xvi)	Cadmium (as Cd) mg/l, Max	0.01	Beyond this, the water becomes toxic	Desirable	No relaxation of this limit is allowed. To be tested, when pollution is suspected
xvii)	Lead (as Pb), mg/l, Max	0.1	Beyond this limit, the water becomes toxic	Desirable	No relaxation being a health parameter. To be tested when pollution/plumbo-solvency is suspected
xviii)	Chromium (as Cr^{6+}) mg/l, Max	0.05	May be carcinogenic above this limit	Desirable	No relaxation. To be tested when pollution is suspected

Table 4·3: Indian Standards for Drinking Water (IS: 10500, 1983)

Sr. No.	Substance or Characteristic	Requirement (Desirable Limit)	Undesirable Effects Outside the Desirable Limit	Desirable/ Essential	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
i)	Colour, Hazen units, Max	10	Above 10, consumer acceptance decreases	Essential	May be extended to 50 only if toxic substances are not suspected, in absence of alternate sources
ii)	Odour	Unobjectionable	-	Essential	a) Test cold and when heated b) Test at several dilution
iii)	Taste	Agreeable	-	Essential	Test to be conducted only after safety has beer established
iv)	Turbidity, NTU, Max.	10	Above 10, consumer acceptance decreases	Essential	May be extended upto 25, in absence of alternate sources
v)	Dissolved solids, mg/l, Max.	500	Beyond this palatability decreases and may cause gastro intestinal irritation	Desirable	May be extended upto 3000, in the absence of alternate sources
vi)	pH value	6.5-8.5	Beyond this range the water will affect the mucous membrane and/or water supply system	Essential	May be relaxed upto 9.2, in absence of alternate sources
vii)	Total hardness as $CaCO_3$ (mg/l), Max	300	Encrustation in water supply structure and adverse effects on domestic use	Essential	May be extended upto 600, in the absence of other sources
viii)	Calcium (as Ca) mg/l, Max	75	Encrustation in water supply structure and adverse effects on domestic use	Desirable	May be extended upto 200, in the absence of other sources
ix)	Magnesium (as Mg) mg/l, Max	30	Encrustation in water supply structure and adverse effects on domestic use	Desirable	May be extended upto 100, in the absence of other sources
x)	Copper (as Cu) mg/l, Max	0.05	Astringent taste, discoloration and corrosion af pipes, fittings and untensils will be caused beyond this	Desirable	May be relaxed upto 1.5
xi)	Iron (as Fe) mg/l, Max	0.3	Beyond this limit taste/appearance are affected, has adverse effect on domestic uses and water supply structures, and promote iron bacteria	Essential	May be extended upto 1.0, in absence of alternate sources

(Contd......)

(1)	(2)	(3)	(4)	(5)	(6)
xii)	Manganese (as Mn) mg/l, Max	0.1	Beyond this limit taste/appearance are effected, has adverse-effect on domestic uses and water supply structures	Desirable	May be extended upto 0.5, where alternate source is not available
xiii)	Chlorides (as Cl) mg/l, Max	250	Beyond this limit, taste, corrosion and palatibility are affected	Essential	May be extended upto 1000, in the absence of other alternate sources
xiv)	Sulphate (as SO_4) mg/l, Max	150	Beyond this causes gastro intenstinal irritation when magnesium or sodium are present	Desirable	May be extended upto 400 provided magnesium (as Mg) does not exceed 30
xv)	Nitrate (as NO_3) mg/l, Max	45	Beyond this methnaemoglobinemia takes place	Desirable	Not relaxation
xvi)	Cadmium (as Cd) mg/l, Max	0.01	Beyond this, the water becomes toxic	Desirable	No relaxation of this limit is allowed. To be tested, when pollution is suspected
xvii)	Lead (as Pb), mg/l, Max	0.1	Beyond this limit, the water becomes toxic	Desirable	No relaxation being a health parameter. To be tested when polluition/plumbo-solvency is suspected
xviii)	Zinc (as Zn) mg/l,Max	5	Beyond this limit it can cause astringent taste and an opalescene in waters	Desirable	May be relaxed up to 15. To be tested when pollution is suspended
xiv)	Chromium (as Cr^{6+}) mg/l, Max	0.05	May be carcinogenic above this limit	Desirable	No relaxation. To be tested when pollution is suspected

(1981) standards for the release of industrial effluents have been given in Table 4.4.

4.3 QUALITY AND ZONING OF SURFACE WATERS

All surface waters should be capable of supporting aquatic life and be aesthetically pleasing. In addition, if required as a public source for drinking water, the water should be treatable to yield a potable supply meeting the drinking water standards. Table 4.5 lists the six common classifications for surface waters on the basis of dissolved oxygen, total dissolved solids and maximum allowable coliforms (Chaudhary, 1981).

The Central Board for the Prevention and Control of Water Pollution (op.cit), India has adopted nineteen parameters for monitoring quality of surface waters.

For the purpose of classification and zoning of surface waters, a concept of 'Designated Best Use' (DBU) suggested by Chaudhary (1981) is widely used. Such a classification and zoning enables concerned water pollution control authorities to base and frame control measures for waste water discharges into a particular stretch of a water body.

Table: 4·4 - Tolerance Limit for Industrial Effluent Discharged (IS:2490(Part I), 1981)

Characteristics	into inland surface water	into public sewer	on land for irrigation	into marine coastal areas for process waste water
Dissolved solids (mg/l)	2100	2100	2100	-
pH value	5.5-9.0	5.5-9.0	5.5-9.0	5.5-9.0
Amm. Nitrogen as (N) (mg/l)	50	50	-	50
BOD 5 days at 20°C (mg/l)	30	350	100	100
COD (mg/l)	250	-	-	250
Lead (Pb) (mg/l)	0.1	1.0	-	0.01
Cadmium (Cd)(mg/l)	2.0	1.0	-	2.0
Total Chromium (Cr) (mg/l)	2.0	2.0	-	2.0
Zinc (Zn) (mg/l)	5.0	15	-	15
Chloride (mg/l)	1000	1000	600	-
Sulphate (mg/l)	1000	1000	1000	-
Sulphide (mg/l)	2.0	-	-	5.0
Dissolved phosphate as (P) (mg/l)	5.0	-	-	-
Free Ammonia	5.0	-	-	5.0

Table 4.5: Beneficial Uses and Quality Standards for Surface Water (Chaudhary, 1981)

Water Use	Dissolved oxygen min. allowable (mg/l)	Solids Allowable		Coliforms Max. Allowable per 100 ml
		Dissolved (mg/l)	Other	
1	2	3	4	5
Public water suply	4.0	500 to 700	No floating solids or settleable solids that form deposits	200 Fecal 10,000 total
Contact recreation	4 to 5	None	Same as above	Mean of 1000 (200 Fecal with not more than 10% samples Execeeding 200 (400 fecal)
Fish propagation and wild life	4 to 6	None	Same as above	Mean of 500
Industrial water supply	3 to 5	750 to 1500	Same as above	nonspecified
Shell fish harvesting	4 to 6	None	Same as above	Mean of 70 with not more than 10% of samples exceeding 230

The tolerance limits for the industrial effluents discharged into public sewer and on land for irrigation purposes are given by Indian Standards Institution (IS:3306, 1974 and IS:3307, 1977). However, a water suitable for discharge on land may be unsuitable for drinking purposes.

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4.4 WATER QUALITY INDICES

Water Quality Indices (WQI) are a powerful tool to indicate the overall suitability and acceptability for specified uses, and are being employed increasingly for evaluating synoptic quality of surface waters. Water quality index may be defined as a Rating reflecting the composite influence on overall quality characteristics (Mitre Corporation, 1972). Lohani (1981) explained that the index itself does not give the final answer to the problem of water quality management. However, it can point out where the trouble is. A system for rating water quality in terms of index number offers promise as a useful tool in the administration of water pollution control abatement. According to Train (1973), quality monitored data must be transformed into easy to understand indices that aggregate data for decision making and a general public policy development. Ott(1978) identified basic uses of environmental indices which are applicable to water quality indices. Horton (1965) proposed a simple method of computing the water quality index from the consideration of assignment of ratings and weightages to various variables such as sewage treatment, DO, pH, coliform, chlorides, alkalinity, specific - conductivity etc. He computed the index through an arithmetic mean. However, his approach is not very sensitive to the effect of change of values of individual parameters. Brown et al. (1970) presented a water quality index similar in structure to Horton's index. This was supported by the National Sanitation Foundation (NSF), and the resulting index is known as NSFWQI. In this system of index, the arithmetic mean used does not permit sufficient lowering of the index if any one variable is of a low quality. As its modification, therefore, Brown et al. (1972) proposed a multiplicative index. Prati et al. (1971) proposed an index for surface water quality classification system used in a number of different countries. Prati's index is computed as the arithmetic mean of 13 subindices worked from individual parameters. McDuffie et al. (1973) presented a relatively simple water quality index (based on sum of n sub indices times a scaling factor) which they called the River Pollution Index (RPI). Harkins (1974) based his water quality index on a varying number of water quality variables by computing 'rank variance' for each variable and the 'Standardised distance' for each observational vector. However, his model was found to be rather complicated for computing the water quality index. Walski and Parker (1974) published a water quality index specially intended for the recreational use of water such as swimming and fish culture. They took geometric mean of the quality of each variable expressed through a number (ranging from 0 to 1) called the sensitivity function. Their model included weight assigned to each variable, but this weight was not reflected rationally in the computed index values, due to the difficulty of assigning proper weightage to avariable for a given use.

Inhaber (1975) described a system based on two distinct subindices. The first deals with industrial and domestic pollution in river water and is a pollutant source subindex based on effluents from point sources. The second subindex deals with ambient water quality Schaeffer and Janardhan (1977), Barker and

Kramer (1972) and Dunnette (1976) also proposed the criteria for development and evaluation of water quality indices. Bhargava (1983a) suggested that a simplified approach to water quality index should include the effect of change of variable in the sensitivity function itself for different beneficial uses. His method seeks to eliminate the necessity of incorporating a weight factor of individual variables in the index expression for each specific use, thus simplifying the computation of the index.

4.5 CONSERVATIVE CONSTITUENTS IN GROUND WATERS AND SURFACE WATERS - General Appraisal

An overall idea of the chemical quality of ground water and surface water of the study area can be obtained by considering the variation in ranges of important parameters viz. electrical conductivity, total dissolved solids, pH, Cl^-, SO_4^{--}, total hardness and trace elements like Cd^{++}, Pb^{++} and total chromium. Theoretical considerations and the common ranges of these constituents in natural water have been discussed by Hem (1985).

The present study indicates that electrical conductivity for ground water and surface water in the study area (Table 4.6) varies in the range of 306 to 2193 µmhos/cm and 233 to 2182 µmhos/cm respectively. The total dissolved solids vary in the range of 438 to 1316 mg/l for ground water and 222 to 1248 mg/l for surface water. The pH of ground water and surface water samples varies in the range of 6.1 to 8.5 and 6.5 to 9.1 respectively indicating generally the alkaline nature of the water but acidic character of the water is also observed at few places.

TABLE: 4.6 : RANGES OF CONCENTRATION OF DIFFERENT CHEMICAL CONSTITUENTS IN SURFACE WATER (May, 85 to Nov., 87) and GROUND WATER (April, 85 to Aug., 86) SAMPLES

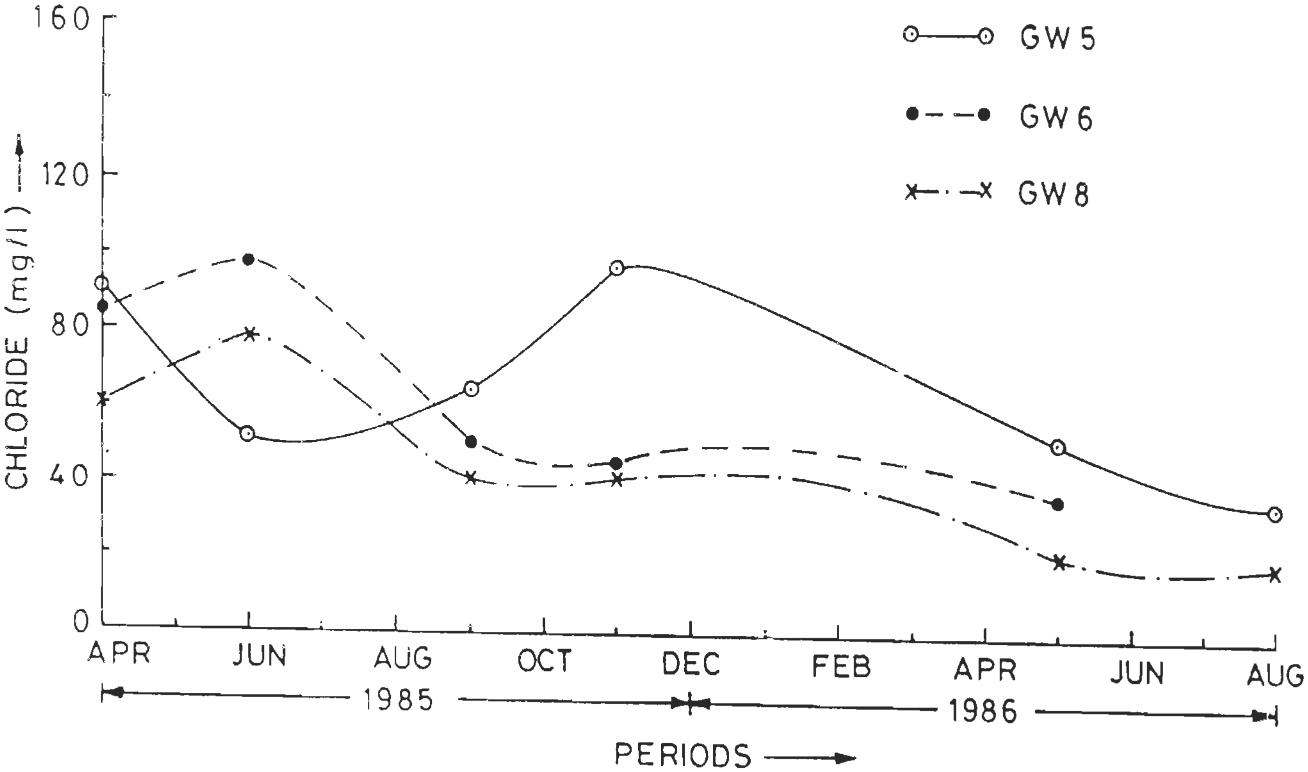
	Electrical conductivity mhos/cm	Total dissolved solids	pH	Chloride mg/l	Sulphate mg/l	Total hardness mg/l	Cd^{++} mg/l	Pb^{++} mg/l	Total chromium mg/l
WHO Limits (Highest Desirable level)		500 mg/l	6.5-8.5	200	200	100	0.01	0.05	0.05
Surface waters	233-2181	222-1248	6.5-9.1	4.0-228	7.0-180	92-587	0.001-0.185	0.02-1.96	0.007-0.315
Ground waters	306-2193	438-1316	6.1-8.5	6.0-184	12.0-264	116-705	0.002-0.094	0.01-1.25	0.002-0.145

The concentration of chloride in surface and ground water samples are 6 - 184 mg/l and 4-228 mg/l respectively. The concentrations of the sulphate in surface and ground water samples varies in the range of 12-264 mg/l and 7-180 mg/l respectively. The total hardness in ground water varies from 116-705 mg/l and in surface water from 92-587 mg/l.

The range of concentration of various conservative constituents in ground water and surface water samples of the study area alongwith prescribed limits for drinking water as recommended by WHO is given in table 4.6 for the periods of May, 1985 to Nov., 1987 for surface water and April, 1985 to August, 1986 for ground water.

Seasonal variation of chloride in ground water during the periods April,1985 and August,1986 from some of the observation points is shown in Fig. 4.1. It is observed that the lowest value of chloride is about 11 mg/l and the maximum is 110 mg/l. Further, it is also observed that in premonsoon period the concentration of chloride and sulphate is generally high as compared with the post monsoon period except for samples at locations GW1, GW3 and GW5 where a reverse trend is discernible. The decreasing chloride values in postmonsoon period are not unexpected but its high value may be due to some extraneous factors or relatively large lag time for recharge to ground water from rainfall. Similar trend has also been observed for sulphate (Table 4.6).

The trace elements Cd^{++}, Pb^{++} and total chromium in surface water and ground water are found to be in higher concentration



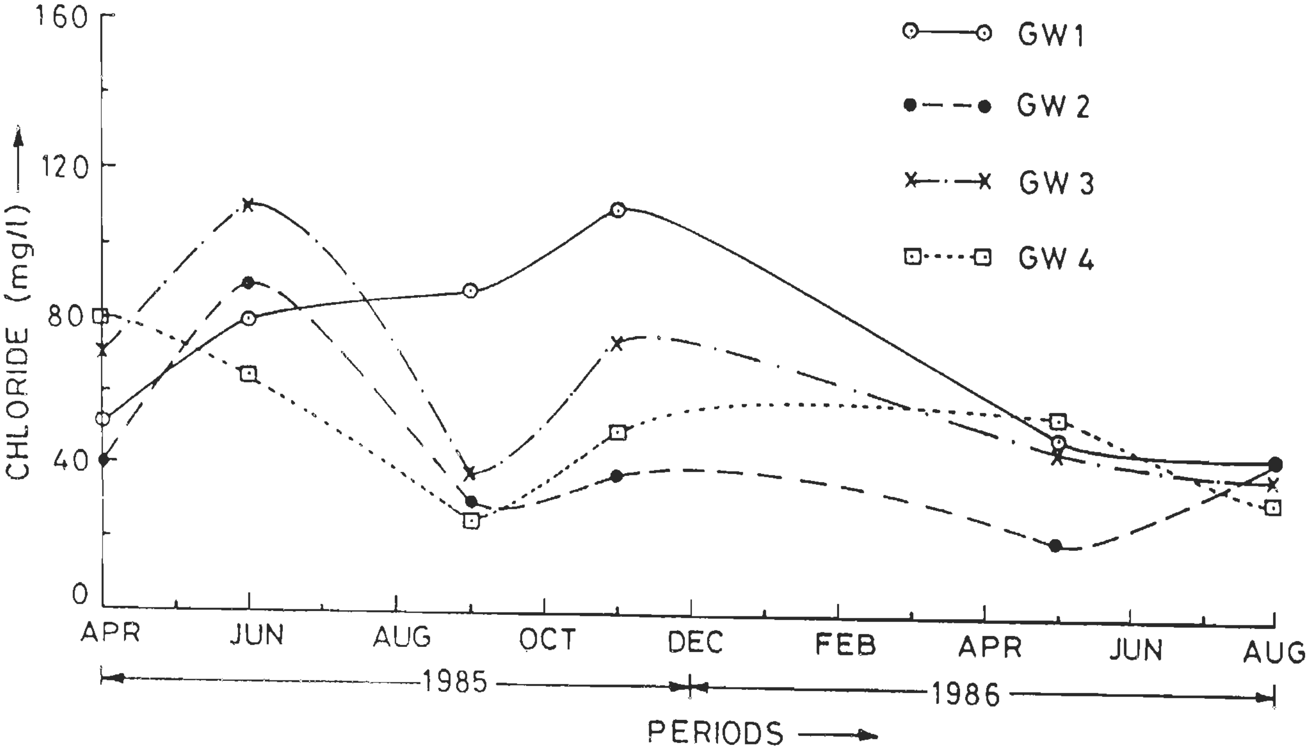


FIG. 4·1 TEMPORAL VARIATION OF CHLORIDE IN GROUND WATER with respect to the WHO limits at a few sampling location (Table 4.6). The WHO limits for Cd^{++}, Pb^{++} and total chromium in drinking water are 0.01 mg/l, 0.05 mg/l and 0.05 mg/l respectively.

Figures 4.2 to 4.4 show the concentration profiles of Cd^{++}, Pb^{++} and Total Chromium in the surface water of the study area. It may be observed from these figures that in general, the concentration of these elements show an irregular variation though occuring in higher ranges, generally above the permissible concentration limits. However, in case of Cd^{++} and Pb^{++} a significant increase in concentration is observed in the vicinity of waste outfall(s) from major industrial units, especially near SW_5 (near Dairy waste outfall) and SW_{21} (near Paper Mill outfall). However, in some cases such a trend is not decipherable probably due to insufficient mixing and can be noticed only in the further downstream locations. These observations are also correlated from the concentrations value of Pb^{++} and Cd^{++} in the effluents of Paper mill and Dairies (Tables 2.2 and 2.3). It may also be noted that the background (upstream) concentration of these elements in the Nagdeo and Hindon streams (viz. near SW_3 and SW_9 locations, Fig. 4.2 & 4.3) also seem to influence the overall concentration of these elements in the surface waters.

As regards the Total Chromium, the main source of its high concentration seems to be from the upstream part of Nagdeo nala (location SW_3). This finding is also coroborrated from data presented in Tables 2.2 and 2.3.

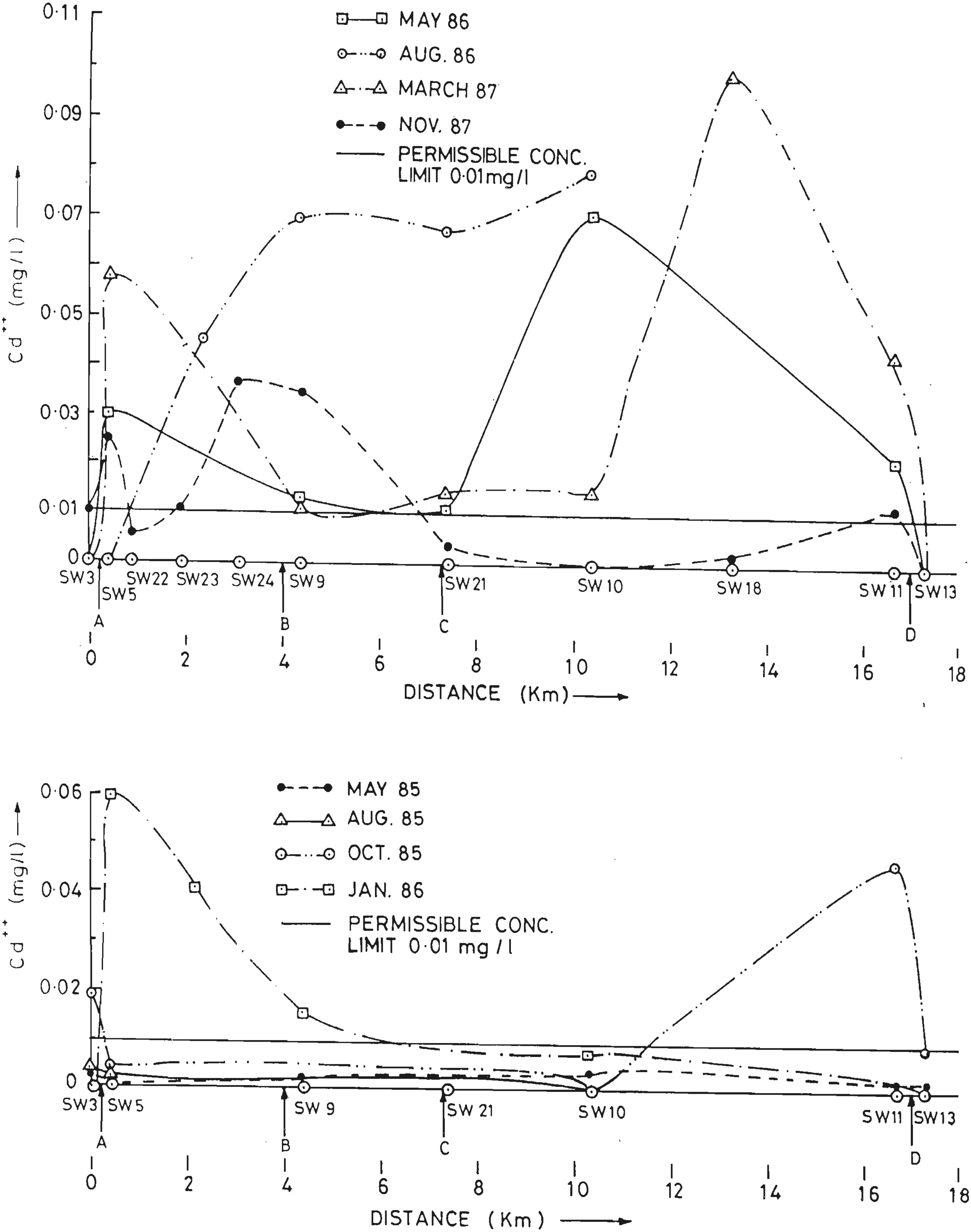


FIG. 4·2 PROFILES SHOWING CONCENTRATION OF Cd^{++} IN SURFACE WATERS ALONG HINDON-NAGDEO STRETCH

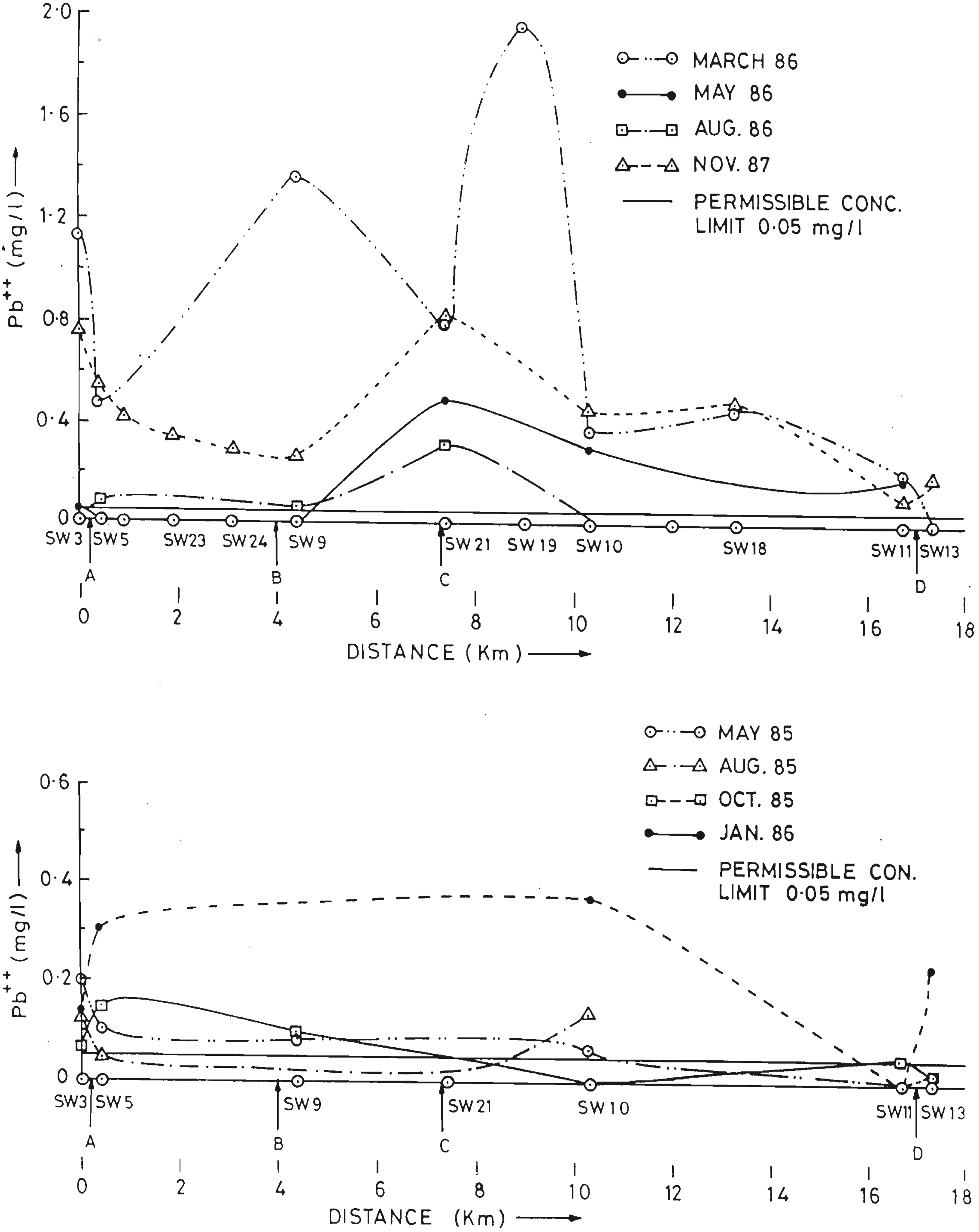


FIG. 4·3 PROFILES SHOWING CONCENTRATION OF Pb^{++} IN SURFACE WATERS ALONG HINDON-NAGDEO STRETCH

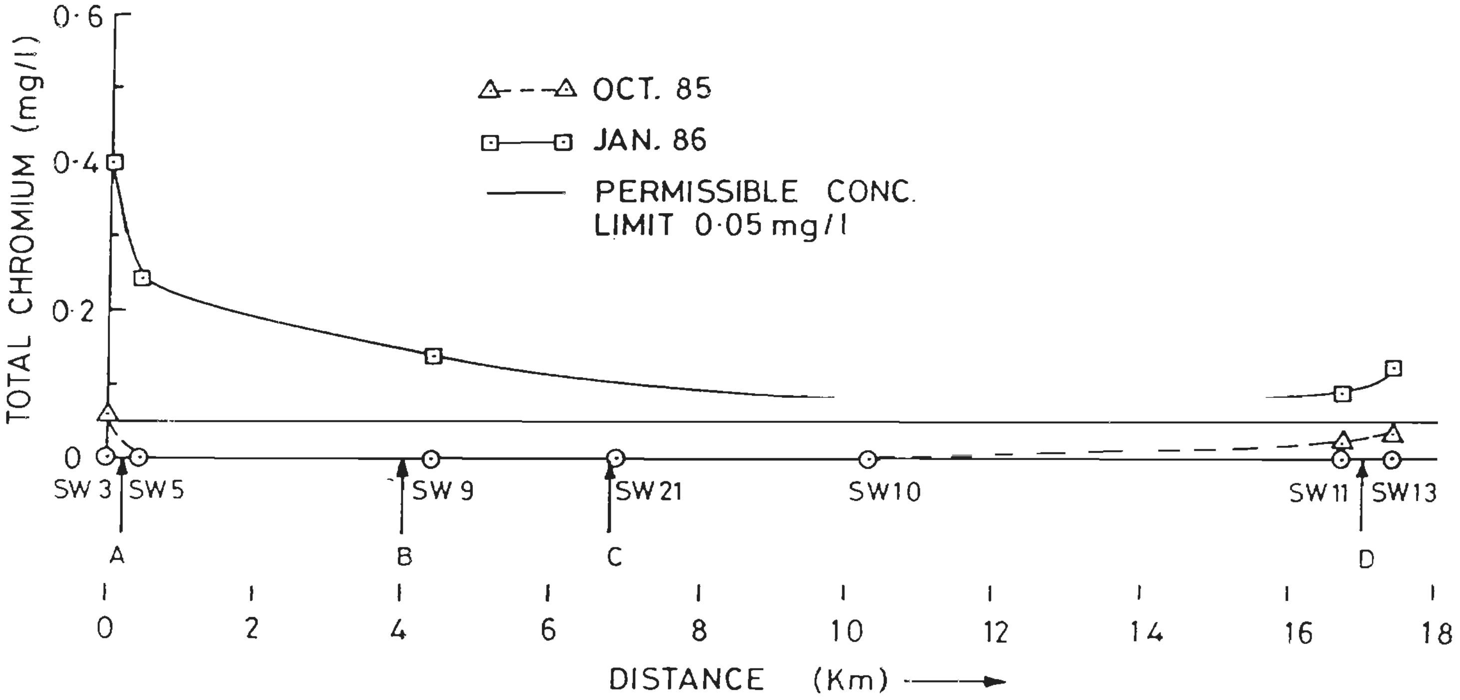


FIG. 4·4 PROFILES SHOWING CONCENTRATION OF TOTAL CHROMIUM IN SURFACE WATERS ALONG HINDON-NAGDEO STRETCH

The effluents released from other industrial units may also contribute trace metals to the river waters (Table 2.1). However, specific field data is not available to support these observations.

The trace elements in ground water show irregular variation and, as such, it is difficult to assign any specific reason for their varying concentration.

4.6 REPRESENTATION AND INTERPREATION OF HYDRO-CHEMICAL DATA

It is necessary to consider the use of different methods of representing hydro-chemical data of surface water and ground water from the study area. The surface water is often susceptible to contamination by effluents released from extraneous sources. Accordingly many of such surface waters will not follow the laws of chemical combination normally applicable to ground waters. Therefore, the classification based on hydrochemical facies and the Trilinear and Stiff's diagrams may not be applicable to the surface waters. On the other hand, various schemes of formulation of water quality indices may not be applicable to the ground water. These views gain support from rather exclusive classification schemes proposed for ground water and surface water by different workers (e.g. Matthess, 1982; Back and Hanshaw; 1965 Freeze and Cherry, 1979; Lloyd & Heathcote, 1985).

Based on the above approach, in the present study, the hydrochemical data for ground water have been represented in the Stiff's diagrams and Piper's trilinear diagrams. The waters have also been classified into the hydrochemical facies of Back and

Hanshwaw (1965). The surface water quality has been evaluated by developing water quality indices based on Horton's approach and ambient water quality indices. However, for comparison with ground water, Stiff's polygon maps for surface water have also been included in the study.

4.7 STIFF DIAGRAM

The Stiff (1951) graphical method using three or four parallel horizontal axes and one vertical axis may be useful in making visual comparison of the chemistry of waters. The cations are plotted along axes to the left of the zero point and the anions are plotted on the right. Concentrations are expressed in equivalents per million. The joining of points representing anions and cations gives a polygon whose shape is characteristic of a given kind of water. In the present study, Stiff polygon maps have been prepared for ground water for June, 1985 and November, 1985 and for surface water for May, 1985 and October, 1985 (Fig. 4.5 and 4.6) which show the temporal and spatial variation in the water quality.

It is observed from figure 4.5 that generally, the overall ionic concentration in the ground water is less in postmonsoon samples which probably is due to dilution caused by rain water. Also, the ground water has higher alkalinity as well as total hardness as manifested by the higher concentrations of bicarbonate & carbonate and calcium-magnesium. However, some ground water samples along Saharanpur-Kailashpur road and at GW_9 (Sheikhpura Qadim)also show high concentration of chloride and sulphate.

The Stiff polygon maps for surface water for May, 1985 and October, 1985 are presented in Fig. 4.6. Along the main Hindon river there seems to be no regular variation in ionic concentration from the north to south. However, the Padli nala (SW_2) and Dairy effluents (SW_4) contain higher ionic concentration as compared to Nagdeo nala (SW_3).

Along the Nagdeo nala, a tributary of the Hindon river, the water is of poor quality, as compared to that of Hindon river. In this nala, (near location SW_2) downstream of the confluence of Padli and dairy effluents, the overall concentration of HCO_3^-, Ca^{++} and, at places, Mg^{++} are rather high, which seems to be due to the effluents from Indana dairies (SW_4) as well as a card board factory.

Stiff polygons for the Dhamola nala water for 1985 have been given in figure 4.6 for the stretch from Saharanpur town upto Sadauli Hariya. It is seen from the figure (4.6), that in upstream parts, the ionic concentration of Cl^- and HCO_3^- for the Pandhoi tributary (location SW_6) is higher than in Dhamola nala (location SW_7). However, at Sadauli Hariya (SW_{12}) the concentrations are quite high in comparison to the location SW_8 (confluence of Pandhoi and Dhamola streams) indicating thereby the deterioration in water quality in downstream direction. One reason for this change in quality can be due to addition of wastes into Dhamola nala from hidden unspecified sources. The Stiff polygons for the postmonsson period (October, 1985) show a general dilution by rain water.

4.8 RELATION BETWEEN EC AND TDS

In case of surface water and ground water, the total dissolved solids range between 222 to 1248 mg/l and 438 to 1316 mg/l respectively. The highest desirable level given by WHO (1984) for TDS is 500 mg/l for drinking water.

An attempt has been made in the present study to ascertain the relationship of EC of surface water and ground water with the TDS. The graph between electrical conductivity (EC) and TDS (Fig. 4.7 and 4.8) for surface water and ground waters, indicate a linear relationship, the slope of the straight line being 0.65 and 0.59. Hem (1985) has given the general range of this slope to vary between 0.55 to 0.75.

4.9 TRILINEAR DIAGRAM

The Piper trilinear diagram is a modification of an earlier diagram suggested by Hill (1940).

The Piper trilinear diagram has three distinct fields for plotting the chemical data; two triangular fields (a lower left hand triangle for plotting cations and a right hand triangle for plotting anions) and a central diamond shaped field for representing overall chemical characteristics of water (Fig. **4.9**). In the cation field, the percentage (epm) reacting values of three cations (Ca^{++}, Mg^{++} and Na^{+} + K^{+}) are plotted as a single point and the three anions (Cl^{-}, SO_4^{--} and HCO_3^{-}+ CO_3^{-}) are plotted as a single point in the anion field. The central diamond shaped field gives the overall characteristics of the water sample by a single point in terms of relative concentration of a combination of

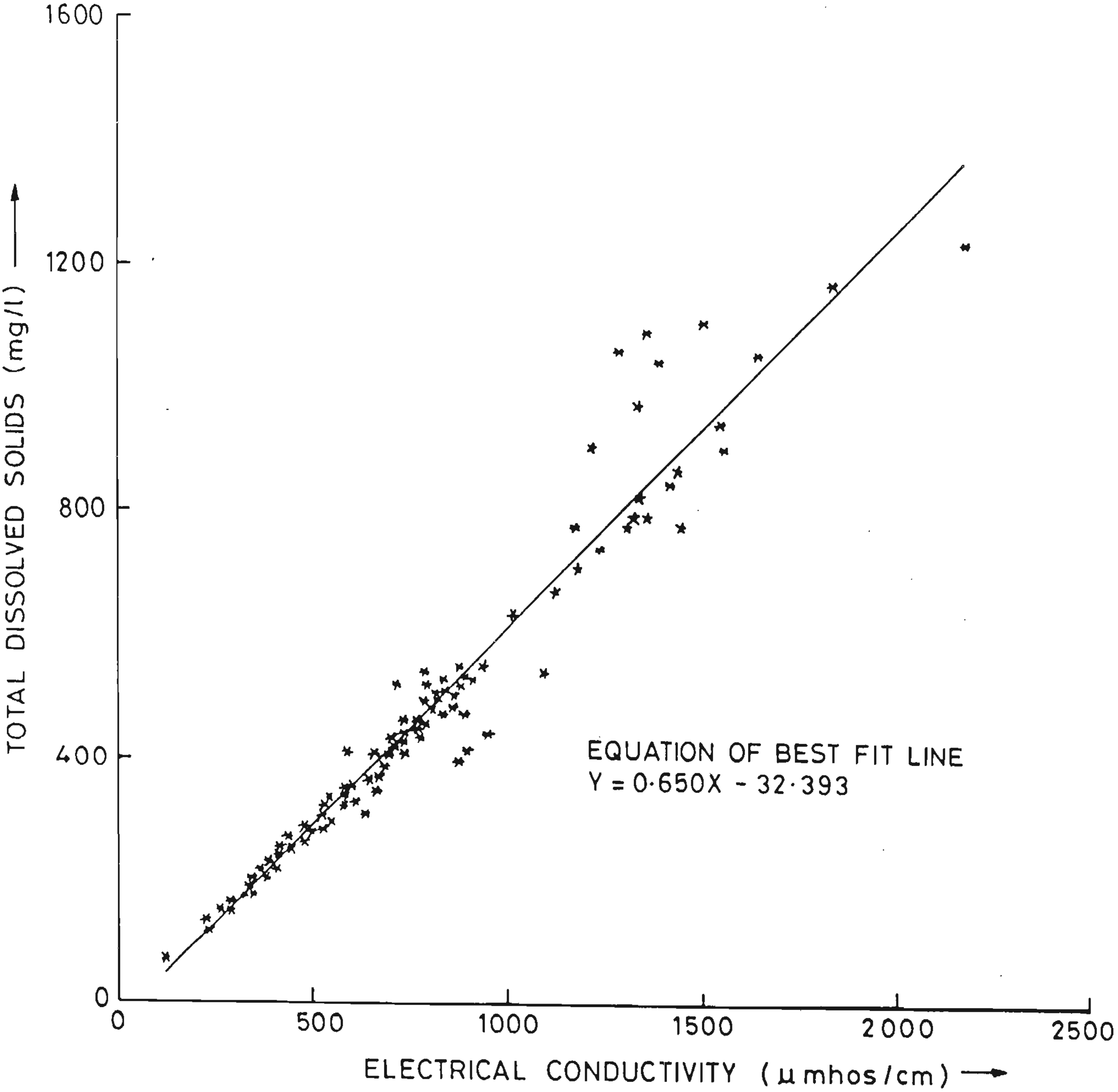


FIG.4·7 RELATIONSHIP BETWEEN ELECTRICAL CONDUCTIVITY AND TDS FOR SURFACE WATER

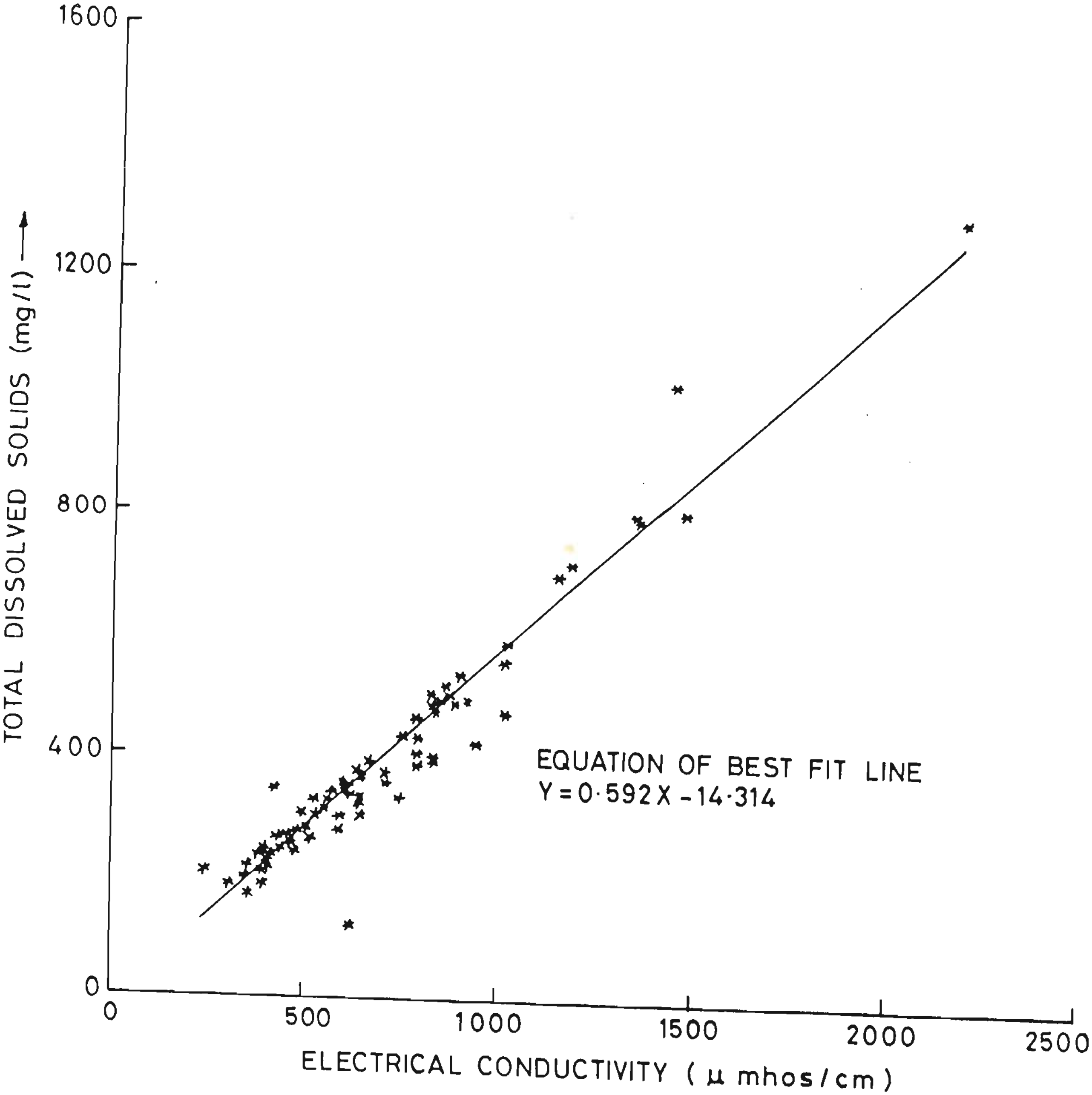
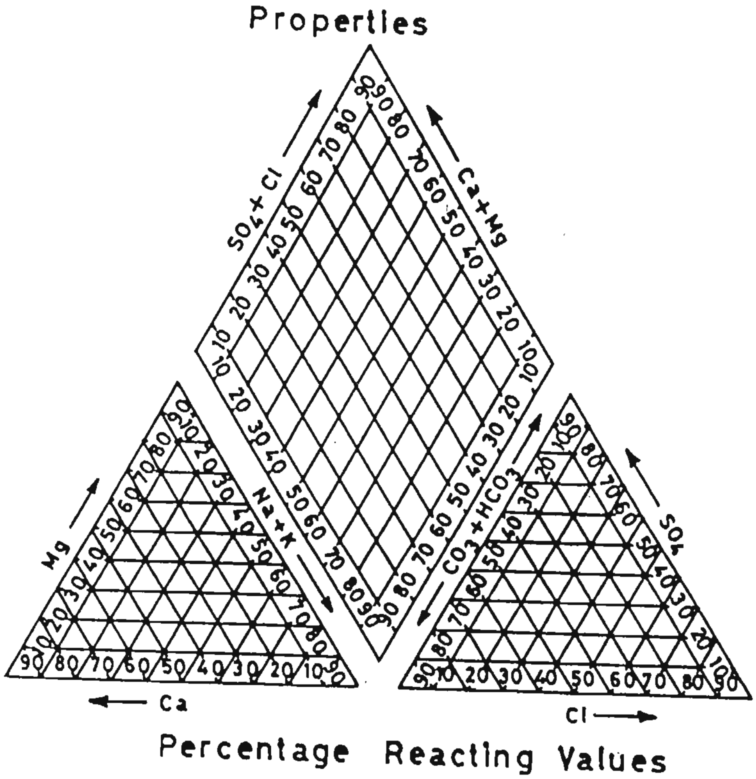


FIG. 4·8 RELATIONSHIP BETWEEN ELECTRICAL CONDUCTIVITY AND TDS FOR GROUND WATER



PIPER TRILINEAR DIAGRAM

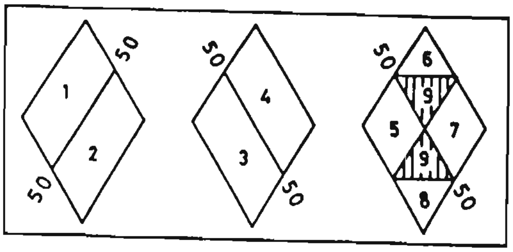


FIG. 4·9 SUBDIVISIONS OF DIAMOND-SHAPED FIELD OF PIPER TRILINEAR DIAGRAM cations and anions. The central diamond shaped field can be divided into several sub areas, each of which represents waters of different geochemical character (Fig. 4.9) as given below:

Area 1: alkaline earths exceed alkalies

Area 2: alkalies exceed alkaline earths

Area 3: weak acids exceed strong acids

Area 4: strong acids exceed weak acids

Area 5: carbonate hardness (Secondary alkalinity) exceeds fifty percent.

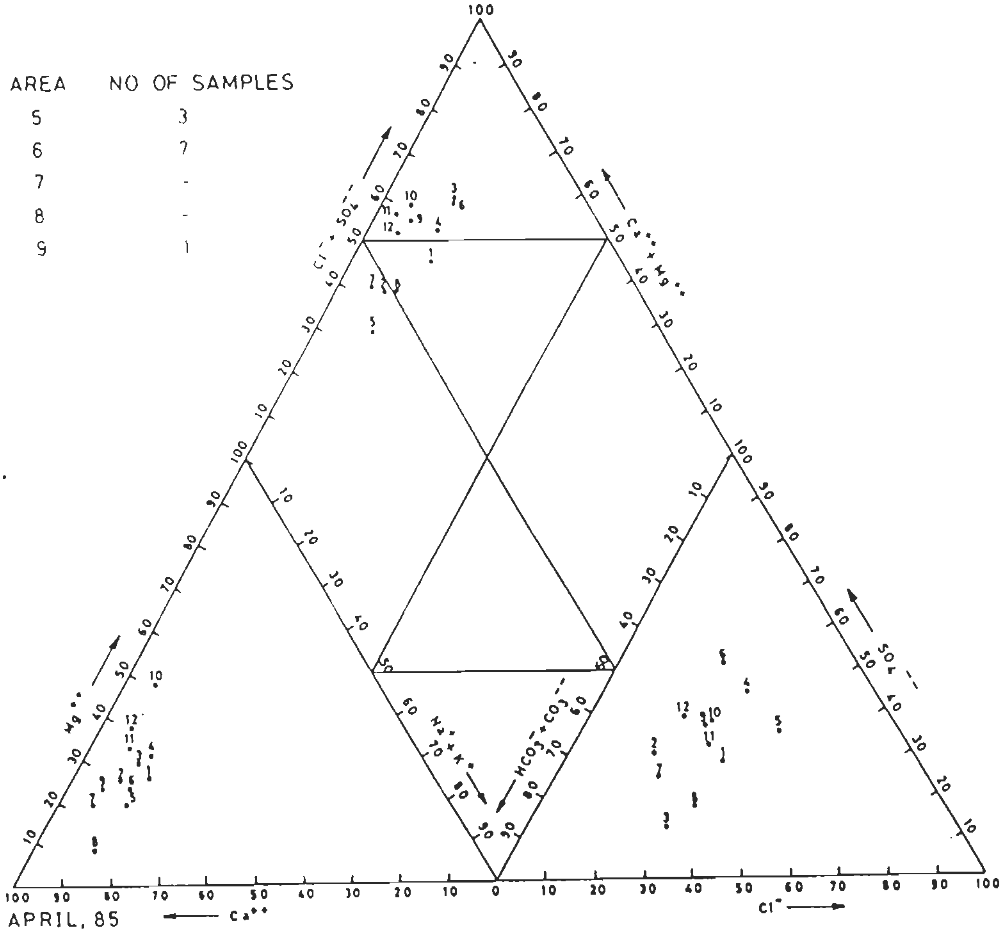
Area 6: noncarbonate hardness (Secondary salinity) exceeds fifty percent.

Area7: non carbonate alkalies (Primary salinity) exceeds fifty percent.

Area 8 : carbonate alkalies (Primary alkalinity) exceeds fifty percent.

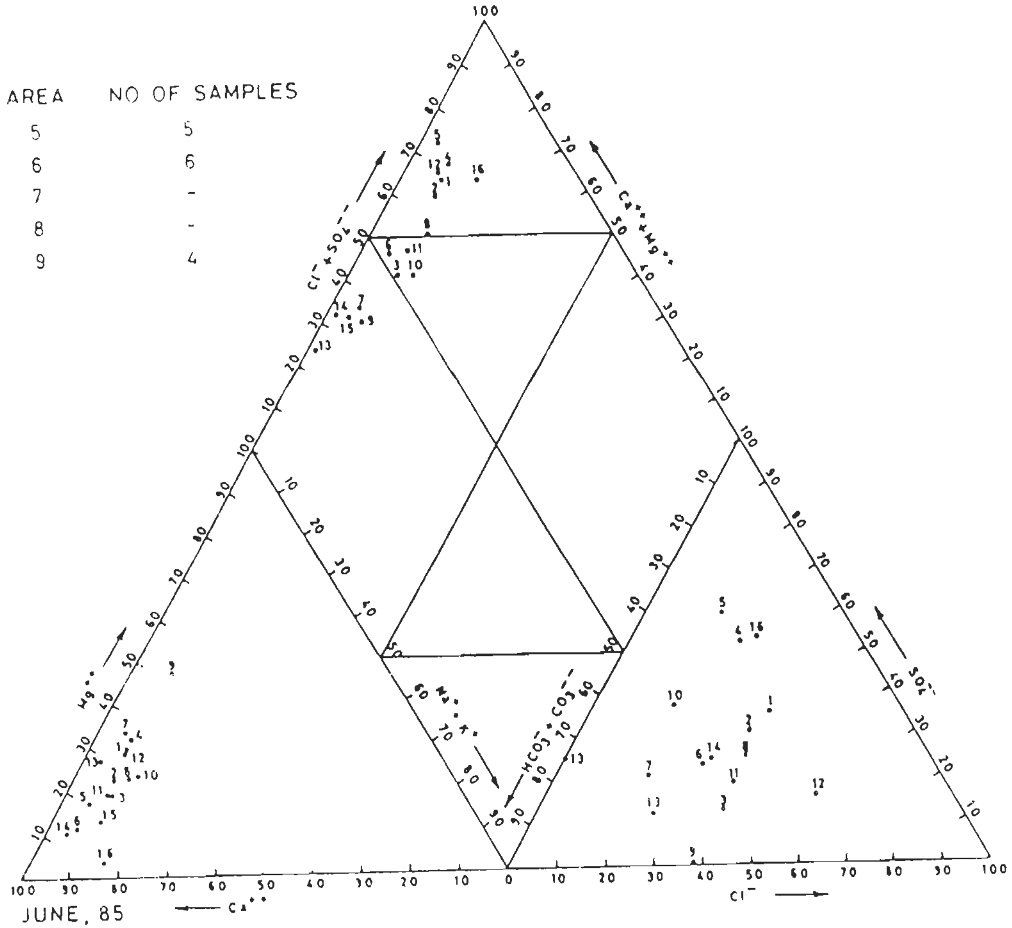
Area 9: no one cation-anion pair exceeds fifty percent.

The chemical characteristics of ground waters for the period April, 1985 to August, 1986 from the area are plotted in the Piper trilinear diagram (Fig. 4.10 to 4.15). The chemical characteristics of these water samples are given in table 4.7. From the table it is clearly seen that the majority of the ground water samples have dominant carbonate hardness as they belong to area 5 of the Piper trilinear diagram. However, in the months of April, June and November 1985, the ground water has dominant secondary salinity (area 6) indicating thereby that non-carbonate hardness exceeds fifty percent in ground water. The remaining ground water samples have intermediate chemical character as they belong to area 9 of the diagram. A common chemical attribute of



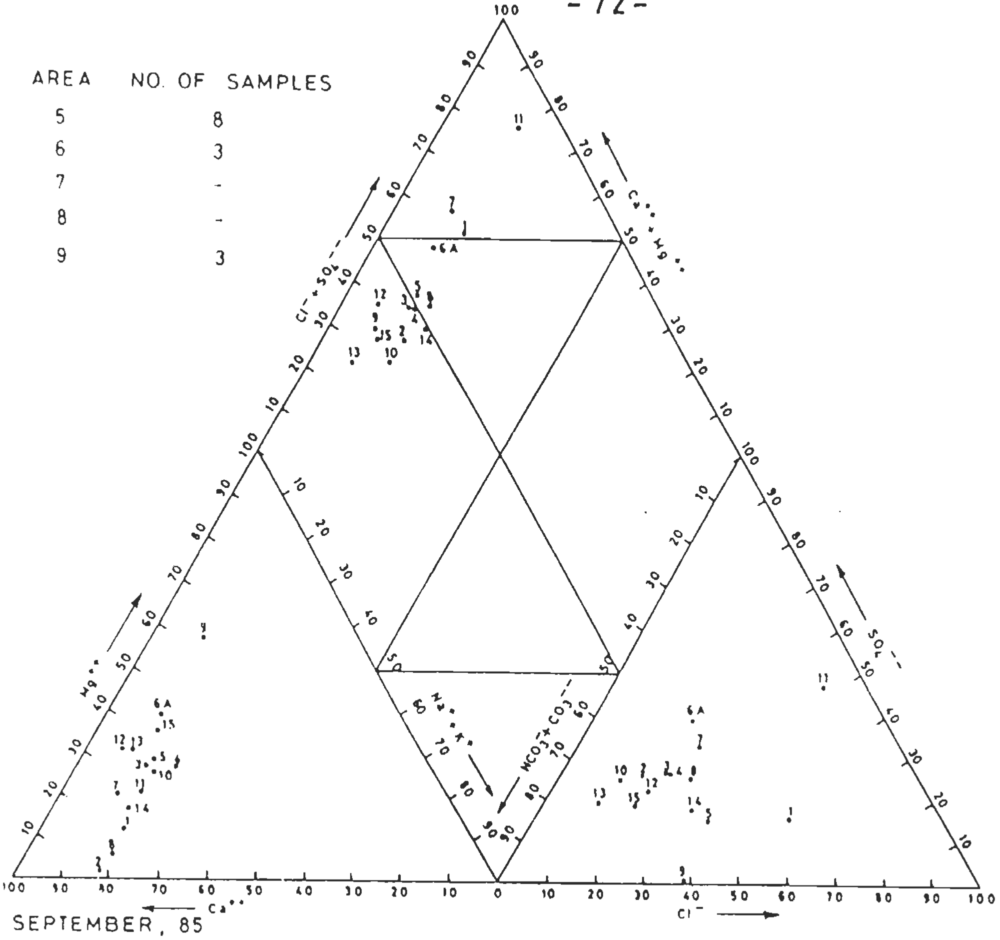
AREA	NO OF SAMPLES
5	3
6	7
7	-
8	-
9	1

FIG. 4·10 PIPER TRILINEAR DIAGRAM FOR GROUND WATER SAMPLES APRIL, 85



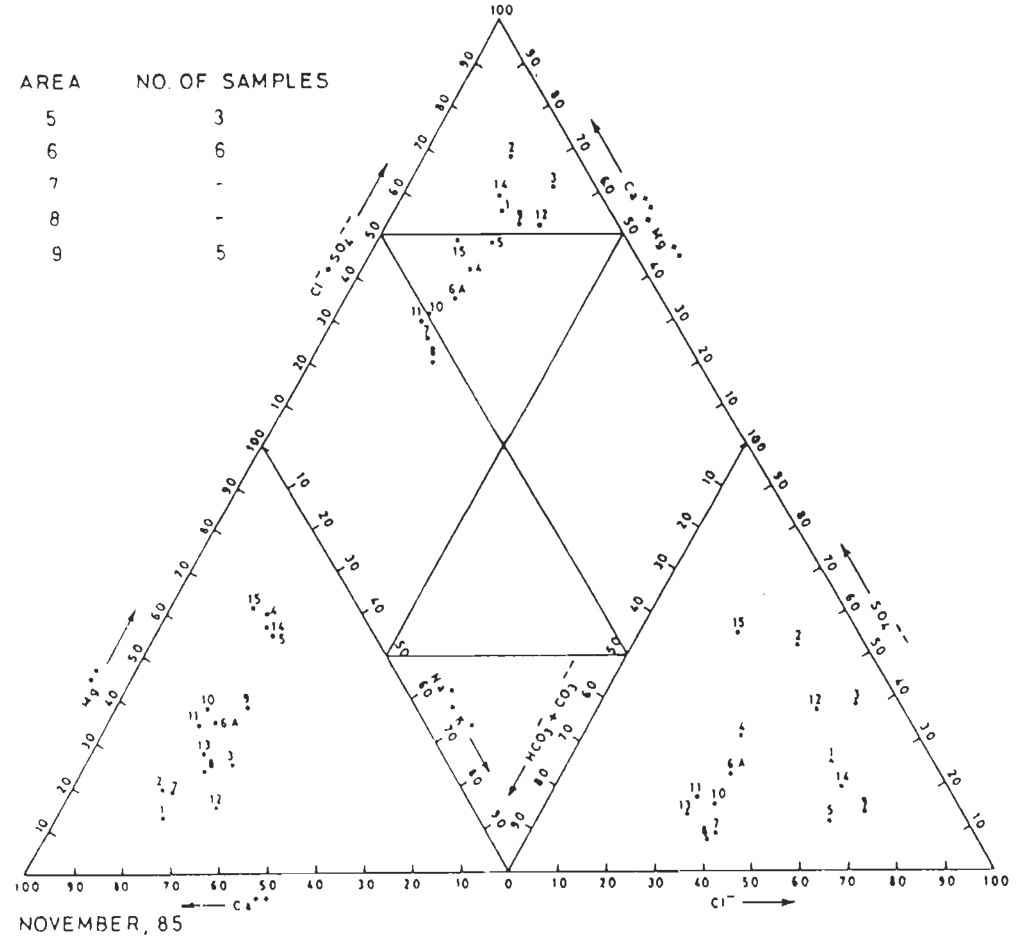
AREA	NO OF SAMPLES
5	5
6	6
7	-
8	-
9	4

FIG. 4·11 PIPER TRILINEAR DIAGRAM FOR GROUND WATER SAMPLES JUNE 85



AREA	NO. OF SAMPLES
5	8
6	3
7	-
8	-
9	3

FIG 4·12 PIPER TRILINEAR DIAGRAM FOR GROUND WATER SAMPLES SEPTEMBER,85



AREA	NO. OF SAMPLES
5	3
6	6
7	-
8	-
9	5

FIG 4·13 PIPER TRILINEAR DIAGRAM FOR GROUND WATER SAMPLES

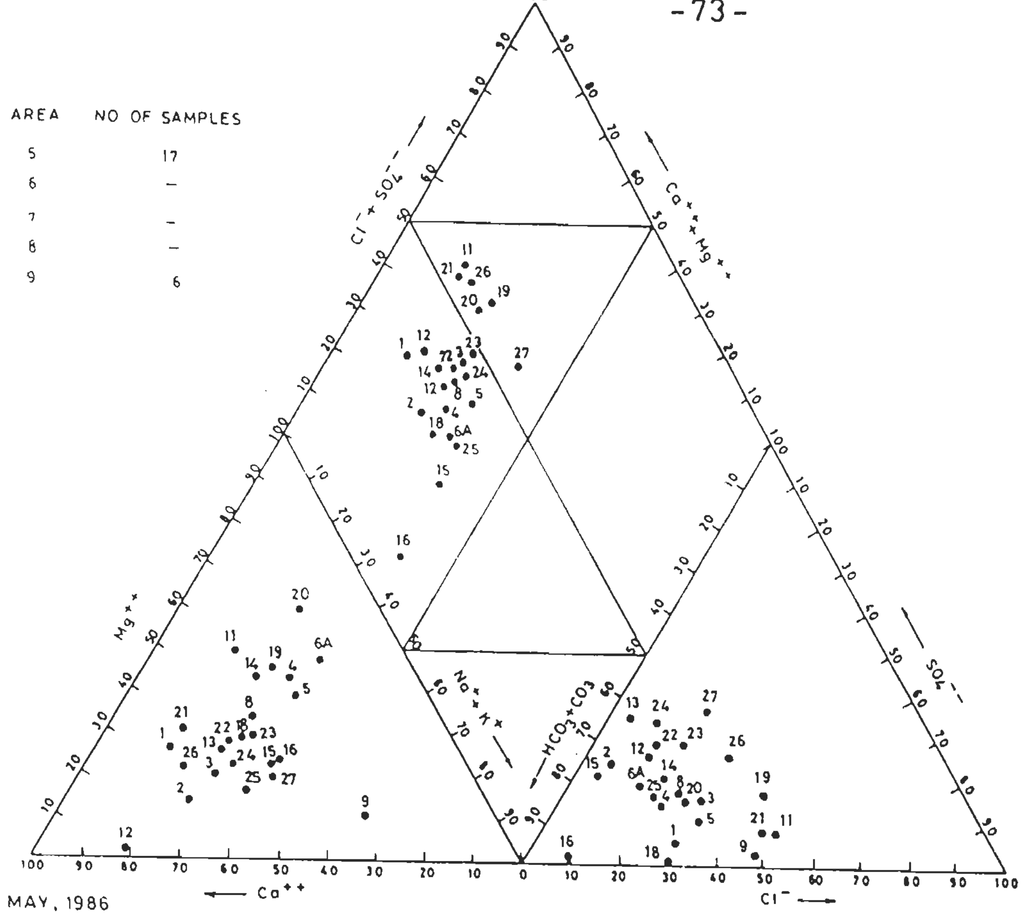


FIG 4·14 PIPER TRILINEAR DIAGRAM FOR GROUND WATER SAMPLES MAY, 86

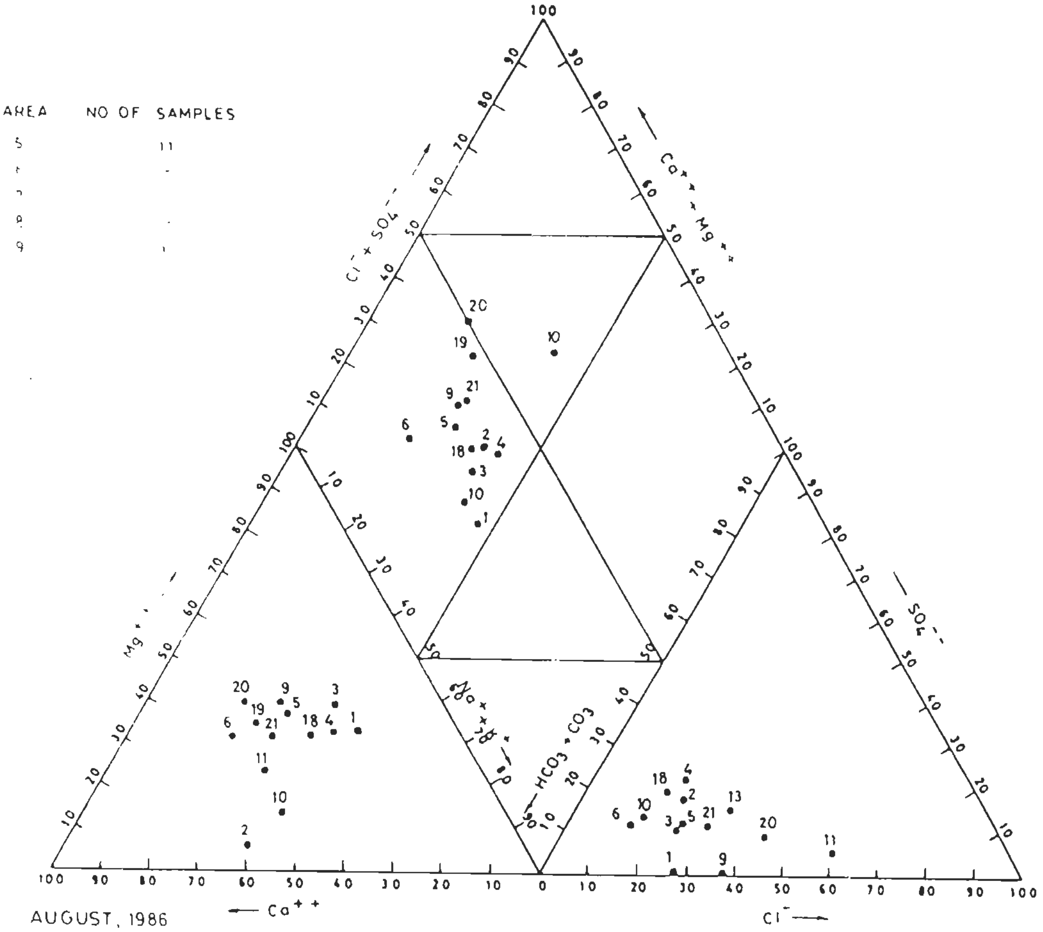


FIG 4·15 PIPER TRILIEAR DIAGRAM FOR GROUND WATER SAMPLES AUGUST,1986

Table: 4·7 : Details of Ground Water Samples Belonging to Different Areas of Piper Trilinear Plots

Area No.	in Trilinear Plot	April '85	June '85	September '85	November '85	May '86	August '86
Area : 5	Carbonate Hardness (Secondary alkalinity) exceeds fifty percent	3	5	8	3	17	11
Area : 6	Non-carbonate hardness (Secondary salinity) exceeds fifty percent	7	6	3	6	-	-
Area : 9	No one cation-anion pair exceeds fifty percent	1	4	3	5	6	1

the ground water of the area is the dominance of alkaline earths(Ca^{++} and Mg^{++}). This is also noticed from the Stiff diagrams.

It has been suggested by Handa (1964) that the ground water in the Bhabhar-Tarai belt of the Indo-gangetic alluvial tract in western Uttar Pradesh and Punjab belongs to the bicarbonate province indicating that a substantial part of ground water is derived as recharge from the Bhabhar zone in the north. In an area of high rainfall where evapotranspiration is low, the chlorides and sulphates are leached off and, therefore, ground water will belong to the alkaline earth bicarbonate province. It seems difficult to assign any specific reason for the dominant secondary salinity (non-carbonate hardness) in some of the ground water samples of the present area. However, in the hydrochemical provinces map given by Handa (1964), HCO_3^- chloride province is seen to have its north-eastern boundary passing close to the river Yamuna. The dominance of chloride-sulphate in the ground water of Hindon Yamuna Doab was also reported by Khan (1987). One of the reasons for relatively high concentration of the chloride-sulphate in some ground water samples can be due to the relatively high evapotranspiration taking place in low rainfall periods, due to which the near surface ground water gets enriched in chloride and sulphate.

4.10 HYDROCHEMICAL FACIES

The concept of hydrochemical facies(Back, 1960; Seaber, 1962) has been used to provide a model for explaining the distribution and genesis of principal types of ground water in the study area. Back and Hanshaw (1965) have suggested two main type of facies i.e. cation facies and anion facies. The overall chemical character of water is determined by both cation and anion facies. For the purpose of classifications, the central area of the Hill-Piper diagram is divided into segments depending upon the dominant ions. For example $Ca^{++} + Mg^{++}$ facies indicate that water is having over 90% Ca^{++} and Mg^{++} and $Na^{+} - K^{+}$ is less than 10%. On the other hand, $Na^{+} + K^{+} - Ca^{++} + Mg^{++}$ facies indicate that $Na^{+} + K^{+}$ are the dominating ions in comparison to $Ca^{++} + Mg^{++}$. The analytical data of ground water samples of the study area has been classified into 8 hydrochemical facies as given in table 4.8.

Table 4.8: Hydrochemical Facies of Ground Water

Hydrochemical facies	No. of water samples in each facies					
	April 85	June 85	Sept. 85	Nov. 85	May 86	Aug. 86
I $Ca^{++}+Mg^{++}-HCO_3^{-}-Cl^{-}+SO_4^{--}$	1	5	3	-	-	-
II $Ca^{++}+Mg^{++}-Cl^{-}+SO_4^{--}-HCO_3^{-}$	4	8	-	10	-	-
III $Ca^{++}+Mg^{++}-Na^{+}+K^{+}-HCO_3^{-}-Cl^{-}+SO_4^{--}$	2	-	6	-	17	12
IV $Ca^{++}+Mg^{++}-Na^{+}+K^{+}-C + SO_4^{--}-HCO_3^{-}$	5	2	6	4	6	2
V $Na^{+}+K^{+}-Ca^{++}+Mg^{++}-HCO_3^{-}-Cl^{-}+SO_4^{--}$	-	-	-	-	-	-
VI $Na^{+}+K^{+}-Ca^{++}+Mg^{++}-Cl^{-}$	-	-	-	-	-	-

$+SO_4^{--} - HCO_3^{-}$						
VII $Na^{+}+K^{+}-HCO_3^{-}-Cl^{-}+SO_4^{--}$	-	-	-	-	-	-
VIII $Na^{+}+K^{+}-Cl^{-}+SO_4^{--}-HCO_3^{-}$	-	-	-	-	-	-

For the months of April, 1985 and June, 1985 ground water samples mainly belong to $Ca^{++} + Mg^{++} - Cl^{-} + SO_4^{--} - HCO_3^{-}$ hydrochemical facies, followed by $Ca^{++} + Mg^{++} - HCO_3^{-} - Cl^{-} + SO_4^{--}$ and $Ca^{++} + Mg^{++} - Na^{+} + K^{+} - Cl^{-} + SO_4^{--} + HCO_3^{-}$. In the month of September, 1985 generally the ground water samples represent the $Ca^{++} + Mg^{++} - Na^{+} + K^{+} - HCO_3^{-} - Cl^{-} + SO_4^{--}$ and $Ca^{++} + Mg^{++} - Na^{+} + K^{+} - Cl^{-} + SO_4^{--} - HCO_3^{-}$ hydrochemical facies. Similarly, for the month of November, 1985, the ground water samples mainly belong to $Ca^{++} + Mg^{++} - Na^{+} + K^{+} - Cl^{-} + SO_4^{--} - HCO_3^{-}$ hydrochemical facies, and for May, 1986 & August, 1986 to $Ca^{++} + Mg^{++} - Na^{+} + K^{+} - HCO_3^{-} - Cl^{-} + SO_4^{--}$.

A perusal of the hydrochemical facies indicates that in the ground water of the study area, alkaline earths predominate the alkalies. Among the anions, bicarbonate is dominant over Cl^{-} and SO_4^{--} mainly in wet periods, whereas chloride and sulphate are dominant over bicarbonate in other periods. This phenomenon has been earlier discussed in the interpretation of Hill Piper Trilinear plots.

4.11 WATER QUALITY INDICES

In the present study, two approaches have been used to determine the water quality indices (WQI).

(i) A method based on Horton's (1965) approach, in which the weighted arithmetic mean of individual parameters are used to find the rating values.

(ii) Ambient Water Quality Index: An approach modified after Inhaber (1975) in which an 'Ambient Water Quality Index' has been computed using subindices for toxic and decaying substances.

4.11.1 Horton Based Water Quality Index

The following four steps have been adopted for the formulation of Horton based W.Q.I.

1. Selection of quality characteristics
2. Establishment of rating scale
3. Weighting of characteristics
4. Computation of Water Quality Index.

4.11.1.1 Selection of Quality Characteristics

The selection of quality characteristics on which the index is to be based is significant because too large a number of characteristics would make the index unwieldy; it should appear practical to use only those characteristics which are of greatest importance (Lohani,1981). The quality characteristics considered for WQI formulation are TDS, EC, pH, DO, BOD, COD, Ammonical Nitrogen, Nitrite, Chloride, Sulphate, Cadmium, Lead,total Chromium and Phosphorus. The selection of these parameters was restricted by the choice of monitored variables, as well as their relative significance. The ions like Calcium, Magnesium, Sodium,Potassium and Carbonate etc. were ignored in these indices due to their relatively insignificant role in affecting their cumulative impact for specified uses like public supplies, contact recreation, fish life etc. (Chaudhary, 1981; Hammer and Mackichan, 1981).

4.11.1.2 Establishment of Rating Scale

Rating scales have been chosen so that each of the characteristics can be assigned a value depending on concentration of quality parameters. The suggested rating scale for different characteristics can be mathematically expressed in terms of measured pollutant concentration. In the present work, the ratings have been defined in the range of 100 to 400. The criteria for rating scale is that the minimum (allowable) value of specified parameter for an arbitrary defined use corresponds to a rating value of 100. The maximum value of rating has been taken as 400, being the cut off value, which corresponds to the highly objectionable concentration of specified parameter. These cut off limits are fixed on the basis of available literature (Ott, 1978; Lohani, 1981; Bhargava, 1983a) and the extreme values of specified parameter observed. It may be concluded that higher the concentration of pollutants, higher will be the rating value and poor will be the quality of water with respect to the mentioned pollutant parameter. If X_1 is allowable limit and X_2 is highly objectionable limit of a specified parameter, then the rating scale can be graphically shown as in Fig. 4.16.

If X is the concentration of pollutant parameters, then the corresponding rating value ($Q_{parameter}$) can be obtained as follows:

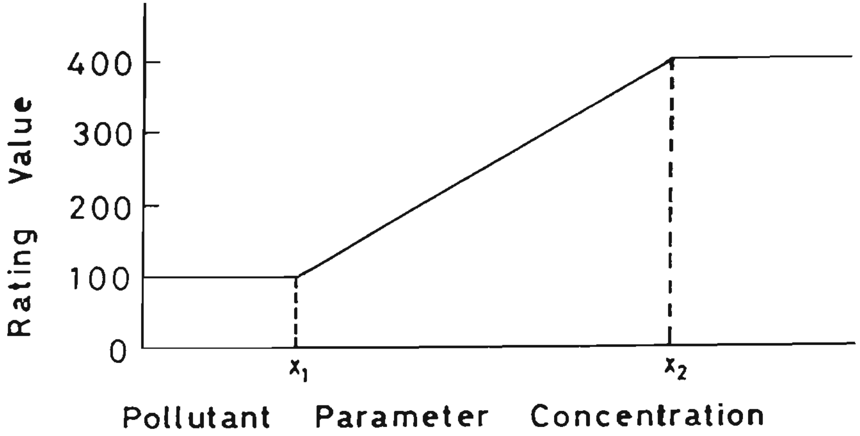


FIG. 4.16 RATING VALUE Vs ARBITRARY POLLUTANT PARAMETER CONCENTRATION

$$Q_{parameter} = \frac{400 - 100}{(X_2 - X_1)} (X - X_1) + 100 \qquad \ldots\ldots\ldots \qquad (4.1)$$

It can be substantiated that the rating value ($Q_{Parameter}$) indicates the percentage pollution of water in relation to allowable pollutant concentration for defined use only when the rating lies in the range 100 + E to 100 -E where E is positive real number (E > 0). The rating value equations as developed in the present case are given in Table 4.9. The graphical representation of the individual parameters is given in Fig. 4.17. and 4.18. It is observed from these plots that each straight line (in a plot) has a definite slope indicating direct relation between Q parameter and X except in case of DO where, an inverse relation between Q(DO % saturated) and % DO saturation has been observed.

4.11.1.3 Weighting of the Characteristics

Weights are assigned to different water quality parameters to show their relative importance. In the present study, the weighting factors are arbitrarily assigned the range of 1 to 5, based on the understanding about the sensitivity of individual pollutants, the weighting factors modified on the basis of Lohani (1984).

4.11.1.4 Computation of water Quality Index (W.Q.I)

Knowing the weighting factor and rating value for each parameter, the W.Q.I can be obtained by taking weighted arithmetic mean i.e.

Table : 4.9 : Selected Water Quality Characteristics, Weighting Factors and Rating Curve Equations for Computation of Surface Water Quality Index

Parameters	Unit	Weight (W_i)	Rating 100 to 400 (X_1)	(X_2)	Rating Curve Equations (Q_i)
Total dissolved Solids	mg/l	2.0	700	2100	$Q_{TDS} = \frac{3}{14}(X-700)+100$
Conductivity	Micro-mhos/cm	2.0	1000	3000	$Q_{Cond} = \frac{3}{20}(X-1000)+100$
pH	-	2.0	6 to 9	-	$Q_{pH} = 100$, for pH in range 6 to 9
D.O.(% Saturation)	-	5.0	40%	5%	$Q_{D.O.} = \frac{-300}{35}(X-5) + 400$
$BOD_{5,20}$	mg/l	5.0	3	100	$Q_{BOD} = \frac{300}{97}(X-3) + 100$
COD	mg/l	5.0	10	200	$Q_{COD} = \frac{300}{190}(X-10) + 100$
Ammonical Nitrogen(as N)	mg/l	3.0	0.1	2.0	$Q_{A.N.} = \frac{300}{1.9}(X-0.1)+100$
Nitrate(as N)	mg/l	3.0	0.0	0.8	$Q_{No_3} = 375X + 100$
Nitrite(as N)	mg/l	3.0	0.1	1.0	$Q_{No_3} = \frac{300}{0.9}(X-0.1)+100$
Chloride(as Cl^-)	mg/l	2.0	10	250	$Q_{Cl} = \frac{300}{240}(X-10) + 100$
Sulphate(as SO_4^{--})	mg/l	1.0	10	250	$Q_{So_4} = \frac{300}{240}(X-10) + 100$
Cadmium(as Cd^{++})	mg/l	4.0	0.01	0.07	$Q_{Cd} = \frac{300}{0.06}(X-.01)+100$
Lead(as Pb^{++})	mg/l	4.0	0.05	0.7	$Q_{Pb} = \frac{300}{0.65}(X-0.05)+100$
Total Chromium (as Cr)	mg/l	4.0	0.05	0.4	$Q_{Cr} = \frac{300}{0.35}(X-0.05)+100$
Phosphate(as P)	mg/l	3.0	0.0	2.0	$Q_{Po_4} = 150X + 100$

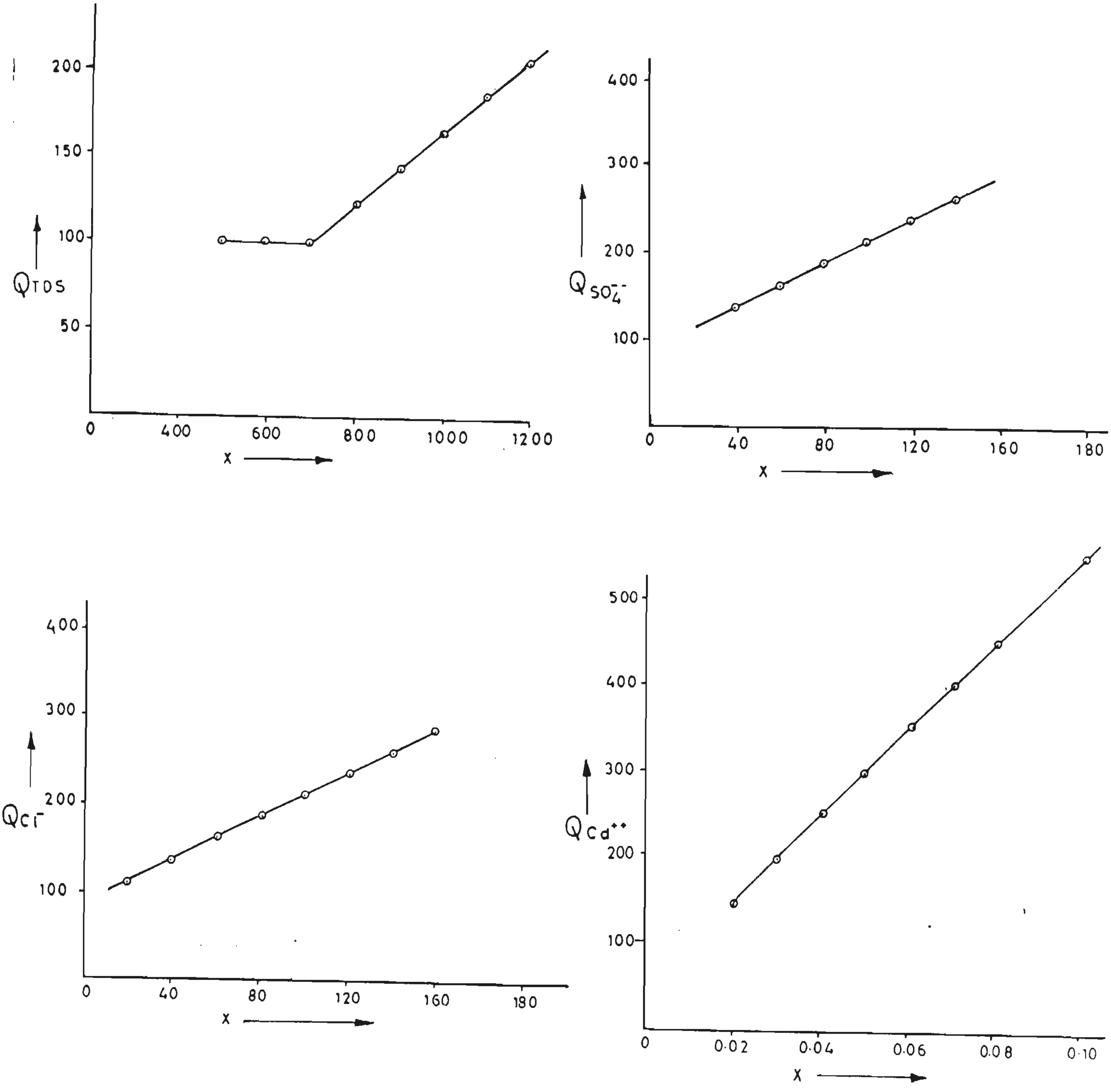


FIG. 4·17 PLOTS OF Q_{TDS}, $Q_{SO_4^{--}}$, Q_{Cl^-} & $Q_{Cd^{++}}$ VERSUS PARMETER VALUE (X)

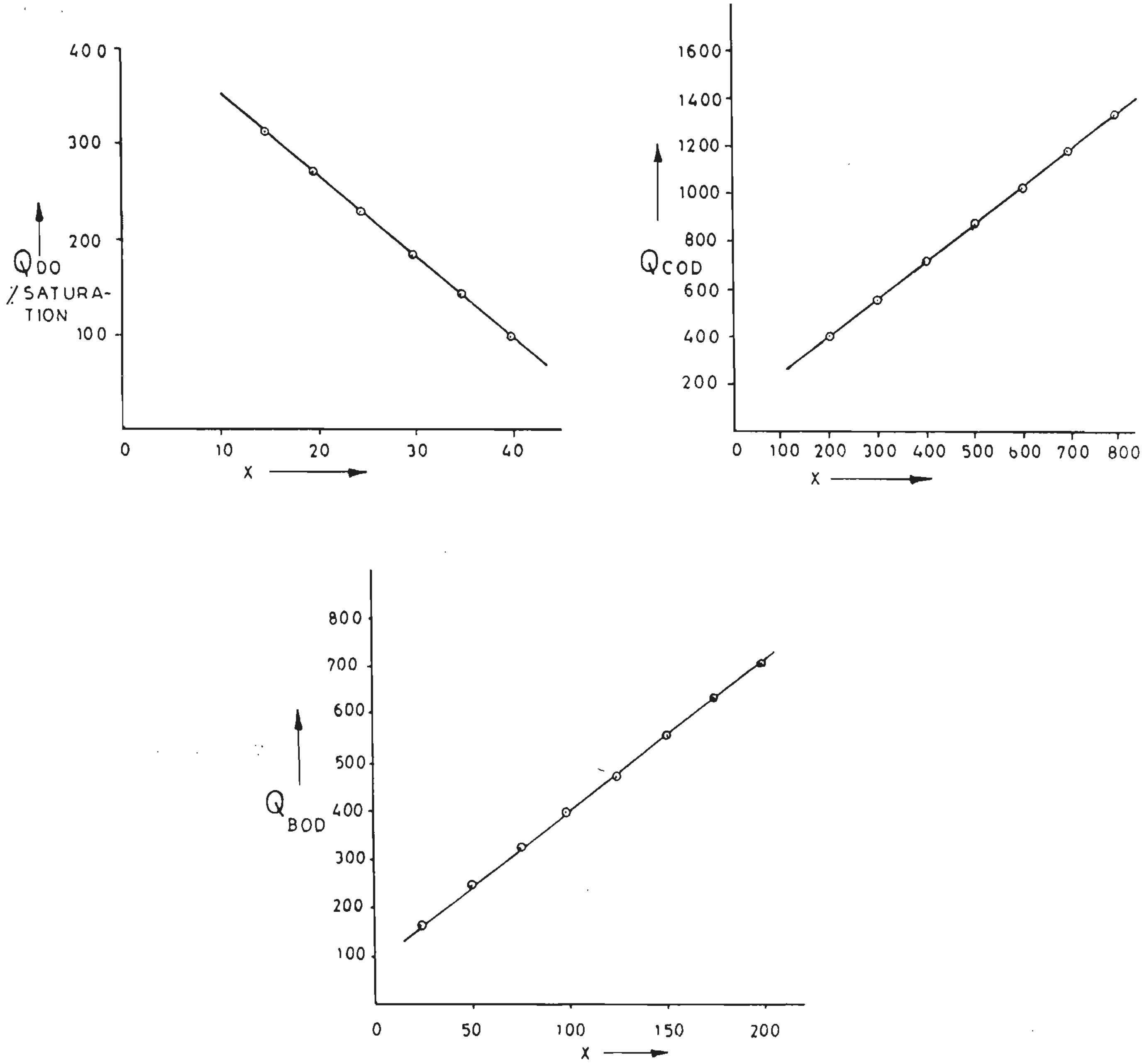


FIG. 4·18 PLOTS OF Q_{DO}% Q_{COD} & Q_{BOD} VERSUS PARMETER VALUE(X)

$$W.Q.I = \frac{\sum^{n} Q_i W_i}{\sum_{i=1}^{n} W_i} \qquad \ldots\ldots (4.2)$$

Where,

Q_i = rating of i^{th} quality parameter

W_i = assigned weight to parameter

n = number of parameters utilised for the computation of W.Q.I.

4.11.1.5 Interpretation of Horton Water Quality Indices

The computed water quality indices for surface waters of the study area for eight different periods between May, 1985 to November, 1987 are summarised in Table 4.10 to 4.17, (Appendix.-I) and are plotted in bar diagrams (Fig. 4.19 and 4.20). From the table, it is observed that the values of water quality indices vary between 117.00 to 307.57. The maximum value is in the month of May, 1986 at location SW_{19} (near village Kapasa) probably due to the effect of mixing with the effluents of paper mill in the proximity. The lowest values of water quality indices are found in the monsoon month of August, 85 at the upstream locations SW_1 (Kailashpur) and SW_3 (Nagdeo nala).

The water quality index (WQI) profiles along the course of river Hindon and its tributaries are shown in Fig. 4.21 to 4.28. Based on all these profiles, it can be concluded that the water quality gets deteriorated in Nagdeo nala at Naugajapir due to the addition of Foremost Daries effluent and Padli nala water. The

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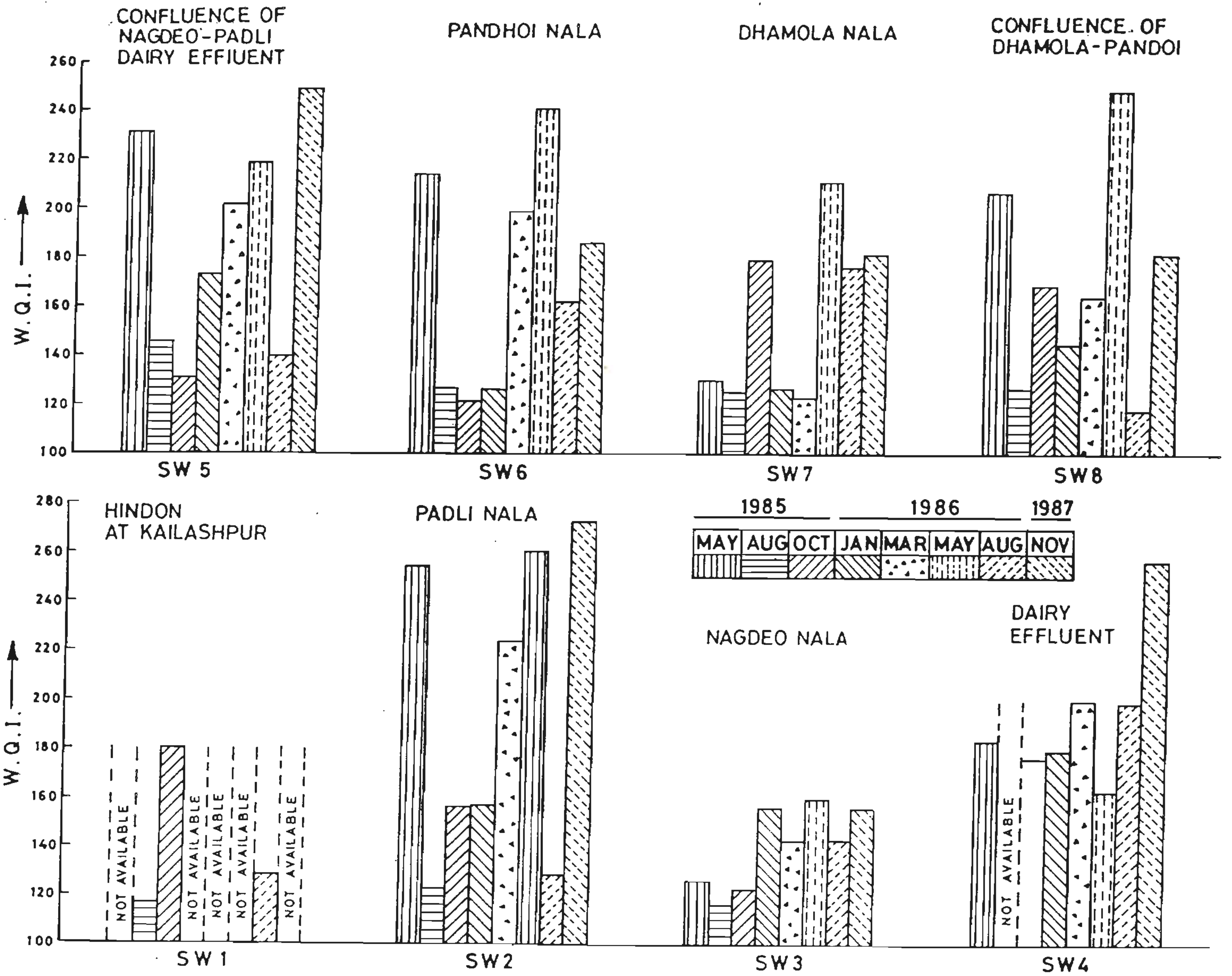


FIG. 4·19 TEMPORAL VARIATION OF WATER QUALITY INDEX AT SURFACE WATER SAMPLING LOCATION SW 1 TO SW 8

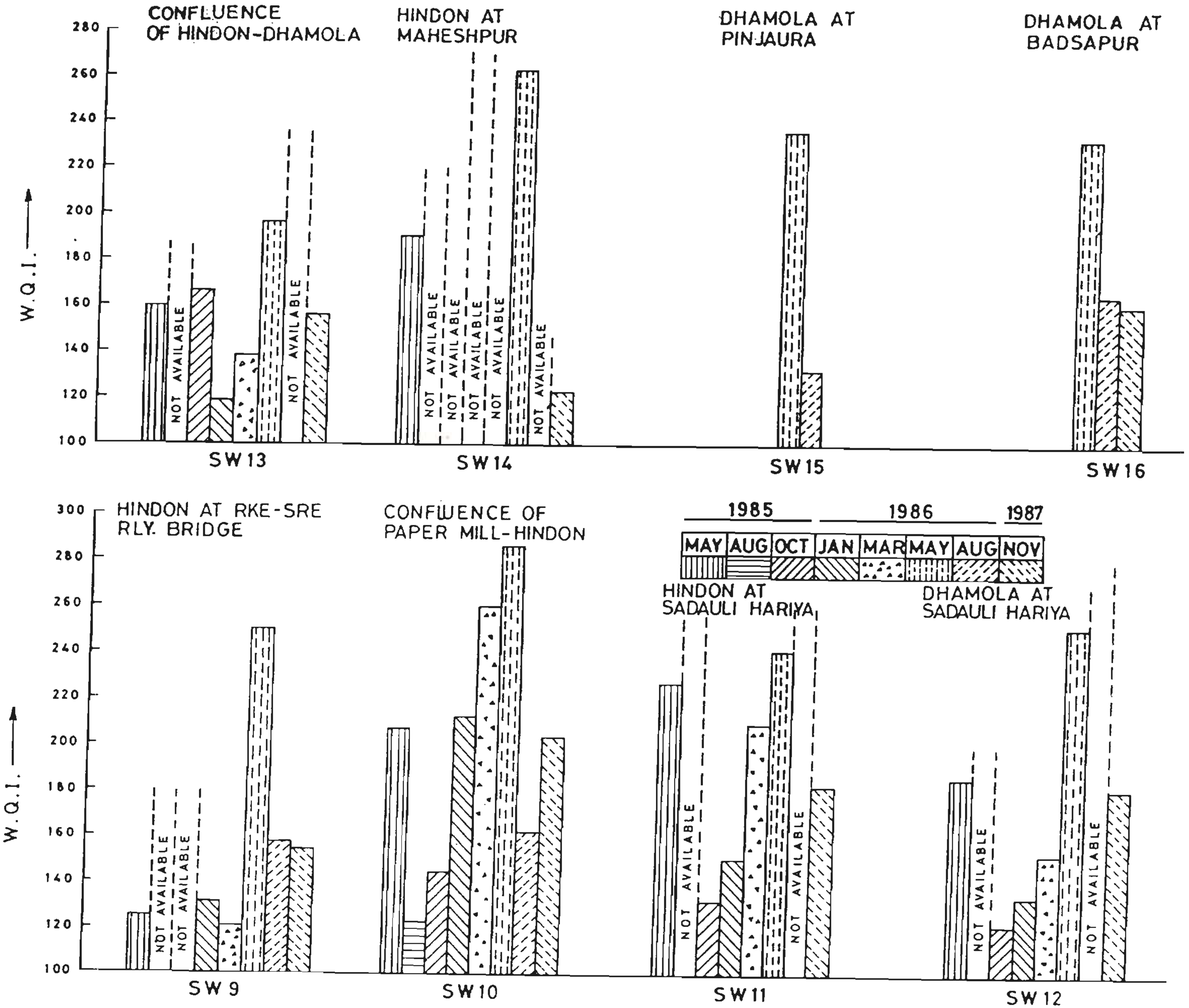
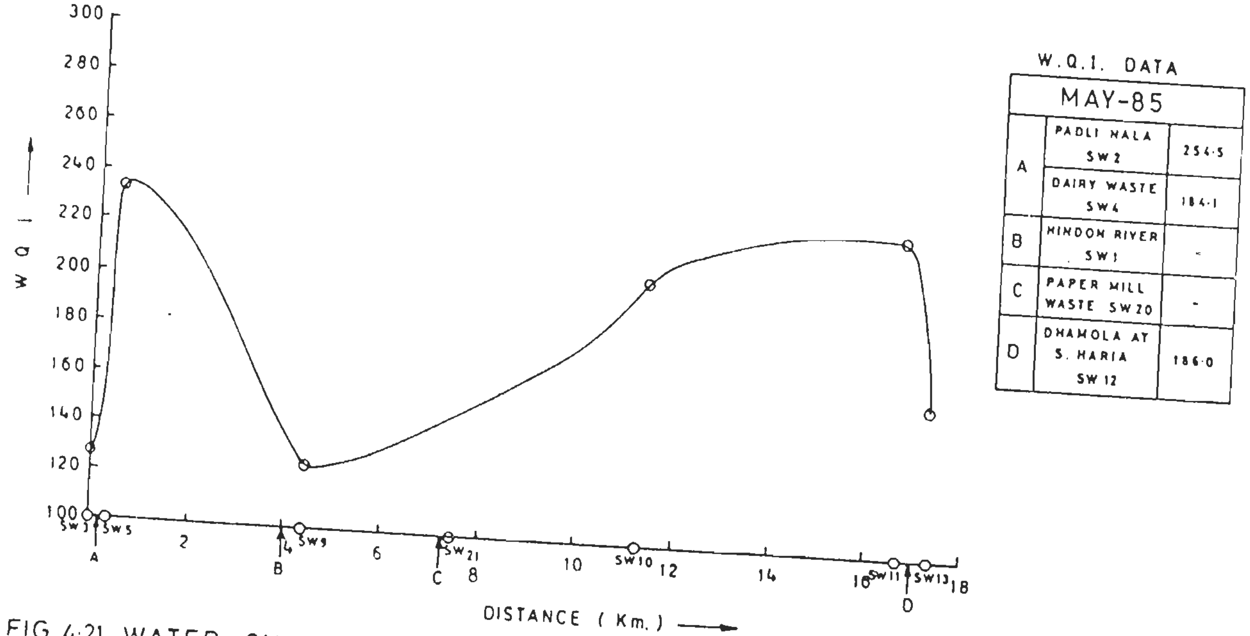


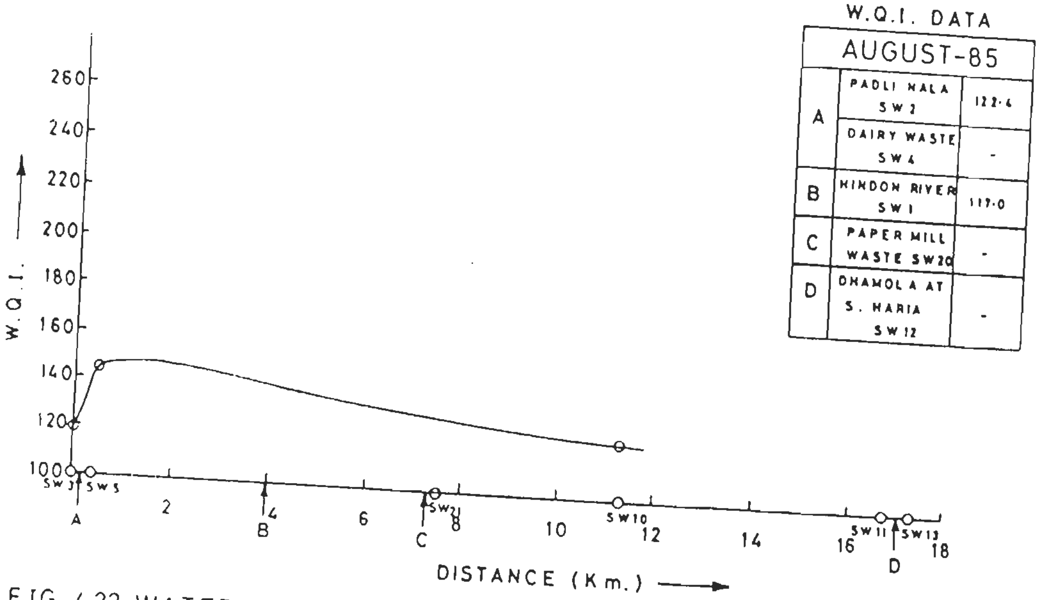
FIG. 4·20 TEMPORAL VARIATION OF WATER QUALITY INDEX AT SURFACE WATER SAMPLING LOCATION SW 9 TO SW 16



W.Q.I. DATA

MAY-85		
A	PADLI NALA SW 2	254·5
	DAIRY WASTE SW 4	184·1
B	HINDON RIVER SW 1	-
C	PAPER MILL WASTE SW 20	-
D	DHAMOLA AT S. HARIA SW 12	186·0

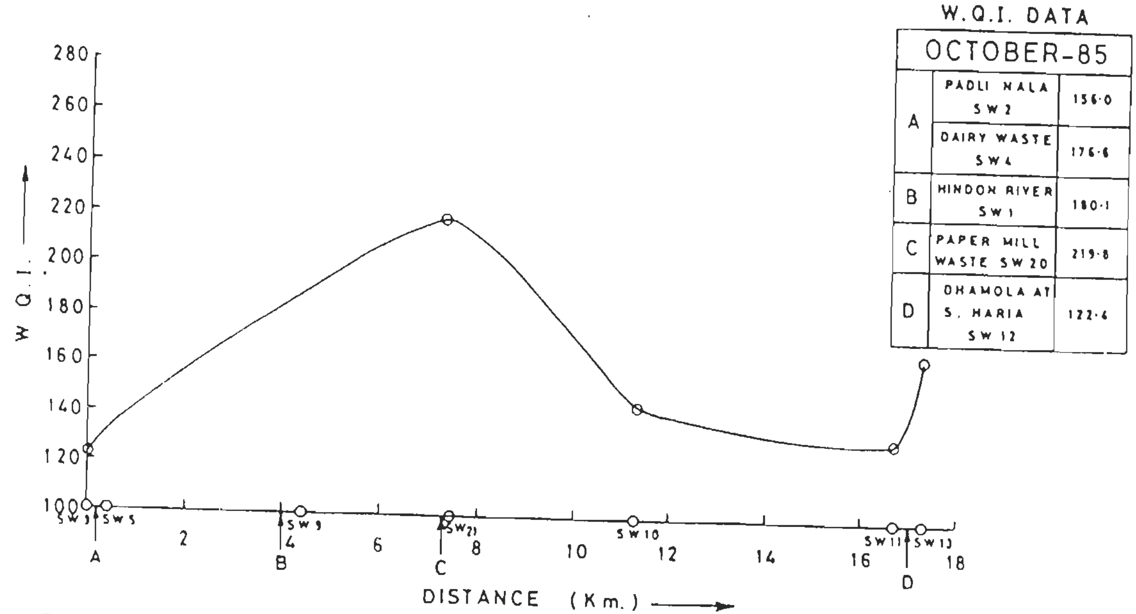
FIG. 4·21 WATER QUALITY INDEX PROFILE ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)



W.Q.I. DATA

AUGUST-85		
A	PADLI NALA SW 2	122·6
	DAIRY WASTE SW 4	-
B	HINDON RIVER SW 1	117·0
C	PAPER MILL WASTE SW 20	-
D	DHAMOLA AT S. HARIA SW 12	-

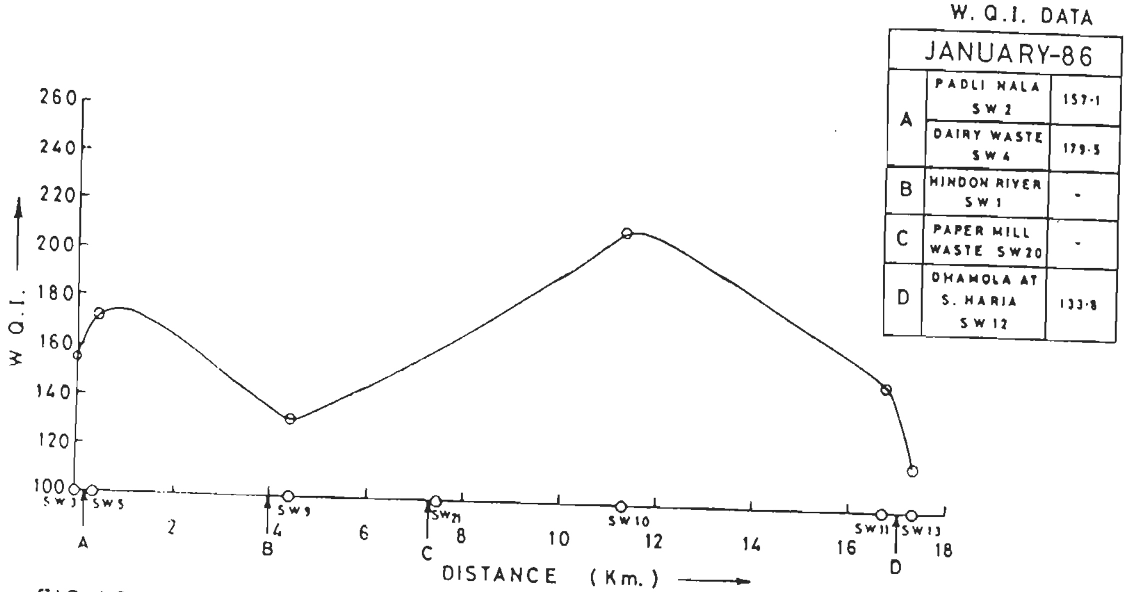
FIG. 4·22 WATER QUALITY INDEX PROFILE ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)



W.Q.I. DATA

OCTOBER-85		
A	PADLI NALA SW 2	156·0
	DAIRY WASTE SW 4	176·6
B	HINDON RIVER SW 1	180·1
C	PAPER MILL WASTE SW 20	219·8
D	DHAMOLA AT S. HARIA SW 12	122·6

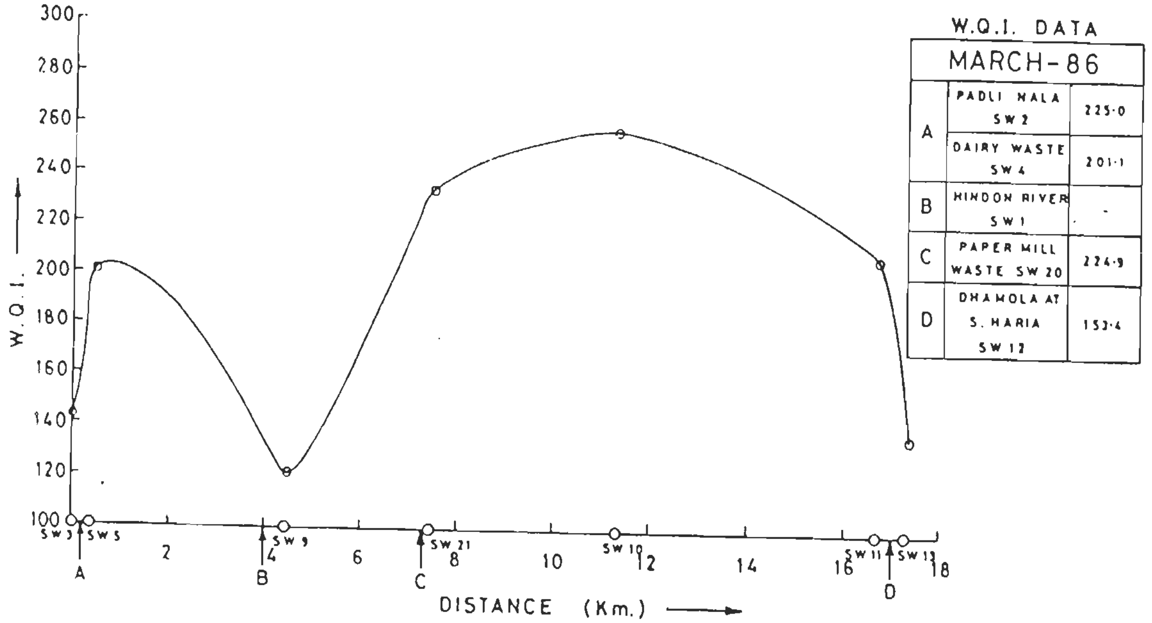
FIG 4·23 WATER QUALITY INDEX PROFILE ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)



W.Q.I. DATA

JANUARY-86		
A	PADLI NALA SW 2	157·1
	DAIRY WASTE SW 4	179·5
B	HINDON RIVER SW 1	-
C	PAPER MILL WASTE SW20	-
D	DHAMOLA AT S. HARIA SW 12	133·8

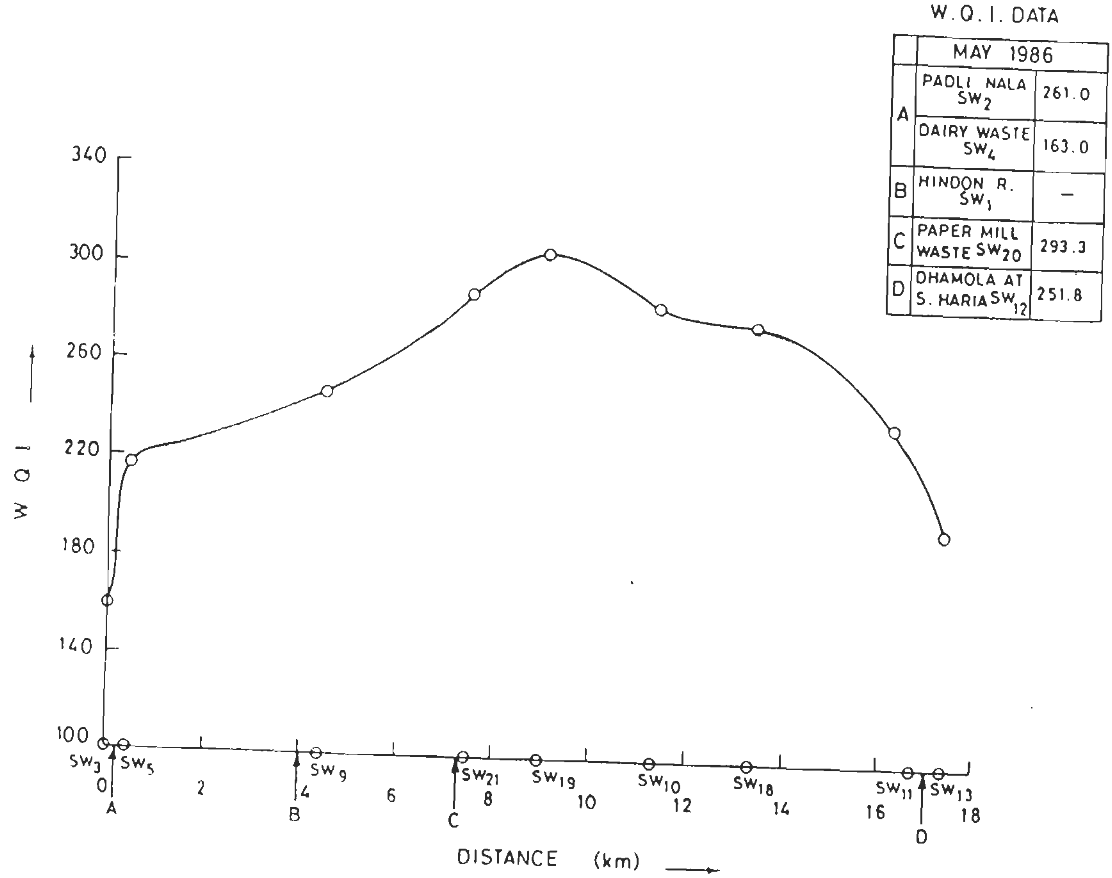
FIG 4·24 WATER QUALITY INDEX PROFILE ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)



W.Q.I. DATA

	MARCH-86	
A	PADLI NALA SW 2	225.0
	DAIRY WASTE SW 4	201.1
B	HINDON RIVER SW 1	-
C	PAPER MILL WASTE SW 20	224.9
D	DHAMOLA AT S. HARIA SW 12	153.4

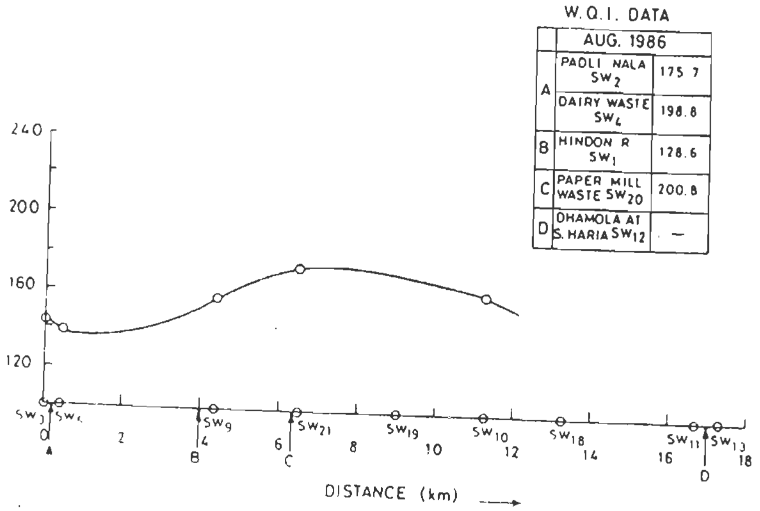
FIG 4.25 WATER QUALITY INDEX PROFILE ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)



W.Q.I. DATA

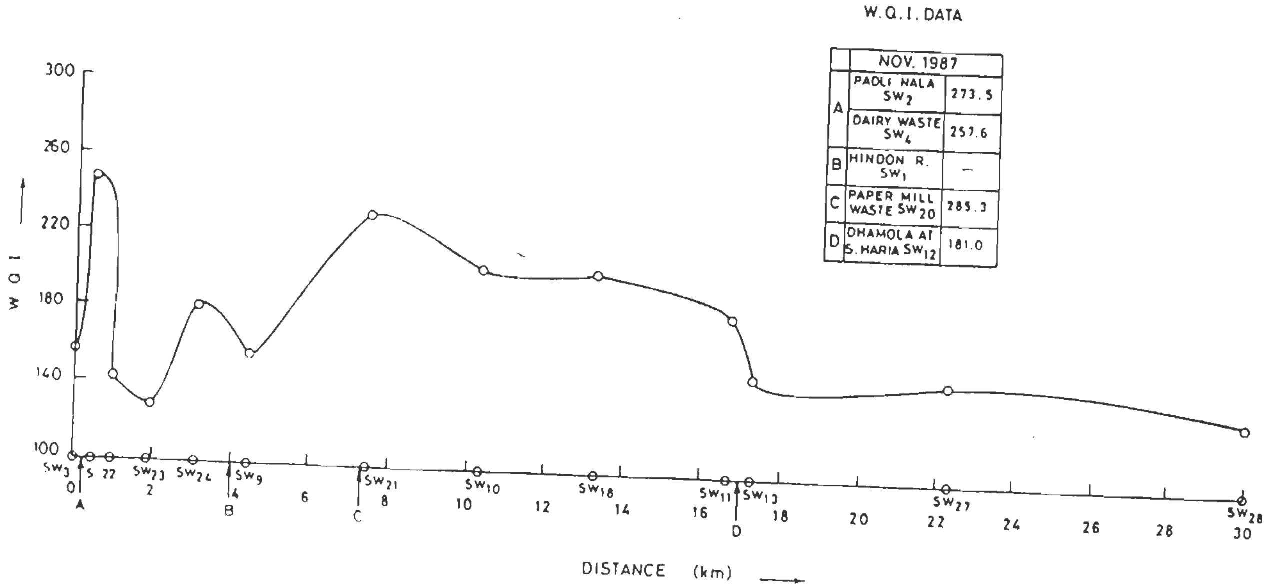
	MAY 1986	
A	PADLI NALA SW$_2$	261.0
	DAIRY WASTE SW$_4$	163.0
B	HINDON R. SW$_1$	–
C	PAPER MILL WASTE SW$_{20}$	293.3
D	DHAMOLA AT S. HARIA SW$_{12}$	251.8

FIG. 4.26 WATER QUALITY INDEX PROFILES ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)


W.Q.I. DATA

	AUG. 1986	
A	PAOLI NALA SW_2	175.7
	DAIRY WASTE SW_4	198.8
B	HINDON R SW_1	128.6
C	PAPER MILL WASTE SW_{20}	200.8
D	DHAMOLA AT S. HARIA SW_{12}	—

FIG. 4·27 WATER QUALITY INDEX PROFILES ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)


W.Q.I. DATA

	NOV. 1987	
A	PAOLI NALA SW_2	273.5
	DAIRY WASTE SW_4	257.6
B	HINDON R. SW_1	—
C	PAPER MILL WASTE SW_{20}	285.3
D	DHAMOLA AT S. HARIA SW_{12}	181.0

FIG 4·28 WATER QUALITY INDEX PROFILES ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY) quality of water further downstream of this confluence (location SW_5) improves steadily until another effluent (from Star Paper mill) joins the Hindon river near locatin SW_{21}. At this point, a steep rise can be noted almost in all WQI profiles, indicating deterioration in the quality of surface water. This increasing trend in W.Q.I values continues downstream upto location SW_{10} (near Tapri Railway bridge, Fig. 1.1), A reversal in this W.Q.I profile is again noticeable further downstream upto Sadauli Hariya(location SW_{13}). In the month of November, 1987, when some additional sampling points were also monitored, the W.Q.I profiles (Fig. 4.28) indicate that the quality of water improves in the Hindon river downstream of Sadauli Hariya village, the minimum value of water quality index being 123 at location SW_{14} (Maheshpur).

It may be noted from Figs. 4.19 & 4.20 that the quality of water in Dhamola stream is generally better than Nagdeo stream as indicated by the overall lower values of W.Q.I (161.14-190.6). Further, the quality of water in Pandhoi nala (SW_6) is poorer than the Dhamola nala at SW_7.

4.11.2 Ambient Water Quality Index

The ambient water quality index (Inhaber, 1975) deals with the overall quality of the water environment excluding the waste discharged into it. The ambient index usually involves the trace metal, contamination of waters, the suitability of river water (in terms of turbidity) for the specified use, and the mercury contamination for fish life. If each of the three components of the ambient water quality index (Iamb) are given equal weights, then,

$$I_{amb} = \sqrt{\frac{(I_{TM})^2 + (I_{turb})^2 + (I_{fish})^2}{3}} \qquad \text{..... (4.3)}$$

where,

I_{amb} = the ambient index

I_{TM} = average index for trace metals

I_{turb} = index for turbidity

I_{fish} = average index for mercury in fish.

As the effluent and ambient water quality indices are found to have an approximately equal weight in an overall water quality index (Inhaber, 1975), equation (4.4) is adopted for evaluating a combined water quality index by integrating these subindices:

$$I_{water} = \sqrt{\frac{(I_{effl})^2 + (I_{amb})^2}{2}} \qquad \text{......(4.4)}$$

where,

I_{water} = combined water quality index.

I_{effl} = effluent quality index.

4.11.2.1 Rationale for a Modified Water Quality Index

As described earlier, the aquisition of field data for the present study precluded evalution of indices for mercury in fish-life as well as turbidity determination; as such it became necessary to estimate an ambient water quality index for the prevailing water environment using available parameters. This necessitated formulation of new relation(s) which would suitably assess the quality status of the ambient waters. Accordingly, a relevant subindex for trace matals (I_{TM}) estimated from the concentration of Cd^{++} and Pb^{++} was conceived as an average index for trace metals along with the associated hardness. Further, to highlight the on-going DO deficits, BOD loads as well as the contribution of anthropogenic sources in the lotic waters (without substantive waste loading outfalls), it was considered necessary to introduce additional parameters in the computation of ambient index (I_{amb}). Such an ambient index is deemed to incorporate the impact of minor hidden and unspecified sources of waste loadings in the study areas.

4.11.2.2 Logic for Relevant Equations

In the present study, the logic given by Inhaber (1975) for computing the index for trace metals (I_{TM}) has been slightly modified keeping in view the tolerance limits of the individual trace metals and the toxicity caused due to the variation in hardness. Thus the innovation in the approach introduced was the degree of high concentration of the relevant trace metals over its minimum objective limit (allowed) (in terms of the ratio of actual concentration to the allowed minimum concentration) in place of Inhaber's method of assigning 0 and 1 values to cadmium or chromium. Accordingly, in this study following indices are considered :

$$\text{Sub index for Cadmium} = \frac{\text{Actual concentration of } Cd^{++}}{\text{Objective concentration of } Cd^{++}}$$

$$\text{Sub index for Lead} = \frac{\text{Actual concentration of } Pb^{++}}{\text{Objective concentration of } Pb^{++}}$$

$$I_{TOX} = \text{Sub index of } Cd^{++} + \text{Sub index for } Pb^{++}$$

For calculation of I_{TM}, the criteria for the influence of hardness of the water on the toxic effect of the trace metals, as considered by Inhaber (1975) was retained, and thus,

When hardness ranges from 60 to 120 mg/l, the sub index (I_H) for water hardness is assigned as 0 ;

When hardness ranges from 0 to 60 mg/l, I_H is taken as 0.5, indicating hazardous water ;

When hardness is above 120 mg/l, I_H is taken as 0.2, indicating merely the impact of hardness alone.

By combining the above criteria, the I_{TM} can be calculated by eq. (4.5).

$$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}} \qquad \text{....(4.5)}$$

Subsequently, the index for trace metals has been integrated with the subindices for dissolved oxygen (I_{DO}), biochemical oxygen demand (I_{BOD}) and ammonical nitrogen (I_{AN}) to yield the ambient water quality index (I_{amb}) of the river waters, as under:

$$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})^2}{4}} \quad ....(4.6)$$

For computation of the individual sub indices for percent DO deficit, BOD and ammonical nitrogen, the relative percent concentration (or deficit in DO) of the relavent constituent(s) as applicable have been considered. The relative % concentration may be worked out from the ratio of the actual concentration to the objective concentration (allowed). Accordingly, sub index for DO is as under :

$$I_{DO_D} = \frac{\text{\% DO deficit}}{\text{Objective DO deficit}}$$

For Indian river conditions, where the mean water temperatures vary between 20°C to 30°C, the objective DO deficit (allowed) is taken to be 60 % of the DO saturation.

Similarly, sub index for BOD is given as :

$$(I_{BOD}) = \frac{\text{Actual BOD concentration in water}}{\text{Objective BOD concentration (allowed)}}$$

and, sub index for ammonical nitrogen is :

$$(I_{AN}) = \frac{\text{Actual ammonical nitrogen concentration in water}}{\text{Objective ammonical nitrogen concentration (allowed)}}$$

The computation of combined water quality index, taking into consideration the index for effluent quality (I_{effl}) could not been attempted in the present study.

4.11.2.3 Interpretation of Ambient Water Quality Indices

The computed ambient water quality indices for surface water of the study area for different periods (May, 1985 to November, 1987) are given in Table 4.18 to 4.25 (Appendix - II) and Fig. 4.29 and 4.30. It is seen that the ambient water quality index is generally in the range of 1.075 to 115.360. The water quality profiles along the Hindon river and its tributaries are given in Fig. 4.29 to 4.30. Based on these profiles, it can be concluded that the general nature of Ambient W.Q.I profiles is similar to that of Horton based quality indices. The water quality gets deteriorated in Nagdeo nala at Naugajapir (location, SW_5) due to the addition of wastes from Foremost daries and card board factory into Padli nala. The quality of water downstream of this confluence improves steadily. The quality of water is also deteriorated at the confluence of paper effluent drain with the Hindon river (near SW_{21}). In general, the quality of water improves further downstream of Dhamola-Hindon confluence near Sadauli Hariya village (SW_{13}).

4.12 DISCUSSIONS

The representation of quality data for surface water and ground water of upper Hindon basin using different methods have helped in evaluating their overall quality in various parts of the basin during different seasons. An explained earlier, the ground water quality can be studied by representing the data in Stiff's diagrams, Piper trilinear diagrms and hydrochemical facies diagrams whereas the chemical data of surface water can be better

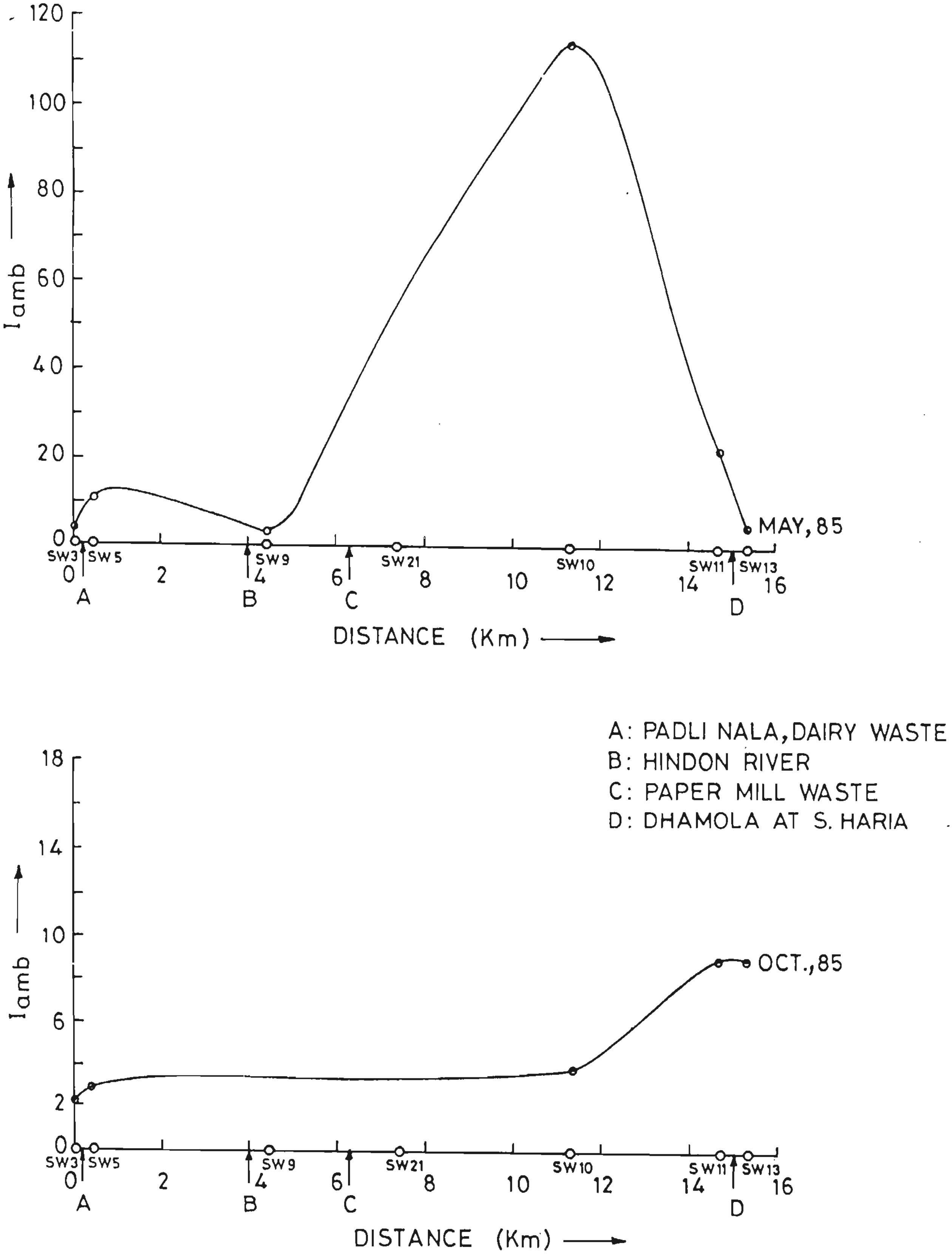


FIG.4·29 AMBIENT WATER QUALITY INDEX PROFILES ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)

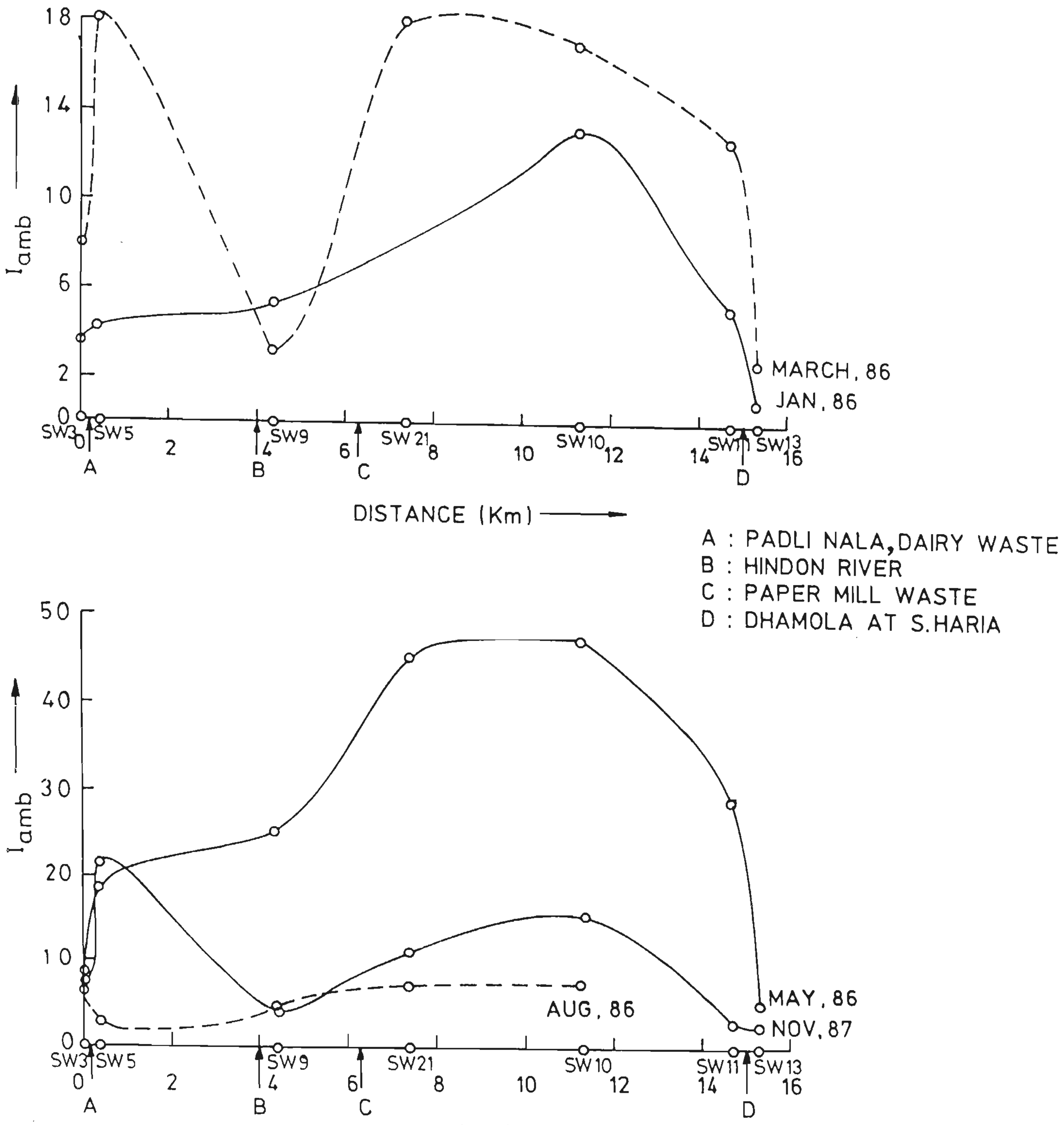


FIG. 4.30 AMBIENT WATER QUALITY INDEX PROFILES ALONG HINDON RIVER (INCLUDING NAGDEO TRIBUTARY)

studied by computing the water quality indices and plotting their values along stream courses.

The ranges of TDS in ground water and surface water of the study area (Appendix - I) indicate their general acceptability for drinking, irrigation and other purposes. However, concentration of some specific ions tend to render these waters unfit for human consumption as well as for irrigation & fish-culture. Some of the toxic metals (Cd^{++}, Pb^{++} and Total Chromium) whose concentration varies between 0.001-0.185, 0.02-1.960 and 0.007-0.315 mg/l respectively are also in higher concentration at several locations (Appendix - I). The reason for higher concentrations of these metals can be probably ascribed to the geology of the watershed of the Hindon river as well as discrete and unidentified sources of miscellaneous waste outfalls. In surface water, usually, the concentration of these ions shows a sudden spurt near the waste out falls from dairy paper mill and other industrial units.

The Stiff polygon maps for ground water indicate its overall dilution after rainy season . The Piper trilinear plots for the ground water indicate dominant noncarbonate hardness (secondary salinity) in the water samples for the year 1985 and carbonate hardness (secondary alkalinity) in year 1986. Based on this indications the hydrochemical facies of ground water in June and November, 1985 seems to be dominated by the $Ca^{++} + Mg^{++} - Cl^{-} + SO_4^{--} - HCO_3^{-}$ facies and by $Ca^{++} + Mg^{++} - Na^{+} + K^{+} - Cl^{-} + SO_4^{--} - HCO_3^{-}$ facies in the months of April and September, 1985, respectively. In 1986, the ground water seems to be dominated by excessive carbonate hardness, i.e. of $Ca^{++} + Mg^{++} - Na^{+} + K^{+} - HCO_3^{-} - Cl^{-} + SO_4^{--}$ facies. One of the reasons for the ground water to acquire a tendency of increasing concentrations of $Cl + SO_4^{--}$ (non-carbonate hardness) in 1985 may be due to low rainfall which was a below-normal rainfall year (850 mm). Handa (1964) has also classified the ground waters of part of Saharanpur district of Western Uttar Pradesh and adjoining parts of Haryana State in the category of $HCO_3^{-} - Cl^{-}$ type waters.

In case of surface waters a perusal of Horton based and modified Ambient water quality indices profiles along the Nagdeo-Hindon river have indicated that overall quality of water gets deteriorated just downstream of outfalls of waste waters from the Dairy/Paper mill and other industries. However, though apparently there is a considerable visual pollution in Dhamola *nala* due to foul odours emanating near the waste outfalls within Saharanpur town this is not established from the quality data. As there is little flow in the upper reaches of Hindon river during dry periods, there is little variation in the quality of Hindon river water near its confluence with the Nagdeo *nala*. A relatively low concentration of dissolved solids is indicated by the improvement of W.Q.I near Sadauli Hariya. It would also appear reasonable to conclude that the main pollutional sources in the area are from the paper and dairy industries which release their waste waters in Nagdeo and Hindon rivers at different places.

CHAPTER-5

DO SAG MODELLING

5.1 INTRODUCTION

It is evident from the discussion in earlier chapters that the major types of effluents in the study area are organic in nature. Accordingly, it appears appropriate to assume that the non-conservative constituents present in the river system and their degradation after mixing with the effluents will not be reflected adequately in the water quality indices given in chapter 4.

In order to ascertain the behaviour and the variation of these effluents in the river system, an attempt has been made to study the combined effects of BOD-removal and reaeration in the upper parts of the Hindon river and its tributaries. The dissolved oxygen sag curves resulting from these combined effects have been computed by using DOSAG-I model given by the Texas Water Development Board (TWDB), USA (1970). The application of the model has to be considered keeping in view the Indian Standards which specify minimum DO level as 6.0 mg/l for drinking water (CBPCWP, 1980) and 4.0 mg/l for supporting aquatic life. In any case, a finite dissolved oxygen content must be maintained to prevent putrefaction.

5.2 DO SAG MODELLING

The dissolved oxygen (DO) in rivers is one of the most significant indices of its condition. The value of a river water for most beneficial uses, particularly fish culture, wild life propagation, and recreational uses is rated on the basis of DO content of the water. Therefore, maintenance of a certain minimum level of DO is a common requirement laid down by the regulatory agencies.

Every stream is limited in its capacity to assimilate organic matter. As long as this limit is not exceeded, the disposal of organic wastes in streams represents the most economical method of waste disposal (Clark et al. 1977).

The Biochemical Oxygen Demand (BOD) of wastes is stabilized through bacterial action in the presence of oxygen and has been studied in considerable detail. After Streeter and Phelps (1925), who first developed BOD formulation model, Thomas (1940) introduced the lag time concept in his model. Orford and Ingram (1953) introduced a coefficient of retardation in their model. Revelle et al. (1965) proposed second order bio-oxidation taking into account the bacterial concentration. Young and Clark (1965) supported, the second order BOD progression concept. Agarwal and Bhargava (1977) showed that the BOD exertion rate at higher concentration of microorganisms exhibits a higher value of the BOD rate constantly. Streeter (1935) considered the effect of sedimentation in BOD removal. Velz and Gannon (1962) examined the effects of biological floc formation in the rate constant of BOD removals.

Newsome (1981) developed a water quality model for Trent river system, England, using the mean concentration of the quality parameters. Delucia & McBean (1981) and Biswas (1981) have developed mathematical models for Saint John river (USA & Canada respectively) by using the BOD and DO of the river system. Hanh and Combrowiz (1981) developed simulations models for descriptive purposes i.e. to develop quantitative relationships for the Neckar river system, West Germany. Bhargava (1983b) found that the assimilation of biochemical oxygen demand (BOD) after the waste outfalls at the urban centres along the Ganga & Yamuna rivers of India was exceedingly fast and followed a 2 stage pattern of BOD removal. Later, Bhargava (1986) established that the conventional Streeter-Phelps models are not able to accurately predict a stream's DO sag immediately after the sewage outfalls. Bhatia and McBean (1986) also carried out steady state modelling of dissolved oxygen in river Speed (Canada).To characterise the dissolved oxygen sag, it is necessary to define and quantify different phenomena in the above processes which were earlier described elegantly by Velz (1953). Song and Linefield (1990) have discussed DO model uncertainties in water quality modelling with correlated inputs.

5.2.1 Development of Dissolved Oxygen Sag Model

The one dimensional unsteady state mass transport equation containing reaction coefficients, photosynthesis, respiration and benthic demand term is as under:

benthic demand term is as under:

$$\frac{dc}{dt} = V\frac{dc}{dx} - K_1' L + K_2' (C_s - C) + P - R - B \qquad \ldots(5.1)$$

where,

V = stream velocity, m/sec.

L = BOD (remaining at time, t, mg/l)

P = Photosynthesis

R = Respiration

B = benthic sludge

K_1' = deoxygenation constant

K_2' = reaeration constant

C_s = DO saturation concentration level, mg/l

C = DO present, mg/l

It may be noted that positive or negative signs indicate source or sink term. In case of steady state, there is no change both in flow and loading with respect to time. Under constant loading, dc/dt will tend to be zero. Also, if velocity V is constant, distance covered, X = V.dt where dt represents travel time of a pollutant downstream. Therefore, equation (5.1) after ignoring photosynthesis, respiration and benthic demand can be written as;

$$\frac{dD}{dt} = K_1'L - K_2'D \qquad \ldots\ldots\ (5.2)$$

The solution of equation (5.2) with boundry conditions t = 0 and D = Do is

$$D_t = \frac{K_1'L_o}{K_2' - K_1'}\left[e^{-K_1't} - e^{-K_2't}\right] + DOe^{-K_2'\ t} \qquad \ldots(5.3)$$

Where,

D_t = Oxygen deficit at time t, (mg/l)

D_o = initial oxygen defict (mg/l) at the point of waste discharge at time t = 0.

Equation (5.3) represents the classic Streeter-Phelps equation commonly used in case of rivers, but it applies to channels of uniform cross section, where the effects of bioflocculation, sedimentation and photosynthesis are considered negligible.

The above equation can be solved by using DOSAG-I model given by Texas Water Development Board (1970). Further, the effects of sedimentation & bioflocculation may be incorporated in the DO sag curves by using the approach of Bhargava (1986).

5.2.2 Salient Features of Dosag-I Model

In order to use the DOSAG-I Quality Routing Model, one must take into account the stream system which is proposed to be simulated and break it down into the elements which are used as input to the program. Fig. 5.1 shows a schematic diagram of the study area which has been decomposed into elements required to model it using DOSAG-I. There are essentially four following major elements into which a system must be decomposed for modelling purpose.

(1) Junctions- The confluence between two streams within the river basin being modeled.

(2) Stretches - the length of a river between junctions.

(3) Headwater Stretches - the length of a river from its head water to its first junctions with another stream

(4) Reaches - the subunits which comprise a stretch (headwater or normal).

A new reach is designated at any point in the stretch where there is a significant change in the hydraulics, or physical

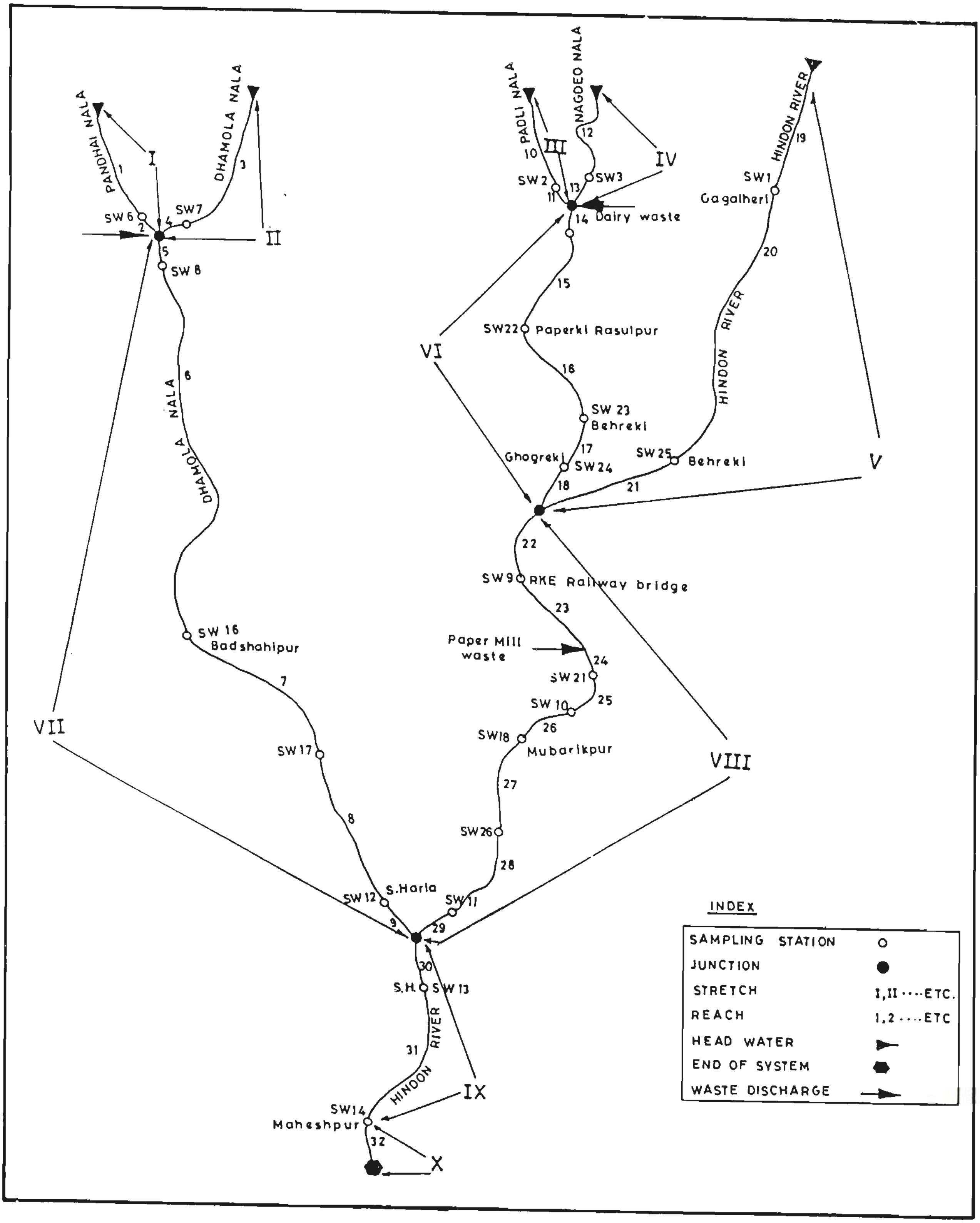


FIG. 5·1 SCHEMATIC DIAGRAM OF HINDON RIVER BASIN characteristics of the channel, including the addition of a water load, or the withdrawal of water from the stream.

Equation (5.4) describes the hydraulic characteristics of each reach in a river system:

$$V = A_1 \; Q^{B_1} \qquad \ldots(5.4)$$

where,

v = mean velocity in a reach (m/sec).

Q = mean discharge in a reach (m^3/sec)

A_1 = a coefficient

B_1 = an exponent

The above coefficient and exponent are used as input data into the program. These must be developed from the data obtained from the actual stream system.

The appropriate coefficients in equation (5.4) are read into the program for every reach for which K_2' is to be computed.

The waste discharges are entered into the system by specifying a new reach at each location at which a discharge takes place. The specified reach should be of zero length and should be located nearest to the site of the actual waste discharge in the prototype system.

5.3 FIELD DATA FOR DO SAG MODELLING

The acquisition of field data for developing the Dissolved Oxygen Sag Model of the Upper Hindon basin (from location, SW_1 to SW_{14}, Fig. 1.1) was planned considering the requirements of model calibrations in different seasons. Accordingly, from September, 1986 to November, 1987 elaborate water sampling and analyses were carried out in four phases i.e. end of a rainy season (September-October, 1986), winter (January, 1987 and November, 1987) and a summer season (July, 1987). The parameters like pH, temperature, discharge and degradable parameters like BOD and DO were monitored with a view to develop DO sag models along the Hindon river and its tributaries, for the above sampling phases. In the three phases (Phase-I, II and III) of observations, the data have been used from sampling locations SW_1 to SW_{14}. The stream discharges were computed using the data of depth, width and velocity of the river water. In phase IV (November, 1987) two additional locations (i.e. SW_{27} and SW_{28}) between locations SW_{13} to SW_{14}, were selected for a more extensive study.

5.3.1 Evaluation of Deoxygenation Coefficient

For developing dissolved oxygen sag curves using DOSAG-I program, deoxygenation coefficeint (K_1') was first determined experimentally at the junctions of either two or more streams or of a river with major waste effluents. To estimate K_1' and ultimate BOD (Lo), experimental BOD values for a series of periods (2,4,5,8,10,12,16 and 20 days) were estimated (Tables 5.1 and 5.2).

5.3.2 Nature of BOD Regression Curves

The BOD of the water samples has been determined experimentally for different incubation periods, e.g., 2-days, 4-days, 5-days, 10-days, 12-days, 16-days and 20-days for all the four phases of sampling (Table 5.1 and 5.2).

It is seen from the BOD versus time (in days) curves (Figs. 5.2 to 5.6) that under laboratory conditions generally 60-70% BOD exertion takes place in first 5-days of incubation periods whereas remaining BOD exertion is achieved in the next 15 days. This is in general agreement with the premise of Velz (1970) that in 5-days upto 68% BOD removal takes place. Further, in the present study, no noticeable effect of nitrogenous BOD (2nd stage) has been observed even after 10-days of BOD utilisation.

Table 5.1: BOD Values in Different Surface Water Samples for the Months of September-October, 1986, January, 1987 and July, 1987.

Periods	Sampling Site	BOD_2	BOD_4	BOD_5	BOD_8	BOD_{12}	BOD_{16}	BOD_{20}
Sept. Oct.,	SW_9	4.4	9.0	9.8	11.0	12.0	12.6	12.6
1986	SW_{11}	1.7	3.8	6.5	11.1	11.5	12.1	12.1
	SW_{13}	3.2	6.4	8.0	12.5	17.5	21.2	21.2
Jan.-1987	SW_9	6.4	11.8	13.1	15.1	15.8	16.0	16.0
	SW_{11}	12.5	19.5	22.5	27.5	30.0	31.1	31.1
	SW_{13}	5.8	11.4	14.3	15.4	16.0	16.3	16.3
July, 1987	SW_9	9.7	14.4	16.4	17.8	19.2	19.6	19.6
	SW_{11}	1.1	4.6	5.6	6.7	7.2	7.5	7.5
	SW_{13}	8.4	13.4	15.9	18.8	20.4	21.0	21.0

Table 5.2: BOD Values in Different Surface Water Samples for the Month of November, 1987

Period	Sampling site	BOD_4	BOD_5	BOD_8	BOD_{10}	BOD_{12}	BOD_{16}
Nov., 1987	SW_4	185.16	191.83	201.83	215.16	221.80	223.50
	SW_5	66.40	73.15	75.40	79.65	82.15	84.65
	SW_9	9.46	11.46	13.67	14.13	15.70	16.13
	SW_{20}	102.00	109.00	112.60	115.66	122.33	125.33
	SW_{21}	37.90	64.15	70.40	74.15	76.65	79.15
	SW_8	4.90	9.90	11.70	12.50	13.80	15.90
	SW_{13}	6.40	9.76	11.20	14.40	15.90	18.10

5.3.3 Evaluation of Rate of BOD Removal

The rate of BOD removal (K_1') was computed from the basic differential equation given by Streeter and Phelps (1944) as under;

$$L = Lo\ e^{-K_1' t} \qquad \ldots \quad (5.5)$$

The value of K_1' were computed for three sampling points in different periods ranging from 0.45 to 12.20 days (Table 5.7 to 5.10, Appendix - III).

5.3.3.1 Evaluation of Rate Constant for Total BOD

The evaluation of DO-Sag curves resulting from deoxygenation and reoxygenation taking place in the stream by conventional models assumes first order kinetics for BOD assimilation, thus ignoring the effects of bioflocculation and settling of the

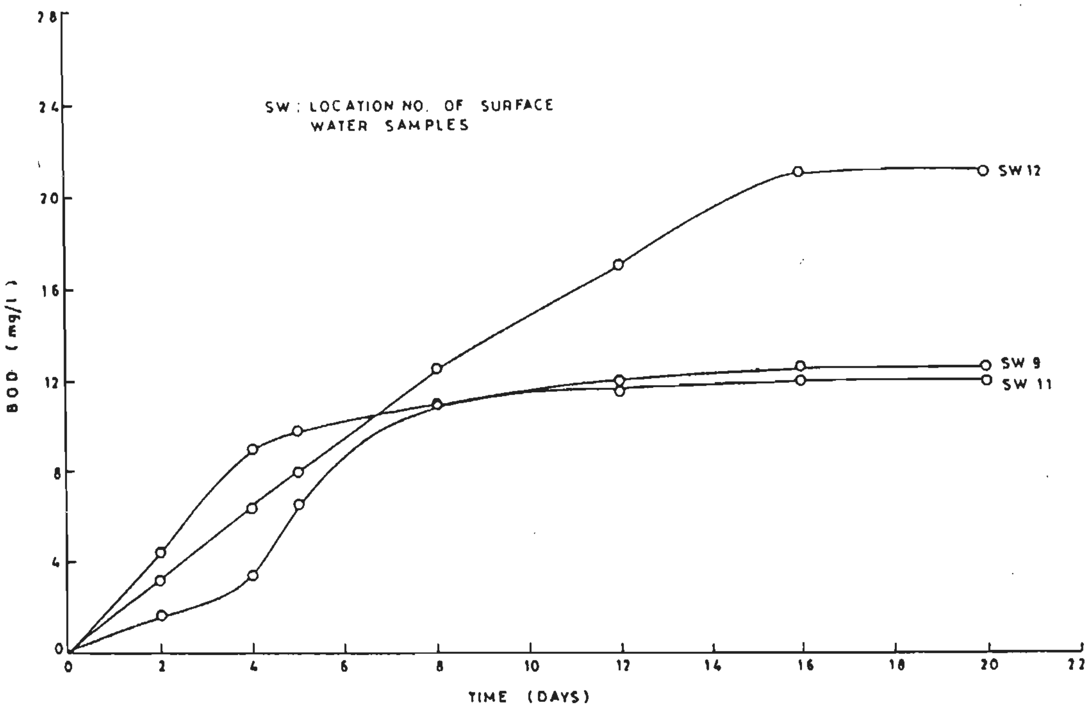


FIG. 5.2 BOD VERSUS TIME CURVE (SEP._OCT. 86)

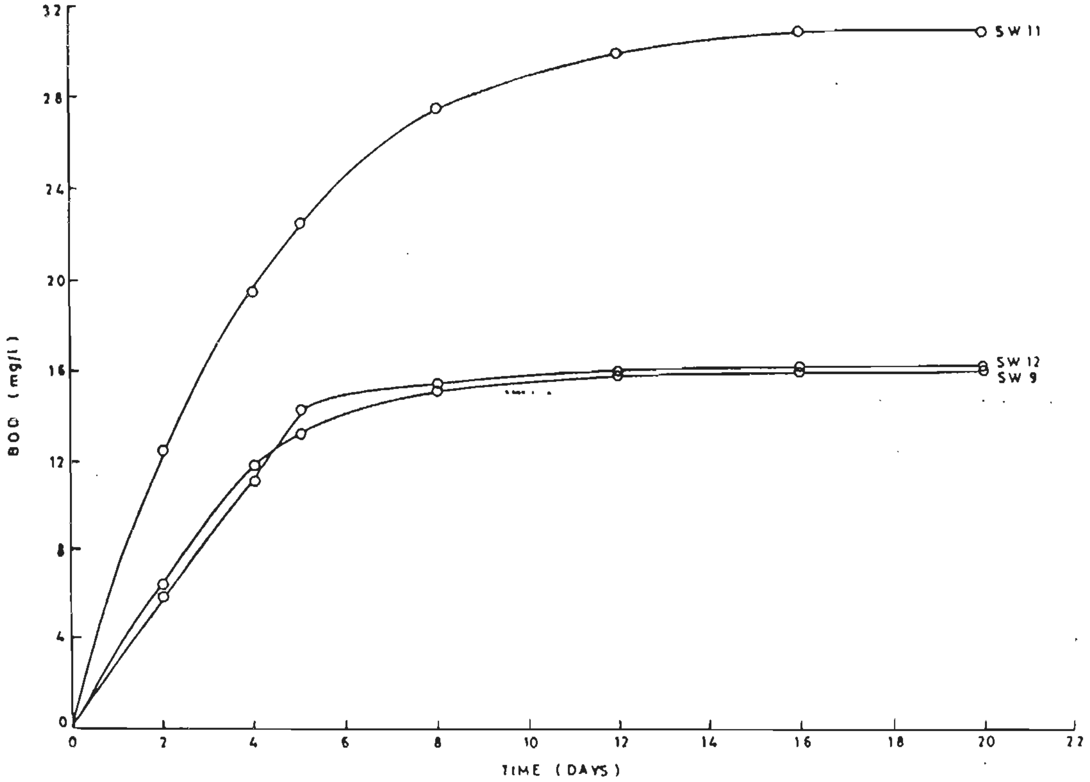


FIG. 5.3 BOD VERSUS TIME CURVE (JAN. '87)

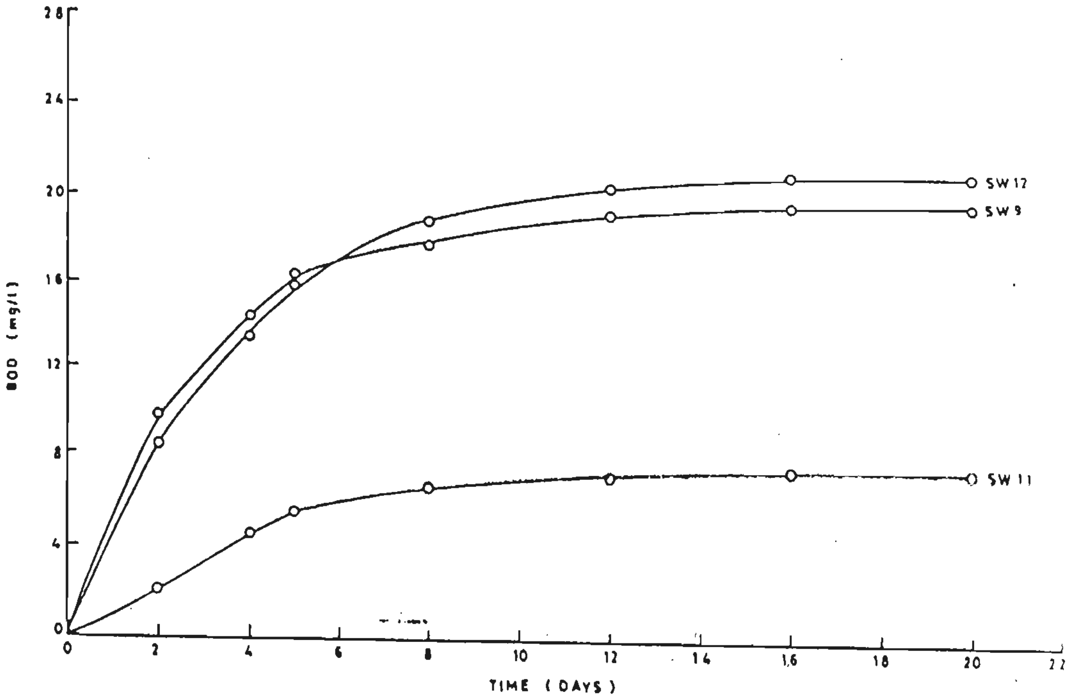


FIG. 5.4 BOD VERSUS TIME CURVE (JULY ,87)

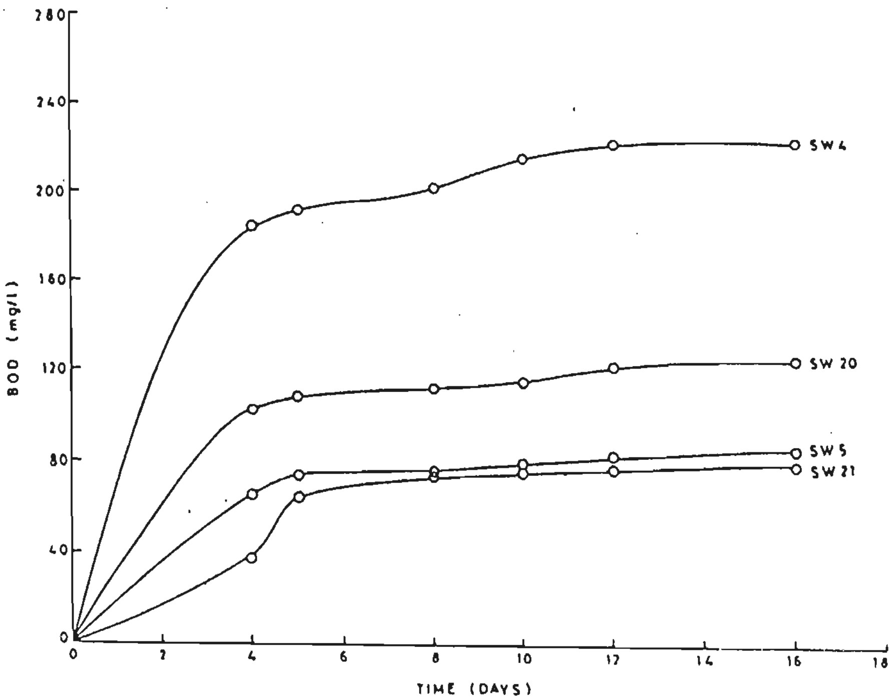


FIG. 5.5 BOD VERSUS TIME CURVE (NOV.'87)

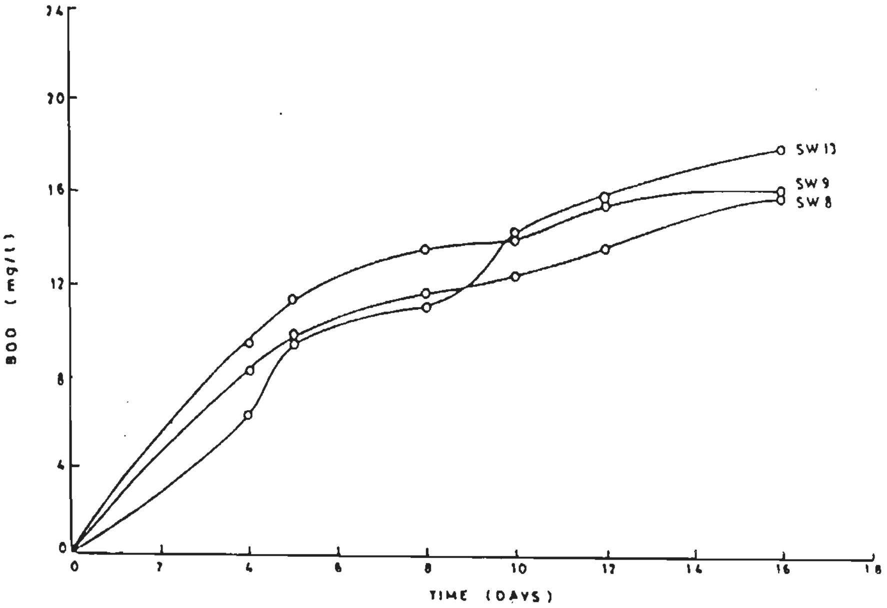


FIG. 5.6 BOD VERSUS TIME CURVE (NOV.'87)

organic matter (Streeter and Phelps, 1925). Such models, therefore seem to be of less relevance in the accurate computation of DO-Sag in polluted streams. Bhargava (1983b, 1986) established that the BOD assimilation can be extremely fast for some of the Indian rivers. He showed that significant bioflocculation of the colloidal part of the organic matter discharged into the rivers amounting to about 60 % of the total BOD gets removed within initial 30 min. to 60 min., with BOD rate constants (base e) ranging as high as 20 to 100 for some stretches of rivers Ganga and Yamuna. Further, BOD assimilation for the later part goes on with K_1' value being much smaller (1.5 per day along Yammuna river and 3.5 to 5.5 per day along the Ganga). In this phenomenon, the suspended and colloidal parts of the BOD are removed with physico-chemical process (coagulation, bioflocculation and settling) taking place just after the waste outfalls, and the remaining BOD is decayed exponentially. Bhargava (1983b, 1986) also suggested an equation for evaluation of DO-Sag curves in such polluted streams.

In the present study, rates of total BOD removal (including the settleables) along the Nagdeo-Hindon stretches have been evaluated in accordance with the approach given by Bhargava (1983b). Thus the values of log $(S_o - L_5)$ have been plotted Vs. travel time (days) as given in Fig (5.7 and 5.8). From these figures, it has been found that the overall BOD progression in the present study area shows four phased trends and the rate of BOD removal can be evaluated from early and late stages after each major waste outfall, i.e. the waste outfall from Foremost Dairies

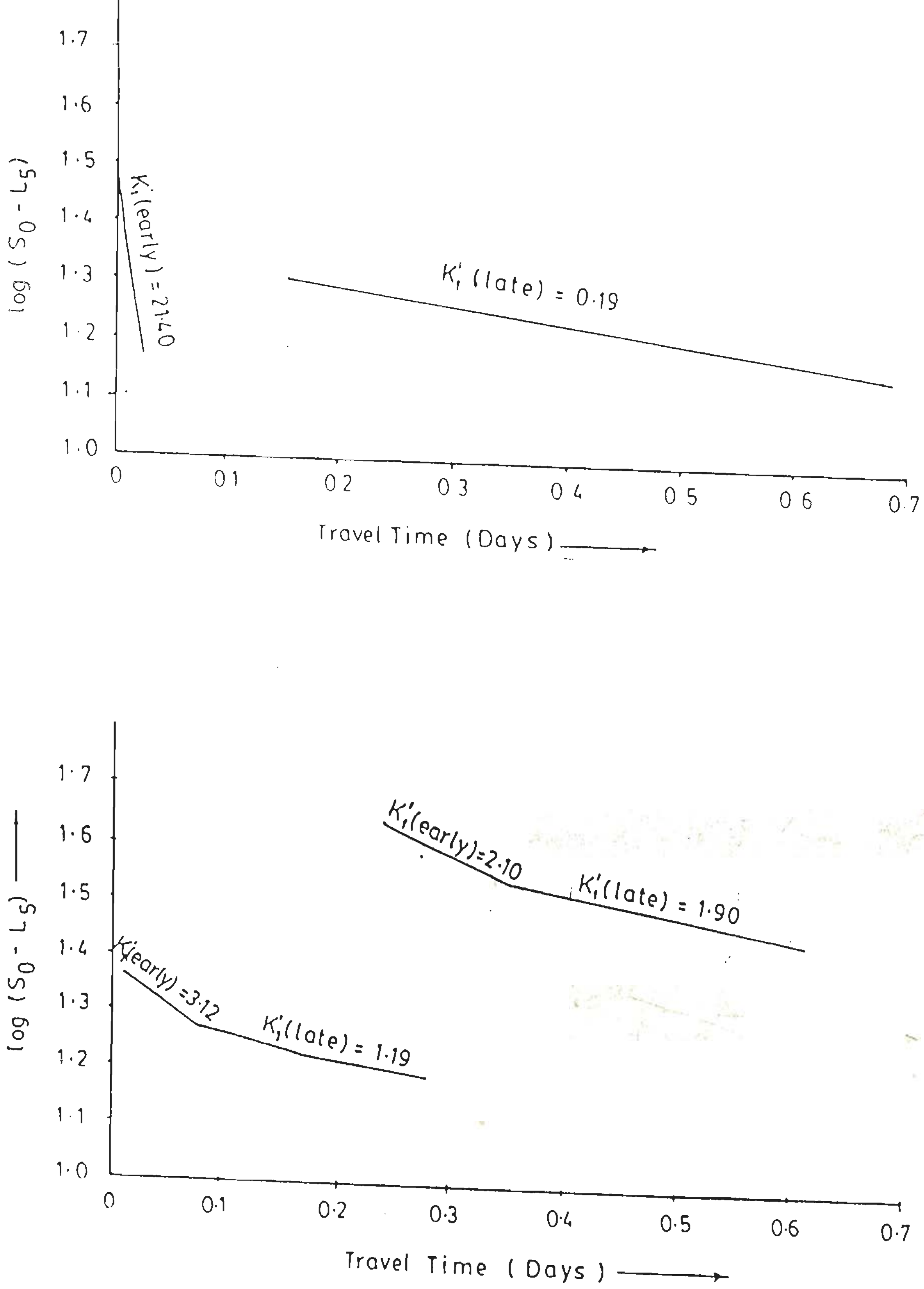


FIG. 5·7 EVALUATION OF BOD RATE CONSTANTS [K_1'(early) AND K_1 (late)] ALONG NAGDEO HINDON STRETCH (SEP., 86 AND JAN., 87)

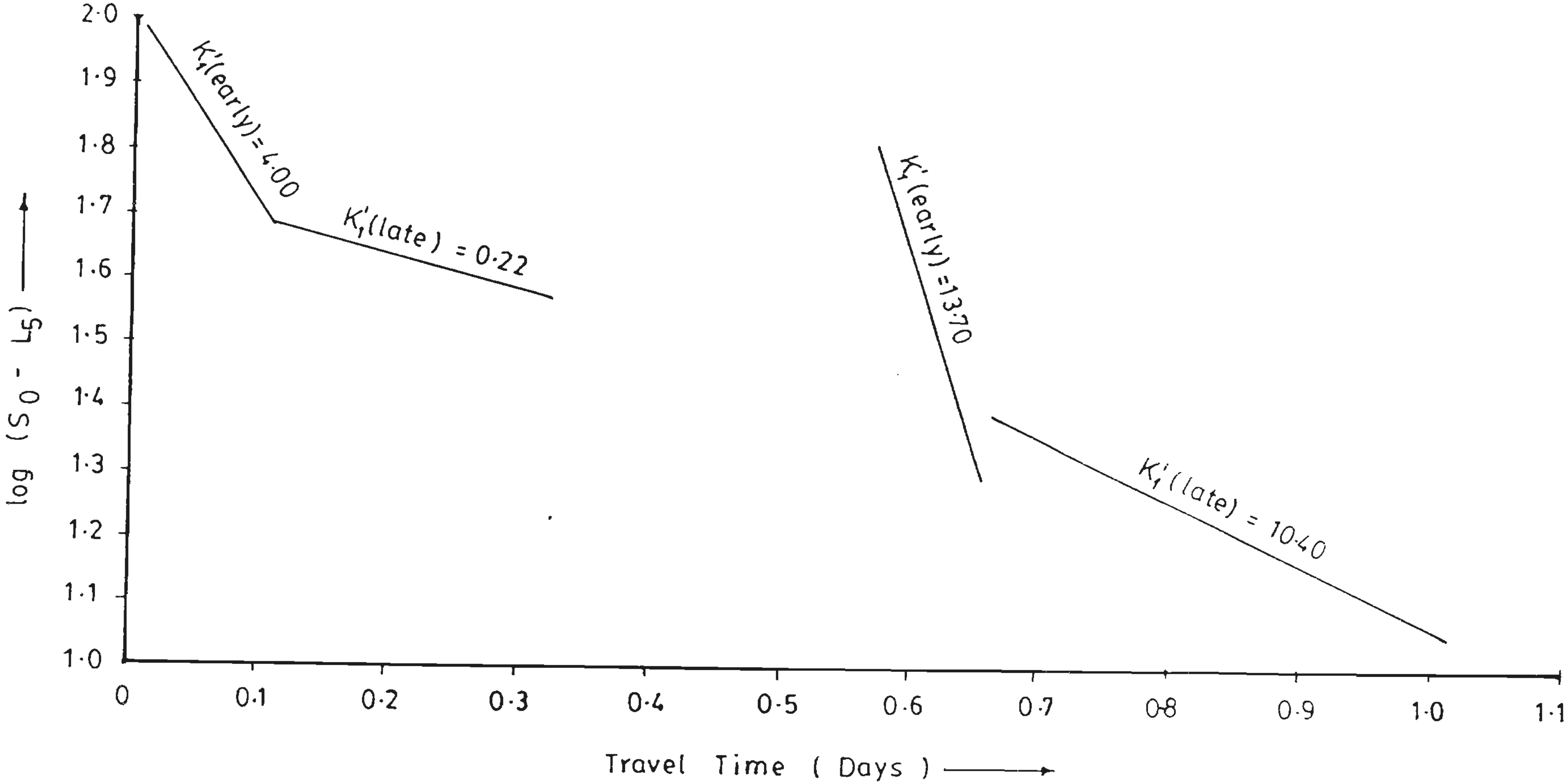


FIG. 5·8 EVALUATION OF BOD RATE CONSTANTS [K'_1 (early) AND K'_1 (late)] ALONG NAGDEO - HINDON STRETCH (NOV., 87)

(SW_5 onwards) and Paper mill (SW_{21} onwards). The regression of these curves has shown distinct ranges of $K_1^{'}$ (base e) for early reaches (SW_5 to SW_{22}) varying from 3.1 to 21.4 in the different periods representing summer, winter and rainy seasons (Table 5.3) Further, $K_1^{'}$ for later reaches (SW_{23} to SW_9) ranges from 0.19 to 7.0 for the same period. Similarly, corresponding to the waste outfall from the paper mill, the $K_1^{'}$ for early reaches ranged from 2.1 to 13.7 and for later reaches, it ranged from 1.9 to 10.4. In the present analysis, unidentified (covered) and insignificant sources of waste outfall have been ignored.

However, a similar analysis for Dhamola nala could not yield $K_1^{'}$ values for the two phases. This is probably because no major sources of waste outfalls, beside the hidden discharges, were identified in this stream between Saharanpur town (SW_8) and near Sadauli Hariya village (SW_{13}, Fig.5.9 and 5.10).

5.3.3.2 Nature of Overall BOD Equations considering Settleable BOD :

The evaluation of the rate constants for total BOD including the settleable components on the lines suggested by Bhargava (1983b) is given in section 5.3.3.1. Table 5.4 shows the BOD progression equations developed on the basis of two separate first order kinetics in the early and later reaches of Nagdeo - Hindon river, for different periods.

In can be clarly seen that as shown by Bhargava (1983b, 1986) the settleable part of BOD is removed according to the settling laws instead of first order kinetics. However, the nonsettleable

Table 5.3 : K'_1 Values for Nagdeo-Hindon Stretch

Periods	After SW_5		After SW_{21}	
	$K'_{1(early)}$	$K'_{1(late)}$	$K'_{1(early)}$	$K'_{1(late)}$
Sept.-Oct. (1986)	21.4	0.19	-	-
January (1987)	3.12	1.19	2.1	1.9
July (1987)	7.00	7.0	9.0	9.0
November (1987)	4.00	0.22	13.7	10.4

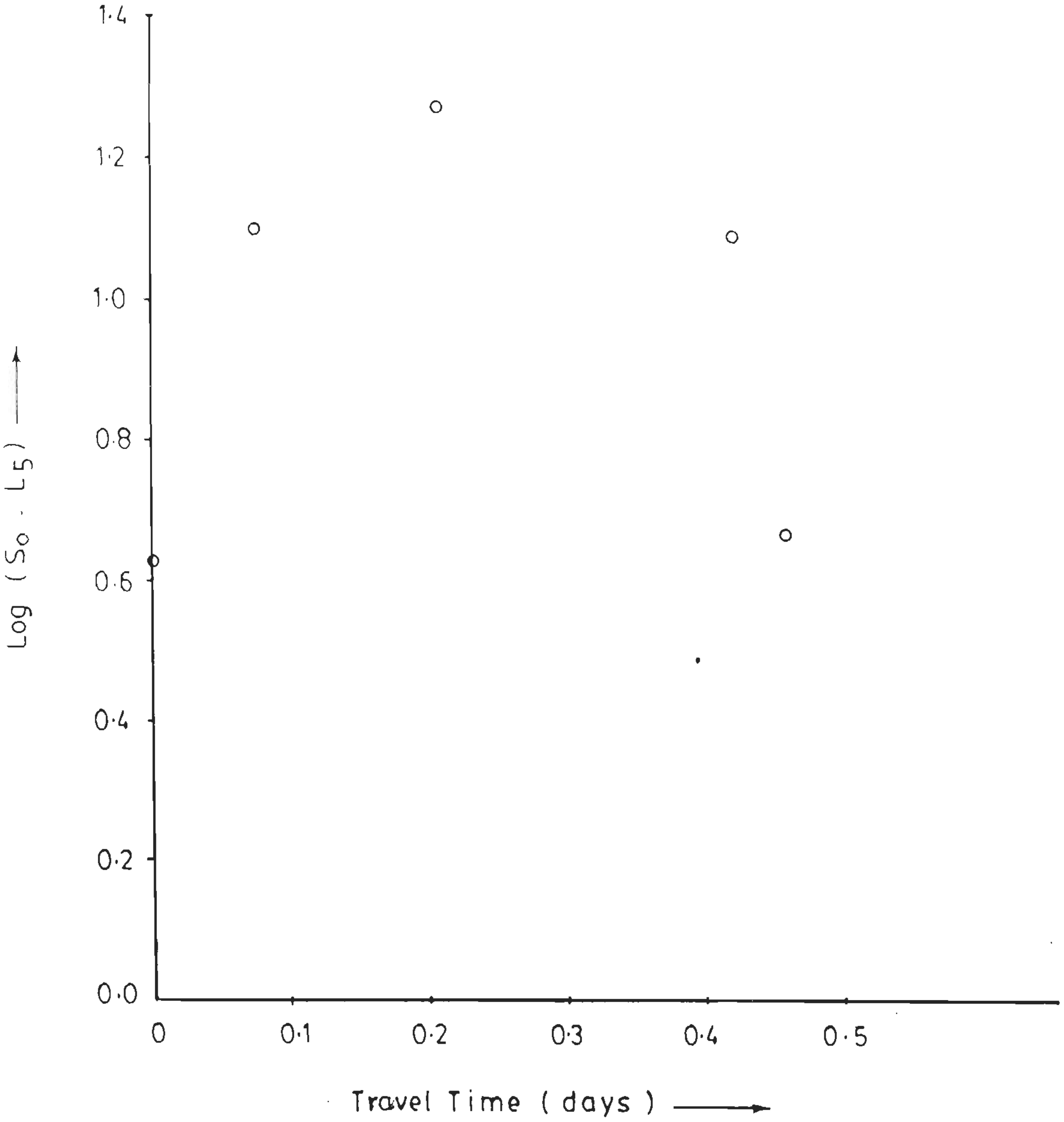


FIG. 5·9 PLOT OF BOD REMAINING Vs TRAVEL TIME FOR DHAMOLA NALA (JAN., 87)

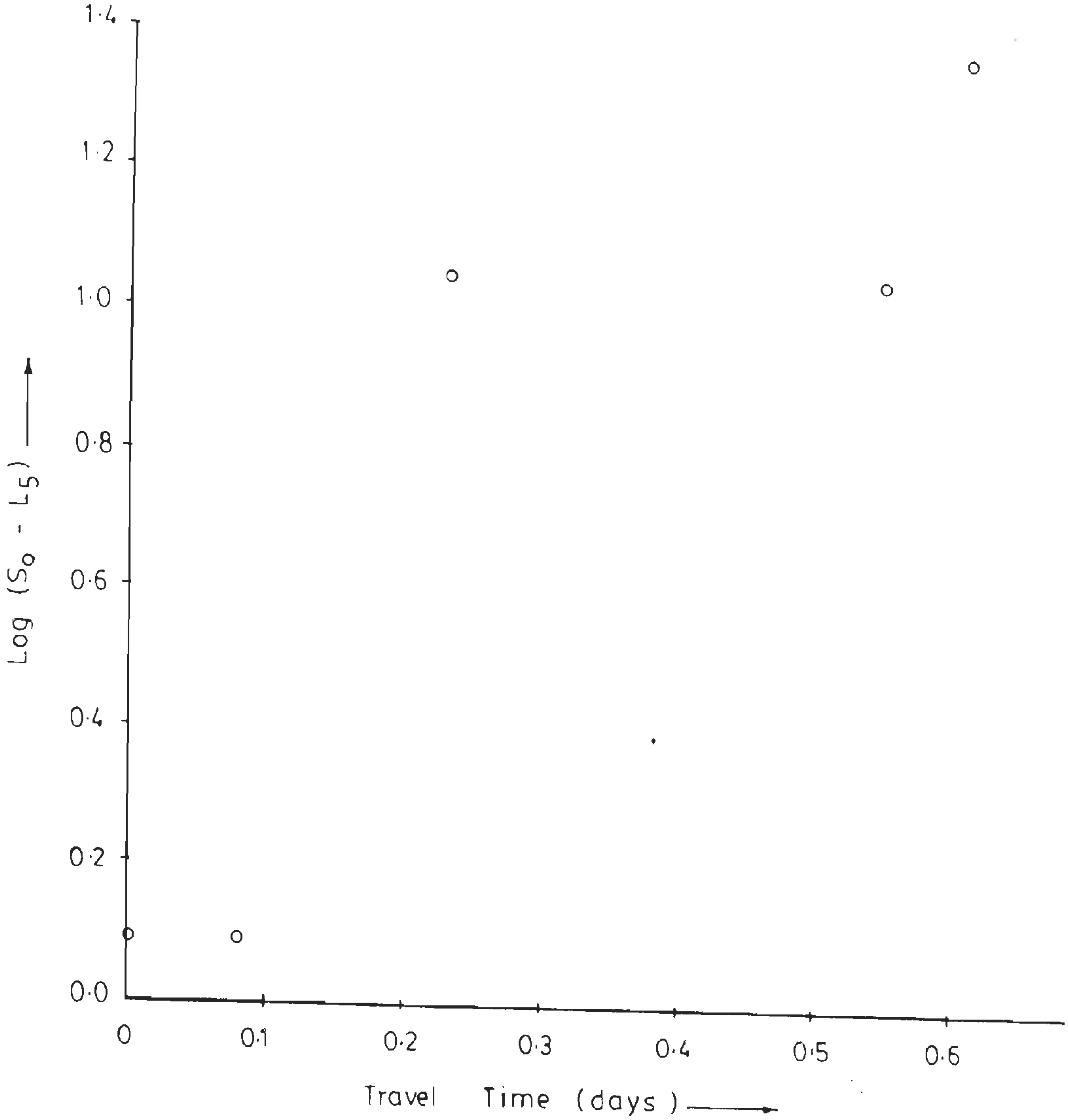


FIG. 5·10 PLOT OF BOD REMAINING Vs TRAVEL TIME FOR DHAMOLA NALA (NOV., 87)

Table 5.4 : BOD Progression Equations Developed on the Basis of Two Separate First Order Kinetics in the early and Later Reaches

Periods	BOD Progression Equations	
	After SW_5	After SW_{21}
Sept.-Oct. (1986)	$S = 17.6\ e^{-(21.4)t} + 11.8\ e^{-0.19t}$	*
January (1987)	$S = 17.8\ e^{-(3.1)t} + 11.8\ e^{-1.19t}$	$S = 30.8\ e^{-2.1t} + 20.6\ e^{-1.9t}$
July (1987)	$S = 32.2e^{-(7.0)t} + 21.4\ e^{-9.0t}$	*
November (1987)	$S = 43.9e^{-4.0t} + 29.3e^{-0.22t}$	$S = 38.5\ e^{-13.7t} + 25.6e^{-10.37}$

* In Sept.-Oct. 1986 and July 1987 negligible waste effluent were discharged from the Paper mill.

part of BOD is assimilated according to the usual BOD kinetics. As such, the overall BOD progression equation would take the following form (Bhargava, 1983b).

$$L = L_{o-x}\left[1 - (V_s/D)t\right] + L_{o-y}e^{-K_1' t} \qquad .. \qquad (5.6)$$

where,

Vs = Settling velocity (m/day) of the bioflocculation particles (taken as 69 m/day for a 1mm diameter particle of Sp. gr. 1.001)

D = Stream Depth (m)

The above equation indicates that the settleable portion would be completely removed within a time of D/69 days after which the BOD exertion would only be due to the nonsettleable matter.

In accordance with the above settling law, the overall BOD progression equations for Nagdeo-Hindon river stretch are given in table 5.5. The equation also presumes 60% of BOD removal in a period as short as 0.0023 day to 0.006 day (about 3 min. to 9 min. only). After this, the BOD removal corresponds to the first order kinetics with K_1' value between 0.19 to 2.16 (for dairy wastes) and 1.92 to 10.40 (for paper mill wastes).

As mentioned earlier, only two major sources of waste outfalls have been identified along the Nagdeo-Hindon stretch whereas along the Dhamola stream no major outfall, was recorded. As such the DOSAG-I model incorporating early and later reaches of BOD removal have been computed only for the Nagdeo-Hindon river(s).

Table 5.5 : Overall BOD Progression Equation on the Basis of Dual Process of Bioflocculation-Biodegradation

Periods	Depth (m)	Time (days)	Equation	
			After SW_5	After SW_{21}
Sept.-Oct. (1986)	0.410	0.006	$S = 17.6(1-167t)+11.8e^{-0.19t}$	*
January (1987)	0.188	0.003	$S = 17.8(1-333t)+11.8e^{-1.19t}$	-
	0.250	0.004	-	$S = 30.8(1-250t)+20.6e^{-1.9t}$
July (1987)	0.195	0.0028	$S = 32.2(1-357t)+21.4e^{-7.0t}$	*
November (1987)	0.159	0.0023	$S = 43.9(1-435t)+29.3e^{-0.22t}$	-
	0.199	0.0028	-	$S = 38.5(1-357t)+25.6e^{-10.4t}$

* In Sept.-Oct., 1986 and July 1987, negligible waste effluent were discharged from the Paper mill.

5.3.3.3 Evaluation of Reaeration Constant (K_2')

Several workers have found that the reaeration coefficient, K_2' can be represented by a general relationship as given in equation (5.7) (Churchill et al. 1962; Langbein and Durum, 1967; O'Conner and Dobbins, 1956 and Owens and Gibbs, 1964).

$$K_2' = \frac{A_3 V^{B_3}}{H^{C_3}} \qquad \ldots(5.7)$$

Where,

A_3 = a coefficient, and B_3 and C_3 are exponents.

V and H are stream velocity and mean depth respectively.

Various investigators have presented the necessary coefficients for use in equation (5.7) (Table 5.6) to calculate the reaeration coefficient for any stream in which the mean velocity and mean depth are known (O' Conner and Dobbin, 1956; Churchill et al, 1962; Langbein & Durum, 1967; and Owens & Gibbs, 1964). Table 5.1 presents these coefficents as determined both in the field and by the laboratory tests. The coefficients developed by Churchill et al. (1962) and Langbein & Durum (1967) have been found to be the better known for the computation of reaeration rate coefficient for general model use.

Table 5.6: Constants for Computation of the Reaeration Coefficient (K_2' per day)

Investigator	A_3	B_3	C_3
Churchill, et al. (1962)	5.026	0.969	1.673
Langbein and Durum (1967)	3.300	0.500	1.330
O'Conner and Dobbins (1956)	5.600	0.500	1.500
Owens and Gibbs (1964)	9.400	0.670	1.850

The reaeration rates can also be determined by using a relation discretized from Streeter-Phelps basic differential equation (5.2) and have been found applicable in field conditions. This equation on discretization leads to equation 5.8 (Datta and Bhatia, 1985).

$$K_2' = \frac{K_1'\bar{L}}{\bar{D}} - \frac{\Delta D}{2.303\Delta t \times \bar{D}} \qquad \ldots\ldots\ldots \quad (5.8)$$

Where,

$\bar{D}$ = DO defcit (taken as mean at two points)

ΔD = Difference of DO deficit between two points

$\bar{L}$ = Ultimate Mean Bio-Chemical Oxygen Demand

Δt = Travel time between two points

K_1' and K_2' have already been defined earlier

In the present study, the values of K_2' were calculated from the relation given by equation (5.8)

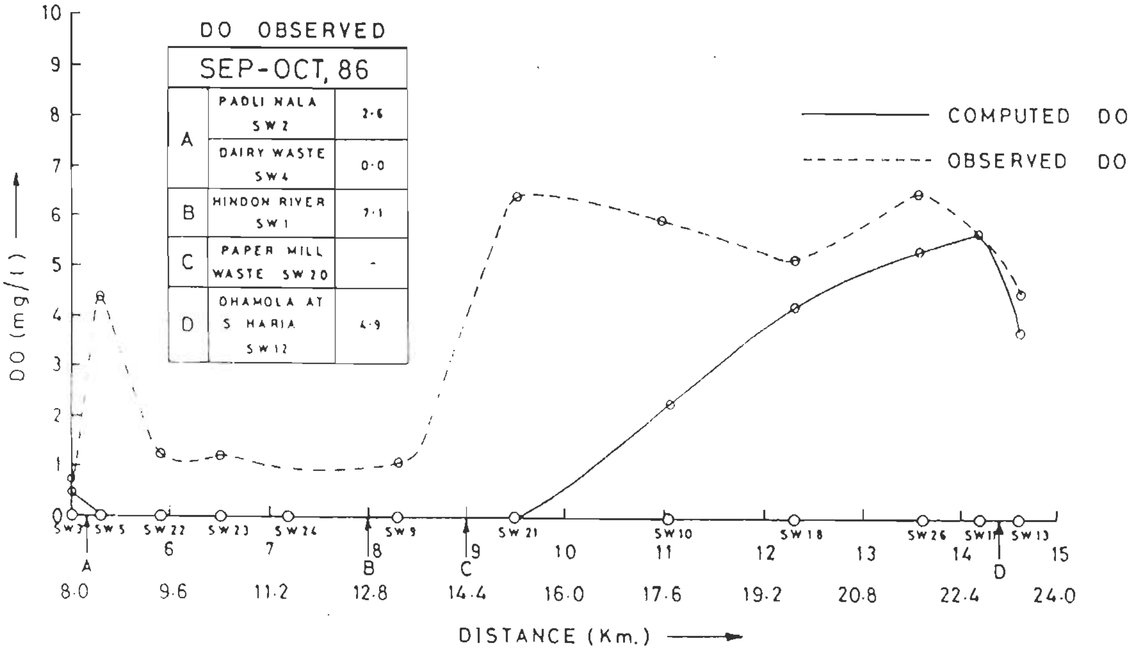
The values of K_2' obtained from the above equation were converted to field temperatures as listed in Table 5.7 to 5.10, (Appendix - III). The K_2' values are found to have a wide range from 1.070 to 149.83; such high values of K_2' are also reported for other Indian rivers (Bulusu et al. 1967; Bhargava, 1983b). One of the reasons for such high values of the reaeration (K_2) constant may be due to the relatively small depth of the streams studied.

5.4 MODIFICATIONS IN THE PROGRAM FOR PRESENT STUDY

1. The waste discharge reach and the confluence reach orders have been reversed.
2. The value of reaeration coefficient (K_2') has been assigned jointly to several reaches (Table 5.7 to 5.10, Appendix - III).
3. The values of K_1', rate of BOD removal, (considering sedimentation and bioflocculation) calculated by equations (Table 5.4)for early and later phases of BOD removal, have been suitably substituted in the DOSAG - I model for obtaining DO projections along the streams.

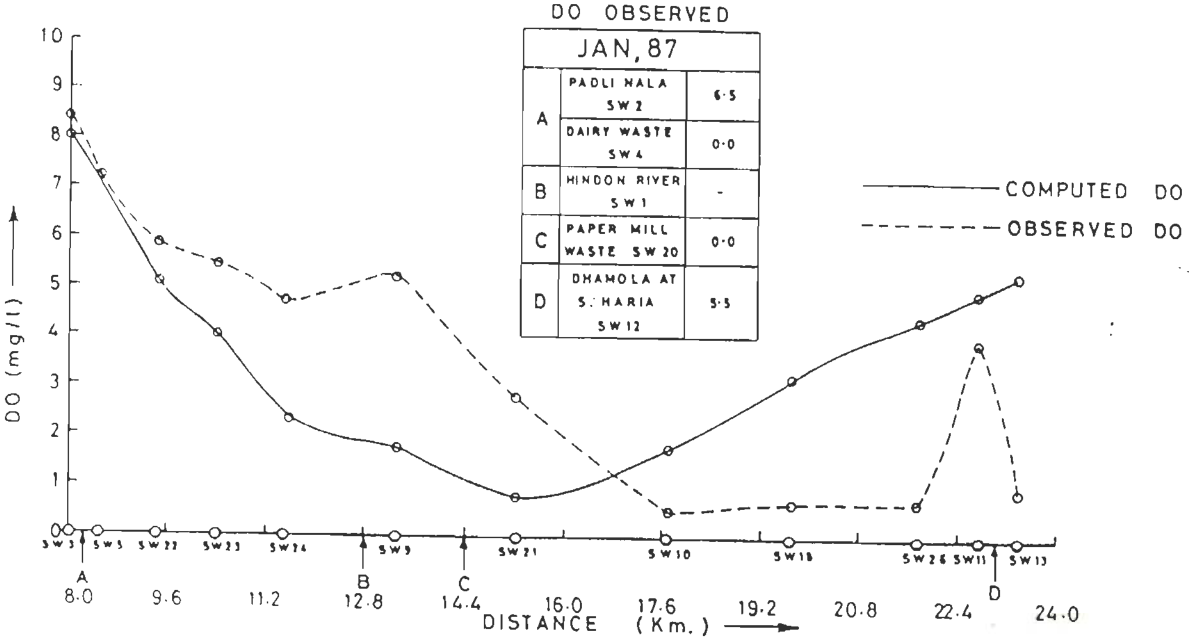
5.5 RESULTS

The DO Sag models developed for different phases of monitoring for the Hindon river highlight the influence of different waste effluents on the quality of surface waters in the Hindon river system. The curves of observed DO and computed DO (by DOSAG - I model) are given in Fig. 5.11 to 5.18 and 5.19 to 5.22.



	SEP-OCT, 86	
A	PADLI NALA SW2	2.6
	DAIRY WASTE SW4	0.0
B	HINDON RIVER SW1	7.1
C	PAPER MILL WASTE SW20	-
D	DHAMOLA AT S. HARIA SW12	4.9

FIG. 5.11 DISSOLVED OXYGEN SAG CURVE ALONG NAGDEO-HINDON RIVER (SEP-OCT, 86)



	JAN, 87	
A	PADLI NALA SW2	6.5
	DAIRY WASTE SW4	0.0
B	HINDON RIVER SW1	-
C	PAPER MILL WASTE SW20	0.0
D	DHAMOLA AT S. HARIA SW12	5.5

FIG. 5.12 DISSOLVED OXYGEN SAG CURVE ALONG NAGDEO-HINDON RIVER (JAN, 87)

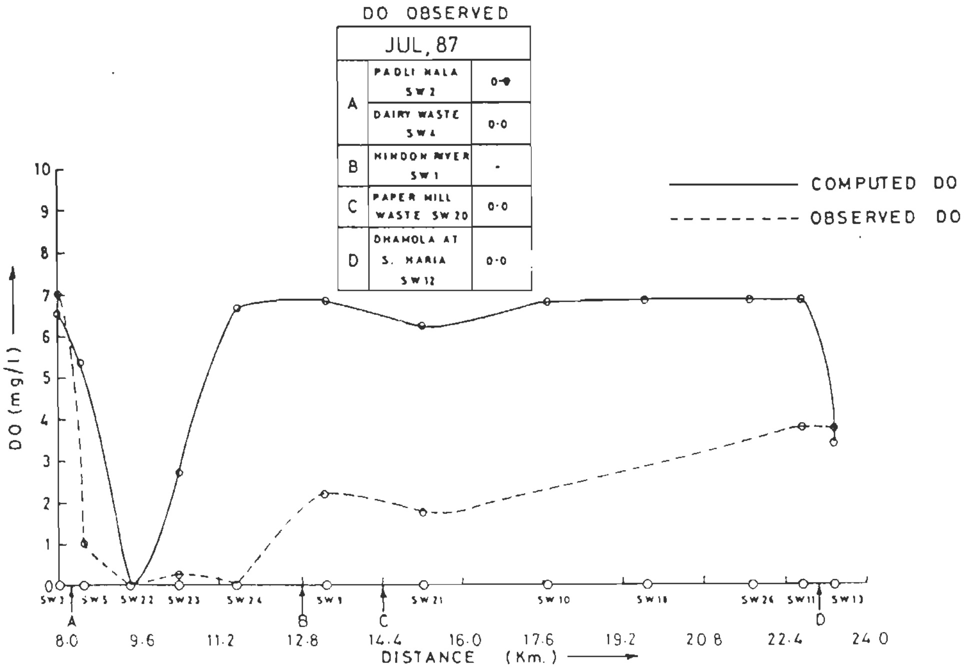


FIG. 5·13 DISSOLVED OXYGEN SAG CURVE ALONG NAGDEO-HINDON RIVER (JUL, 87)

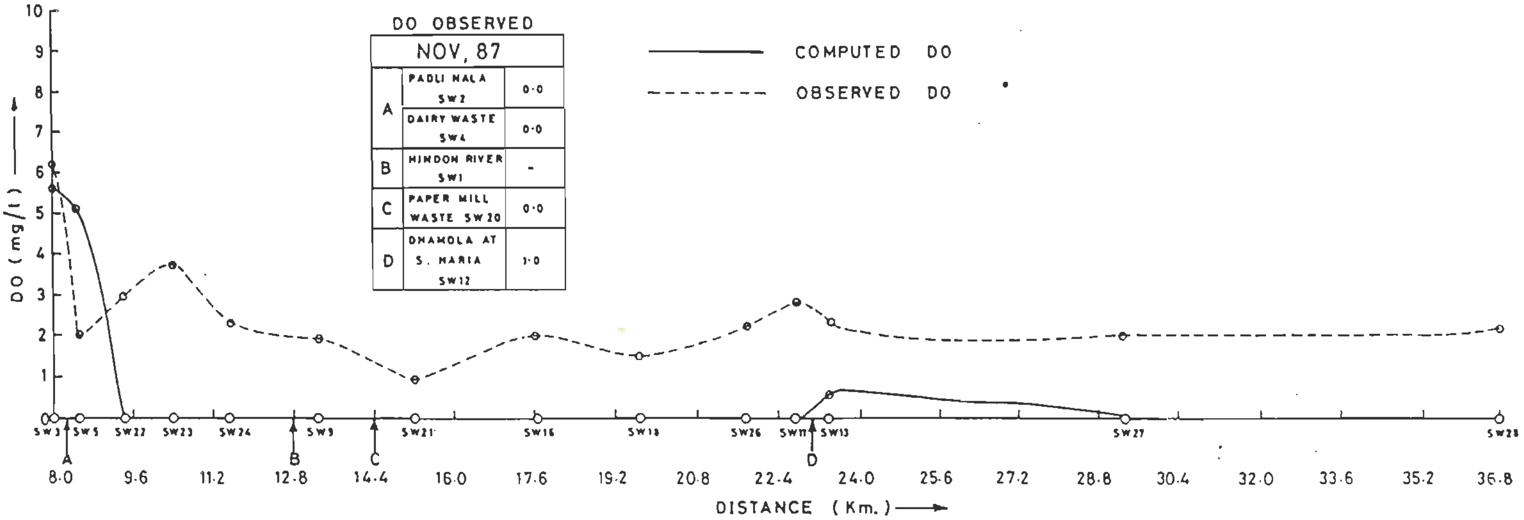


FIG. 5·14 DISSOLVED OXYGEN SAG CURVE ALONG NAGDEO-HINDON RIVER (NOV, 87)

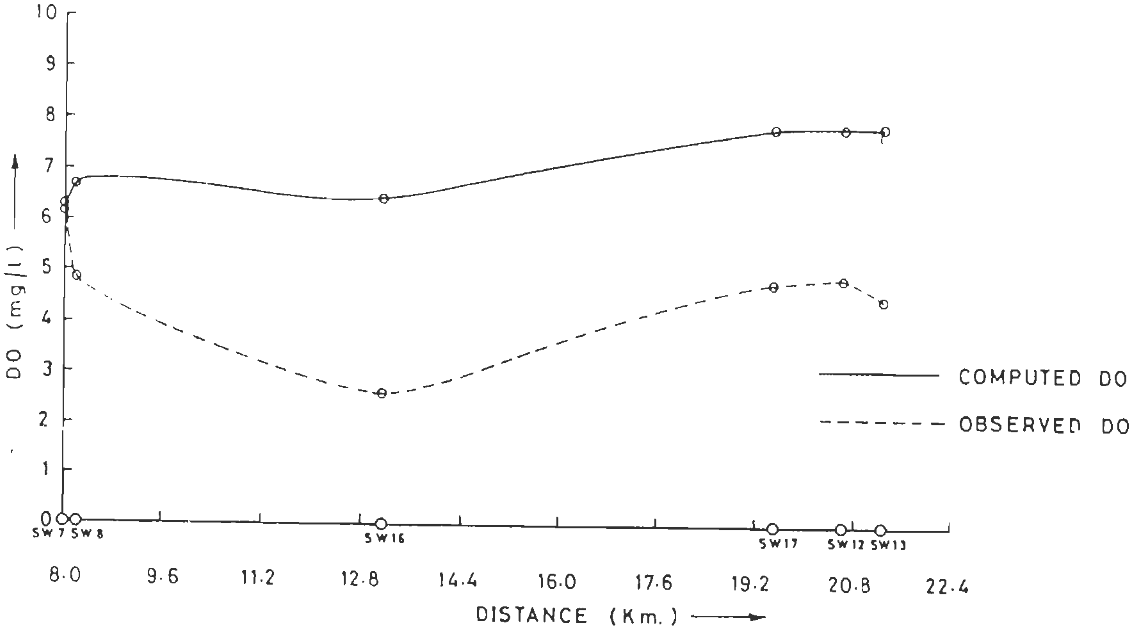


FIG. 5·15 DISSOLVED OXYGEN SAG CURVE ALONG DHAMOLA NALA (SEP-OCT, 86)

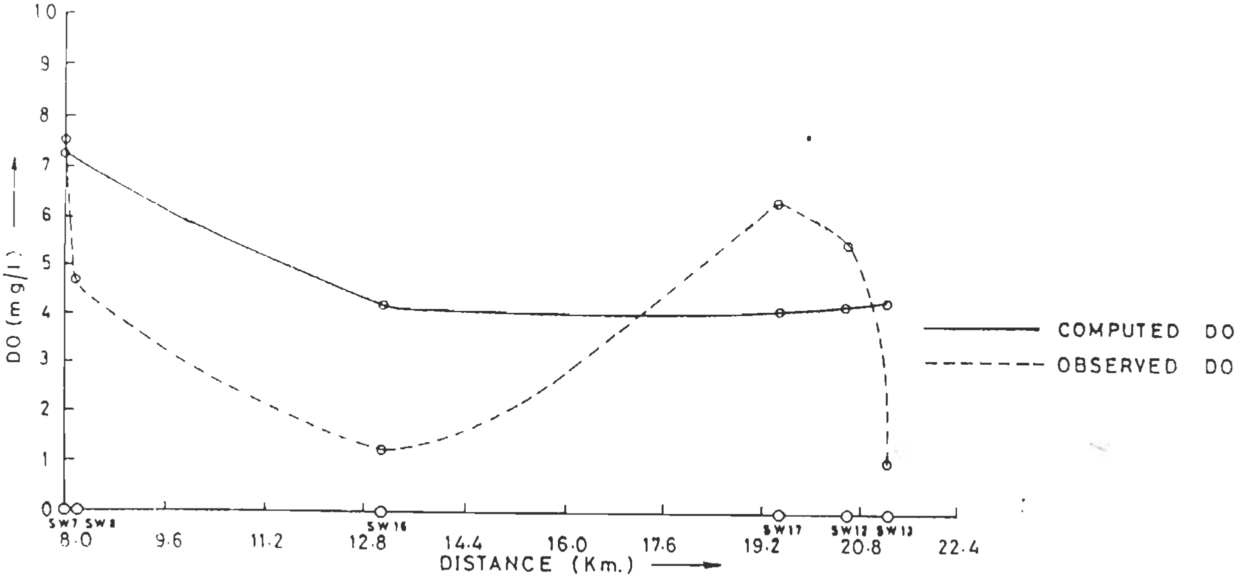


FIG. 5·16 DISSOLVED OXYGEN SAG CURVE ALONG DHAMOLA NALA (JAN, 87)

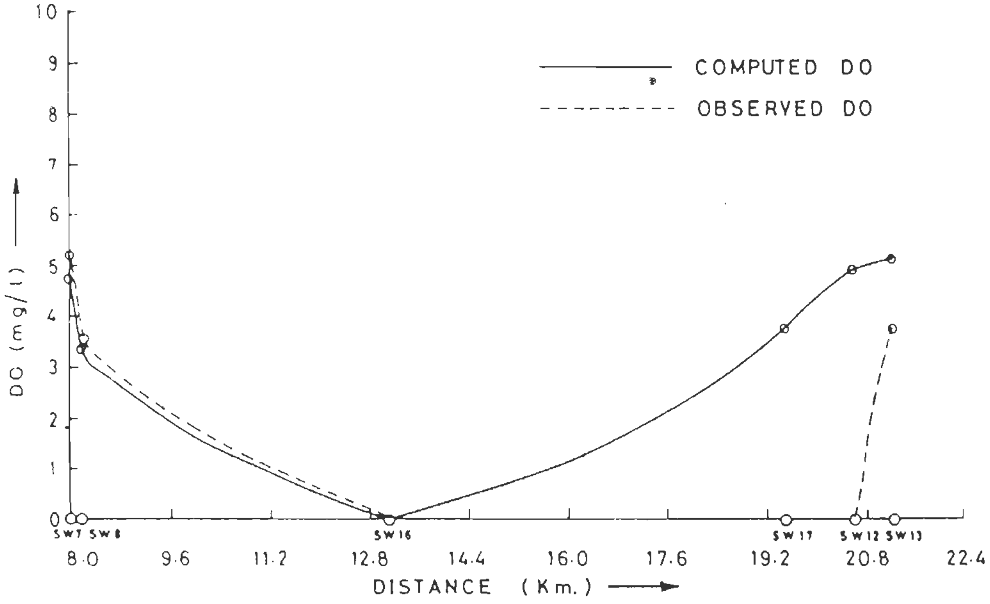


FIG. 5·17 DISSOLVED OXYGEN SAG CURVE ALONG DHAMOLA NALA (JUL, 87)

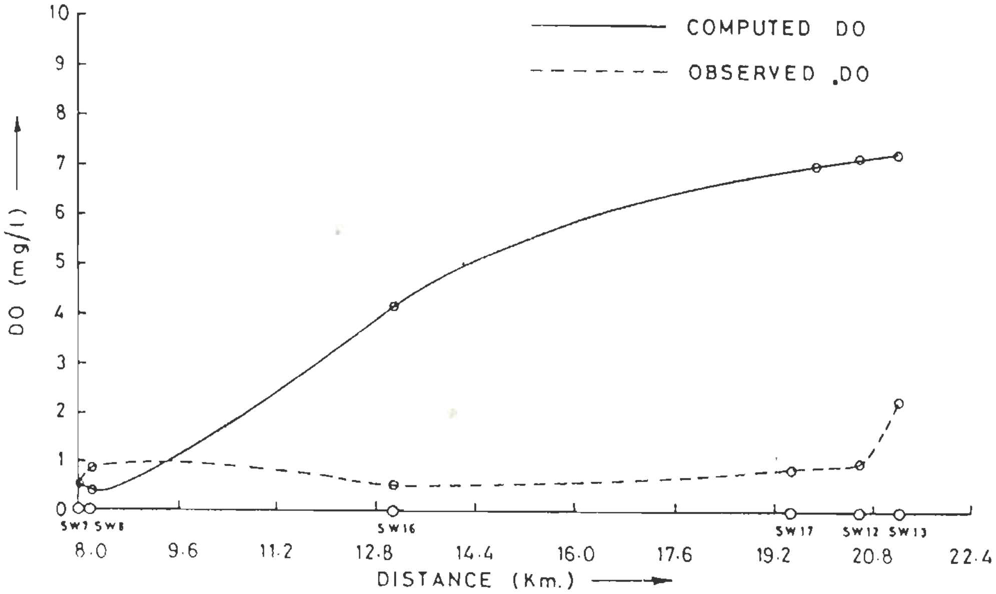
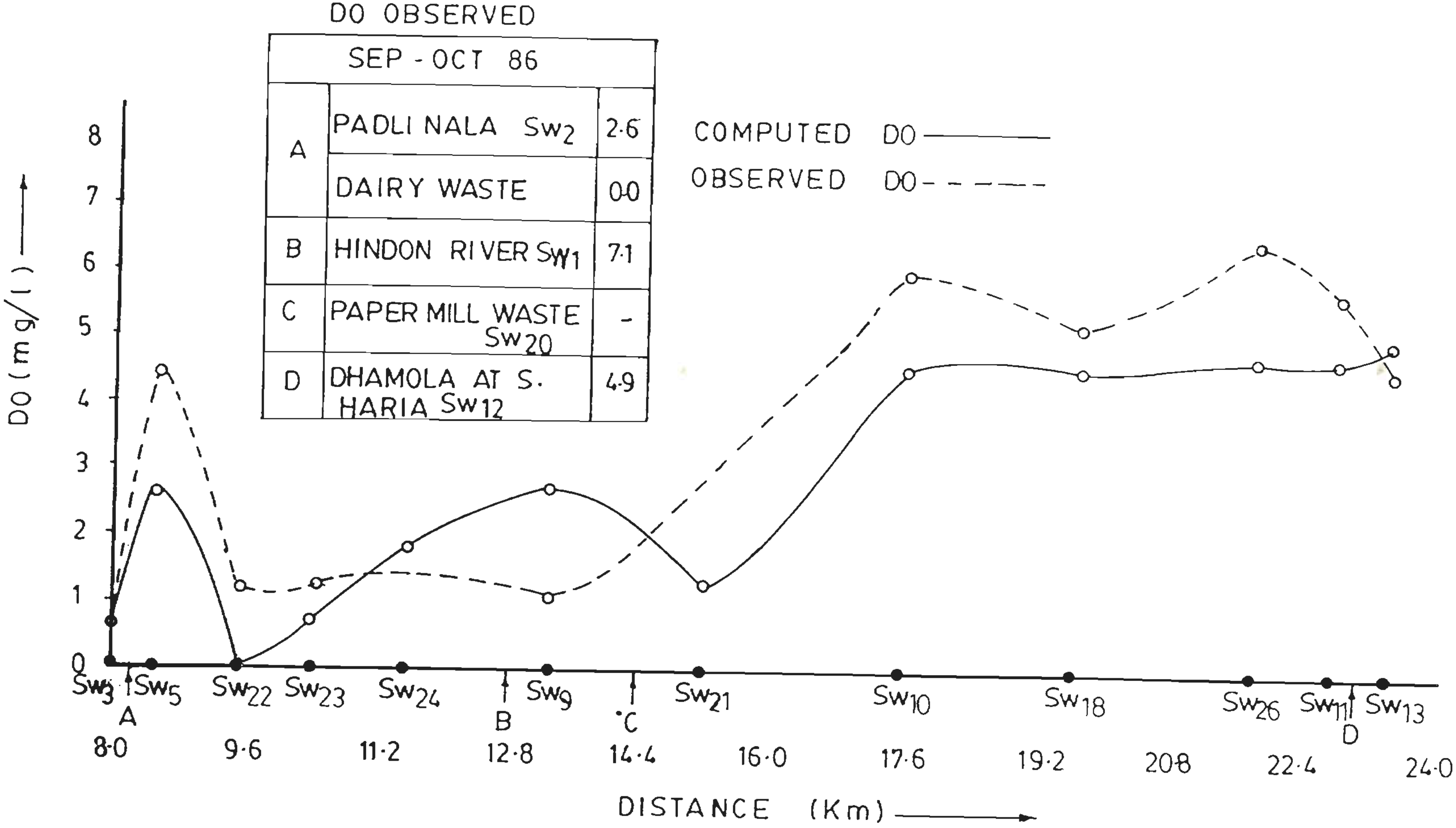


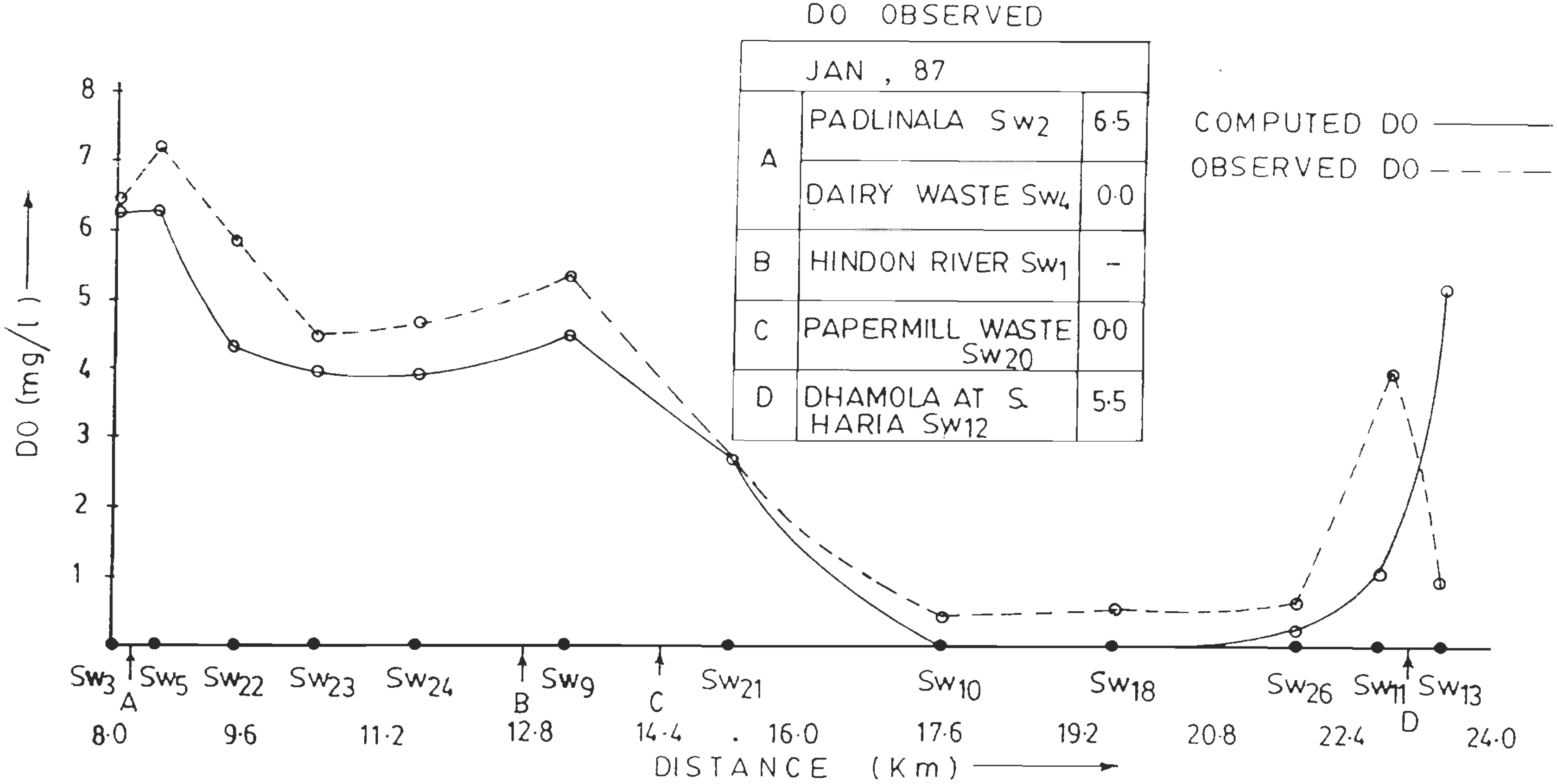
FIG. 5·18 DISSOLVED OXYGEN SAG CURVE ALONG DHAMOLA NALA (NOV, 87)



DO OBSERVED

SEP - OCT 86		
A	PADLI NALA Sw2	2·6
	DAIRY WASTE	0·0
B	HINDON RIVER Sw1	7·1
C	PAPER MILL WASTE Sw20	-
D	DHAMOLA AT S. HARIA Sw12	4·9

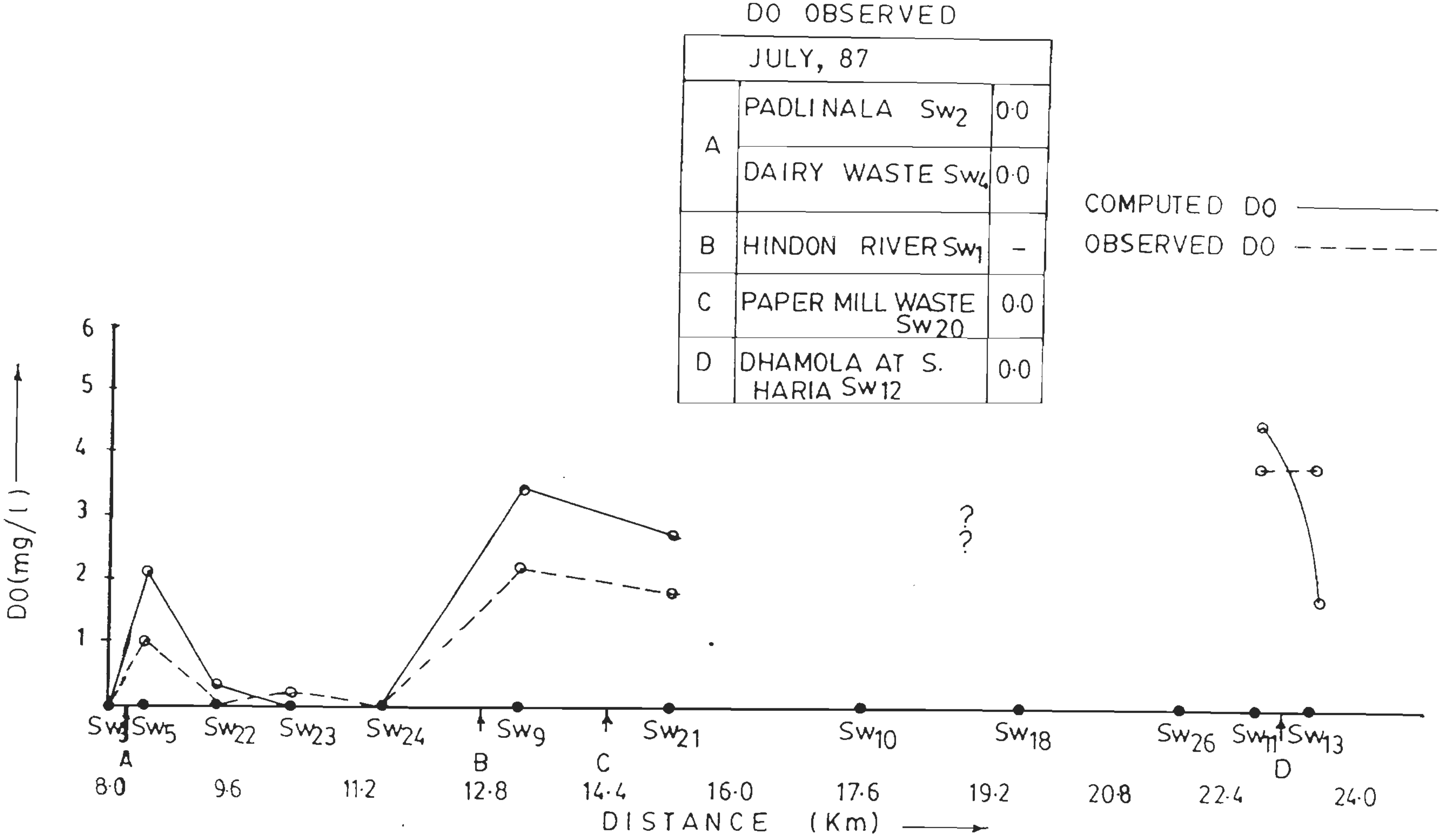
FIG.5·19 DISOLVED OXYGEN SAG CURVE ALONG NAGDEO - HINDON RIVER (SEP.-OCT. 86)



DO OBSERVED

JAN , 87		
A	PADLINALA Sw_2	6·5
	DAIRY WASTE Sw_4	0·0
B	HINDON RIVER Sw_1	–
C	PAPERMILL WASTE Sw_{20}	0·0
D	DHAMOLA AT S. HARIA Sw_{12}	5·5

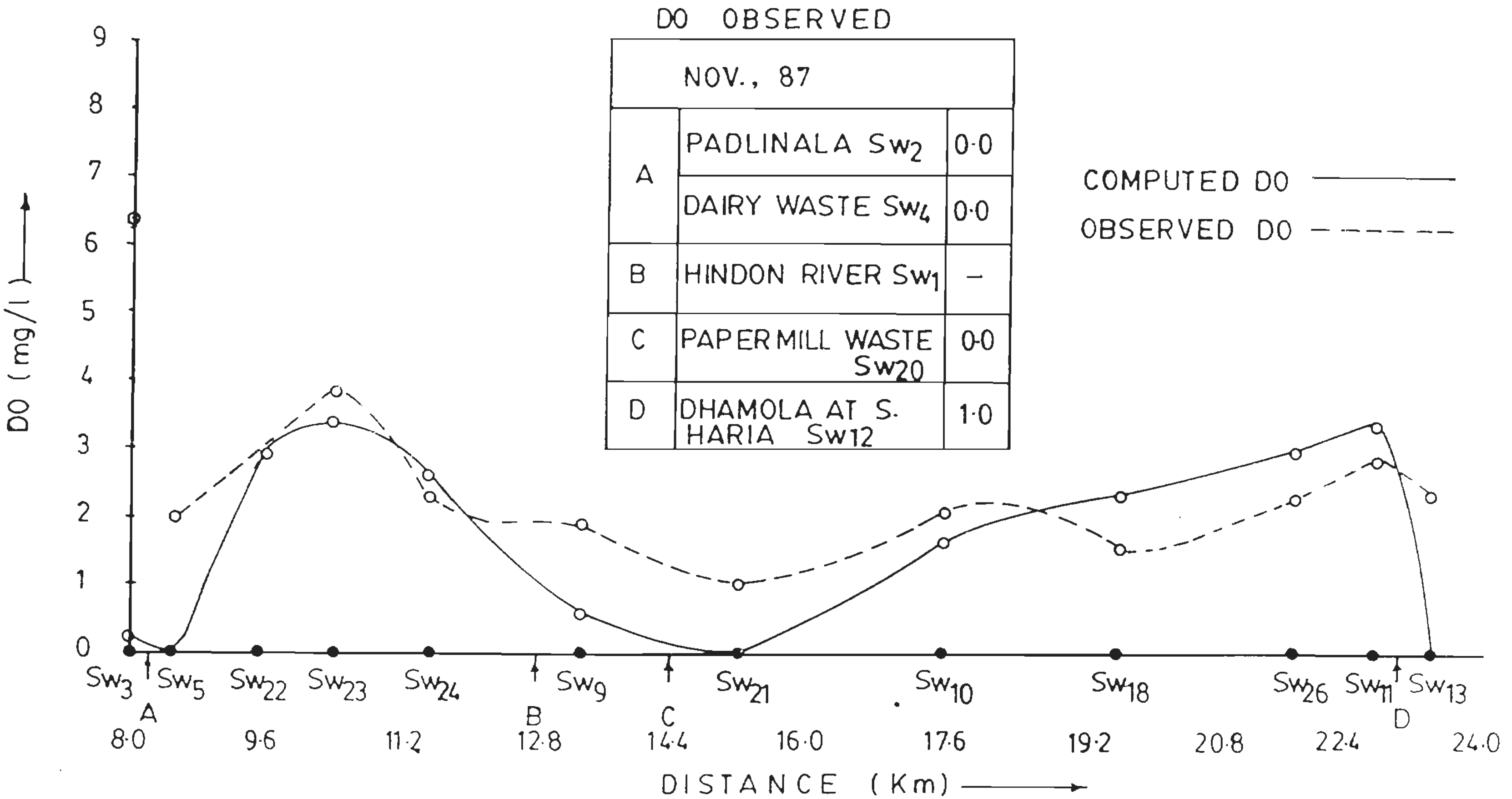
FIG. 5·20 DISOLVED OXYGEN SAG CURVE ALONG NAGDEO – HINDON RIVER. (JAN., 87)



DO OBSERVED

JULY, 87		
A	PADLINALA Sw_2	0·0
	DAIRY WASTE Sw_4	0·0
B	HINDON RIVER Sw_1	–
C	PAPER MILL WASTE Sw_{20}	0·0
D	DHAMOLA AT S. HARIA Sw_{12}	0·0

FIG. 5·21 DISSOLVED OXYGEN SAG CURVE ALONG NAGDEO – HINDON RIVER (JULY, 87)



NOV., 87		
A	PADLINALA Sw2	0·0
	DAIRY WASTE Sw4	0·0
B	HINDON RIVER Sw1	–
C	PAPER MILL WASTE Sw20	0·0
D	DHAMOLA AT S. HARIA Sw12	1·0

FIG. 5·22 DISOLVED OXYGEN SAG CURVE ALONG NAGDEO-HINDON RIVER (NOV.,87)

5.6 NATURE OF DO SAG CURVES COMPUTED BY USING REAERATION COEFFICIENT (K_2')FROM EQUATION (5.8)

From the curves of dissolved oxygen model computed by using reaeration coefficient (K_2') from equation (5.8) for Hindon river and Dhamola stream, a sharp disagreement of the computed DO from the observed values is clearly discernible in most cases.

In the month of September-October, 1986 (Fig. 5.11) for Hindon river, the computed DO drops to zero near location SW_5 and then shows a notable rise from downstream of the confluence of Paper mill drain and Hindon river (SW_{21}). Also, unlike the usual situation, the values of observed DO are found to be higher in comparison to the computed DO.

In the month of January, 1987 (Fig. 5.12) the minimum value of the computed DO is observed at location SW_{21} apparently due to mixing with paper mill effluent. The computed DO increases from location SW_{10} onwards. In case of observed DO, the minimum value is at location SW_{10} and then shows an increasing trend upto SW_{11}.

In the month of July, 1987 (Fig. 5.13), the computed DO shows zero values at location SW_{22} after which it again rises upto SW_{11}. A similar trend of observed DO is also found in this month. It may however, be noted that the waste discharges from Paper mill in this month were insignificant and partially treated.

In the month of November, 1987 (Fig. 5.14) the values of computed DO are generally lower than observed DO. It can also be seen that at location SW_{22}, the computed DO gets depleted fast due to deoxygenation, and with time and distance it attains zero value upto location SW_{11}. After SW_{11} onwards, DO values again start rising upto SW_{27}. The variation in observed DO values in comparison to the computed DO may be due to the incomplete mixing of the samples.

In case of Dhamola nala, it is seen from the figures that generally the computed DO is higher than the observed DO. In the month of September-October, 1986 (Fig. 5.15 to 5.18), the minimum computed and observed DO values are found at the same location SW_{16} (Badshapur) during all the above seasons, indicating the occurrence of critical DO near this location. The DO values start rising from this location upto SW_{13} near village Sadauli Hariya, thus indicating the absence of any significant waste effluents.

In the month of November, 1987 (Fig. 5.19), the computed DO shows a rise from location SW_7 to SW_{13} mainly due to the phenomenon of reoxygenation. The values of observed DO are found low in comparison to the computed DO values probably due to the improper mixing of the samples.

5.7 NATURE OF DO-SAG CURVES OBTAINED BY CONSIDERING SETTLEABLE BOD :

The DO-Sag curves for Nagdeo-Hindon stretch obtained by using DOSAG-I model involving use of the total BOD rate constants ($K'_{1(early)}$ for settleable BOD and $K'_{1(late)}$ for exponential rate of BOD satisfaction; Table 5.3) for both the Dairy waste and Paper mill waste are presented in Fig. 5.19 & 5.22. It is observed from the figures that the computed and observed DO curves for Sept., 1986, Jan., 1987., July, 1987 and Nov. 1987 exhibit fairly close agreement at most locations. For the DO curves in July, 1987, when there is little settleable BOD, the observed DO values at three locations (viz. SW_{10}, SW_{18} and SW_{26}) are not available, thus a complete comparison with computed DO is not possible.

The marked disagreement in the observed and computed model at some points especially in DO curves for Sept., 1986 and Nov., 1987 is difficult to explain. However, effluent discharges from a few hidden drains might influence the DO measurements.

It is also observed that the RMS error for the above four observed and computed curves is 2.3, 1.7, 0.8 and 2.3 mg/l (Table 5.11) for Sept., 1986, Jan., 1987, July, 1987 and Nov., 1987 respectively.

Such computations using total BOD constants for early and late stages could not be attempted for Dhamola stream as there are no visible sources of waste outfalls between Saharanpur town (SW_7) and Sadauli Hariya village (SW_{13}). The hidden drains (not shown in Fig. 1.1) along this stream in this stretch do not seem to have significant impact on the early stage of BOD removal, as observed from Fig. 5.21 and 5.22.

5.8 MODEL CALIBRATION AND VERIFICATION

It may be observed that the values of dissolved oxygen were calculated for Hindon river and Dhamola <u>nala</u> by using two methods viz. K_2' calculated from equation (5.8) and BOD constants (K_1') calculated by taking BOD progression separately for early (settleable) and late (non settleable) phases as suggested by

Bhargava (1983b and 1986). A visual comparison of the observed and computed DO curves (Fig. 5.11 to 5.18 and 5.19 to 5.22) indicates that there is a reasonable match of the observed and computed DO curves obtained from the latter approach. This is also supported by lower Root Mean Square (RMS) values for the Nagdeo - Hindon river, obtained by this method (Table 5.11).

In Dhamola nala the RMS values obtained from equation (5.8) based approach are fairly high (Table 5.11) and a wide disagreement can be noted between the observed and computed DO values. This divergence can be probably attributed to the hidden and widely distributed effluent sources of discharges through covered municipal drains directly emptying into Dhamola nala at numerous locations.

From this discussion, it may be deciphered that a fairly good calibration of the DO-Sag model is obtained by considering the phenomena of bioflocculation and settling of organic waste matter, on the lines given by Bhargava (1986). This is especially true for the Nagdeo-Hindon system of streams for the rainy (monsoon, Sept., 1986) and winter (Jan., 1987) seasons. Further, the sag curves for July, 1987 can be used for summer period for the initial part of the river stretch.

It can thus be concluded that in view of better calibration of observed and computed DO sag curves of Hindon & Dhamola streams for September, 1986 and January, 1987, the models for these periods (i.e. monsoon and winter) can be adopted for future predictions. As an additional complete set of data for diffrent seasons (with changed boundary conditions) was not available for verifying this model, its verification has been attempted only for early winter priod (Nov., 1987) as evident in table 5.11.

5.9 DO-BOD_u RELATIONSHIP

In the present study, the carbonaceous BOD(Lo) values were also computed by the DOSAG-I program using K_1' values computed from the basic differential equation of Streeter & Phelphs (1925). The values of BODu and DO are plotted in figs 5.23 to 5.28 for Hindon river and Dhamola nala.

Generally, figs 5.23 to 5.28 for Hindon and Dhamola stream show an approximately inverse relationship between DO and BOD in different seasons. Thus, the BOD peaks coincide with the corresponding minima of the DO curves. This can be explained due to the onset of increased deoxygenation from the point of high BOD resulting in utilization of dissolved oxygen.

5.10 BOD AND COD RELATIONSHIP

The relationship between BOD and COD has been studied in the past to indicate the level of non-degradable chemical wastes present in water. Eckenfelder (1970) reported BOD_5/COD ratio to vary around 0.94. A correlation between observed BOD_5 and COD for May, 1985 to November, 1987 is given in Table 5.12. From this table, it is observed that the values of BOD/COD ratio are in the range of 0.02 to 0.79. The low values in the samples indicate probably, the presence of smaller fractions of biodegradable wastes in the water. The maximum ratio is observed at location SW_{12} (Dhamala nala, near village Sadauli Hariya) in the month of November, 1987. Most of the lower ratios are observed in Dhamola nala (near

Saharanpur town) and Nagdeo nala (near Dairy waste confluence) for the period of March, 1986 and Nov., 1987.

Table 5.11: Comparison of Root Mean Square (RMS) Error(s) Between Observed and Computed DO by Using Reaeration Coefficients (K_1) by Equation (5.8) and as per Bhargava (1983b, 1986)

From Equation 5.8 (mg/l)		As per Bhargava (1983b, 1986) (mg/l)	
Nagdeo-Hindon river		Nagdeo-Hindon river	
Sept.,86	2.716	Sept.,86	2.310
Jan.,87	2.349	Jan.,87	1.690
July,87	5.071	July,87	0.859
Nov.,87	2.332	Nov.,87	2.330
Dhamola rivulet (nala)		Dhamola rivulet (nala)	
Sept.,86	2.826	Sept.,86	-
Jan.,87	2.330	Jan.,87	-
July,87	2.593	July,87	-
Nov.,87	4.106	Nov.,87	-

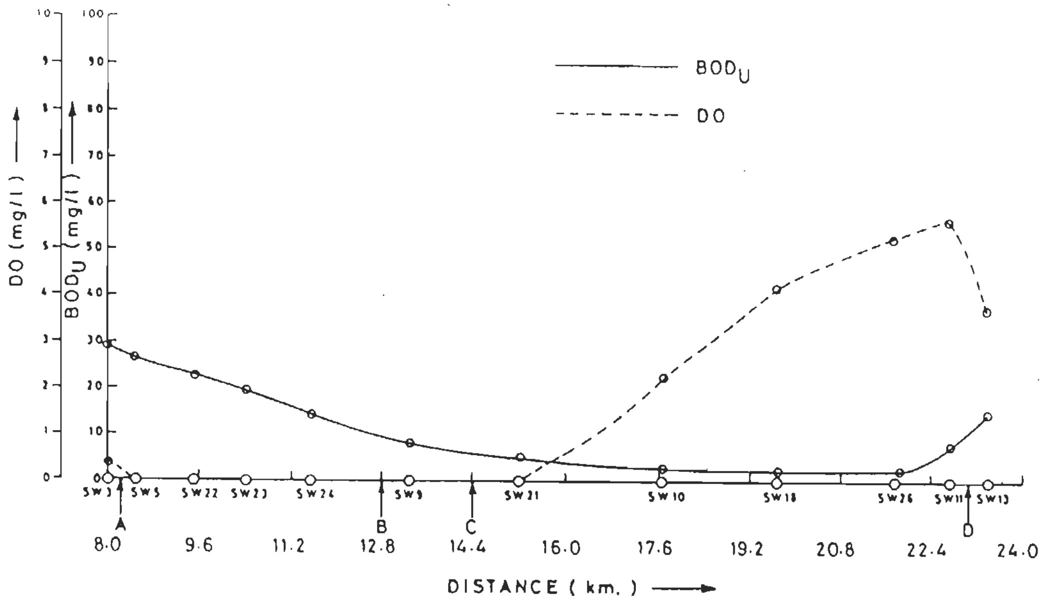


FIG. 5.23 DO-BOD RELATIONSHIP ALONG NAGDEO-HINDON RIVER (SEP.-OCT.,86)

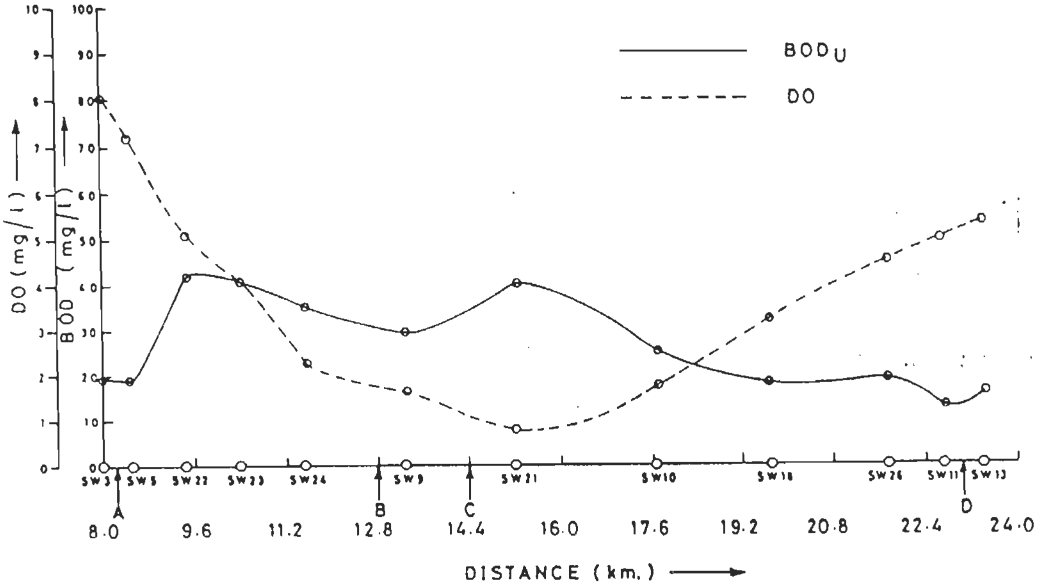


FIG 5.24 DO-BOD RELATIONSHIP ALONG NAGDEO-HINDON RIVER (JAN.,87)

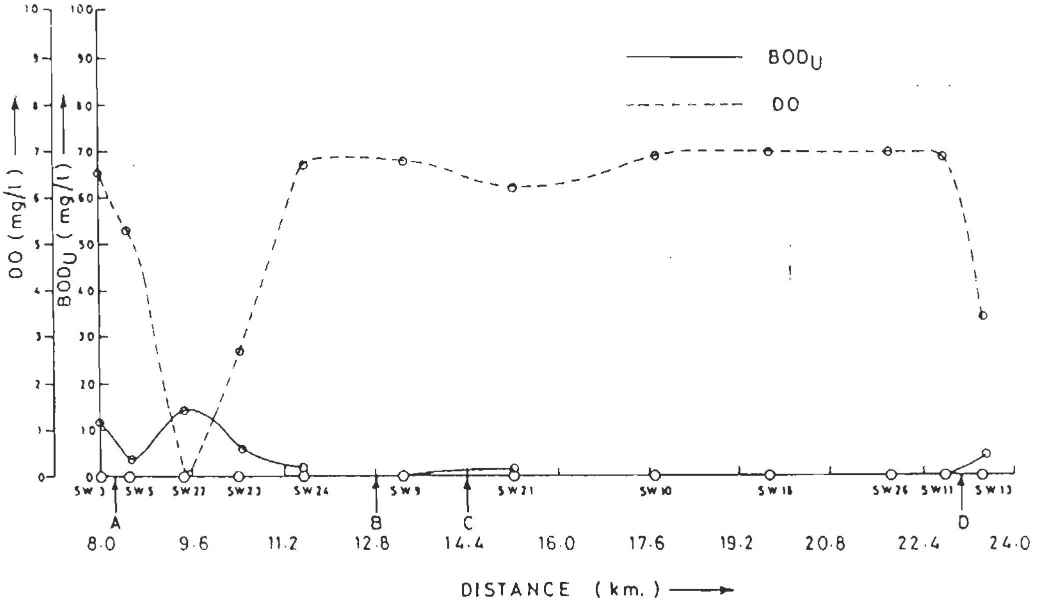


FIG. 5.25 DO - BOD RELATIONSHIP ALONG NAGDEO - HINDON RIVER (JULY, 87)

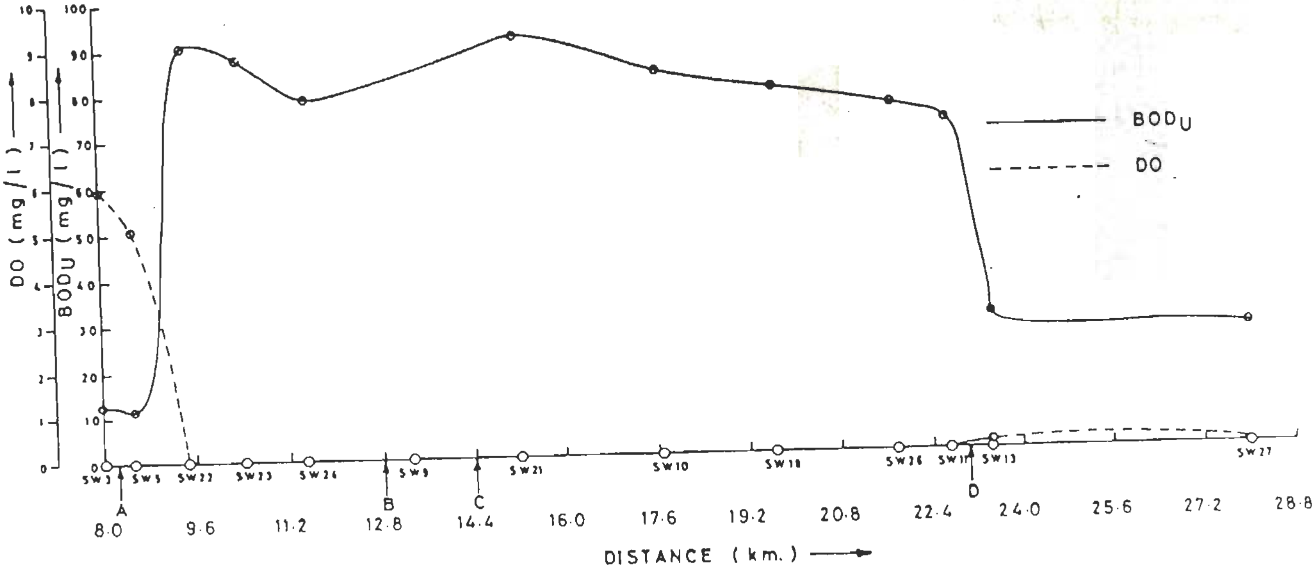


FIG. 5.26 DO - BOD RELATIONSHIP ALONG NAGDEO - HINDON RIVER (NOV., 87)

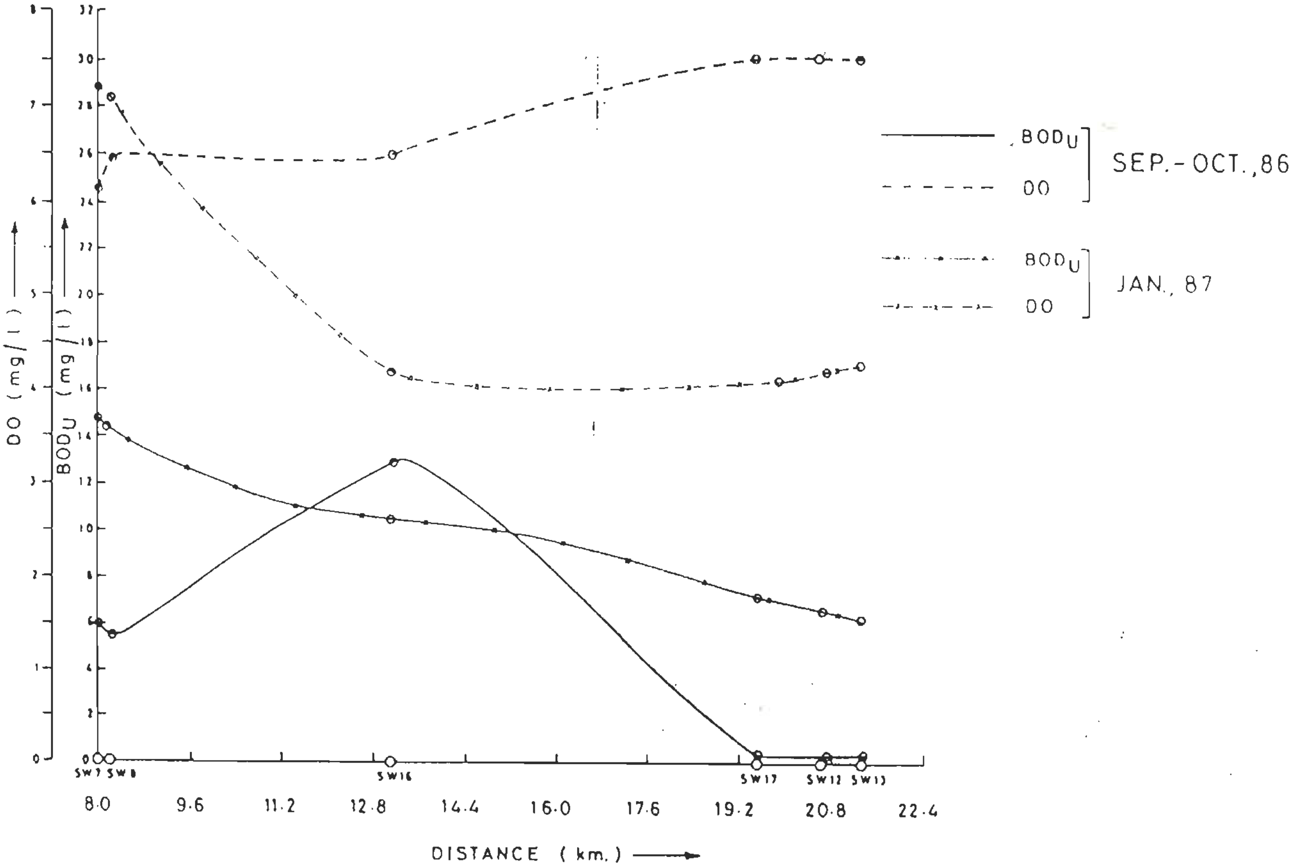


FIG. 5.27 DO - BOD RELATIONSHIP ALONG DHAMOLA NALA (SEP.-OCT.,86 & NOV.,87)

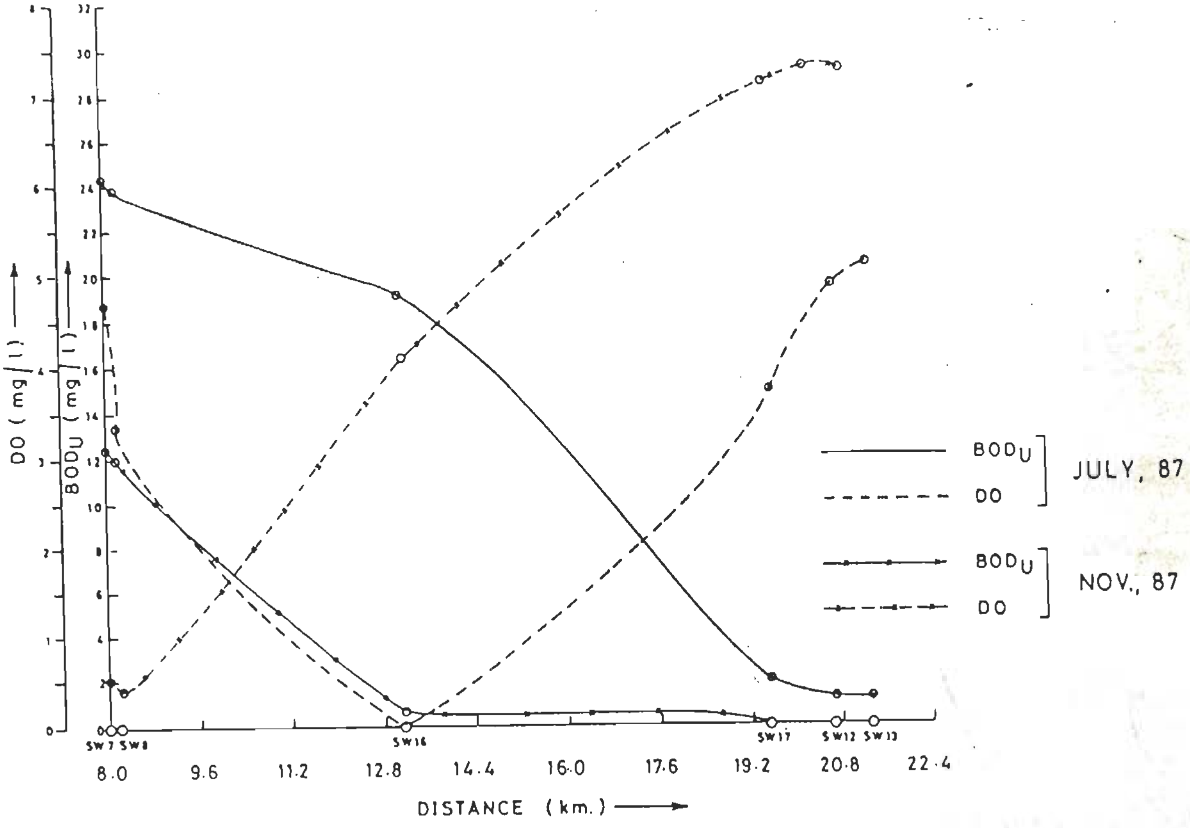


FIG. 5.28 DO - BOD RELATIONSHIP ALONG DHAMOLA NALA (JULY, 87 & NOV.,87)

Table: 5·12 : Relationship Between BOD_5/COD in Different Water Samples for Different Periods of Sampling (May 1985 - November 1987)

May '85		August '85		October '85		January '86		March '86	
Sample location	BOD_5/COD ratio	Sample location	BOD_5/COD ratio	Sample location	BOD_5/COD ratio	Sample location	BOD_5/COD ratio	Sample location	BOD_5/COD ratio
SW_3	0.22	SW_3	0.22	SW_3	0.31	SW_3	0.25	SW_3	0.24
SW_5	0.24	SW_5	0.20	SW_5	0.27	SW_5	0.22	SW_5	0.25
SW_9	0.22	SW_{10}	0.30	SW_9	0.25	SW_9	0.35	SW_9	0.25
SW_{10}	-	SW_8	0.25	SW_{10}	0.25	SW_{10}	0.27	SW_{10}	0.25
SW_{11}	0.20			SW_{11}	-	SW_{11}	0.22	SW_{11}	0.21
SW_{13}	0.22			SW_{13}	0.22	SW_{13}	-	SW_{13}	0.41
SW_8	0.20			SW_8	0.29	SW_8	0.05	SW_8	0.02
SW_{12}	0.25			SW_{12}	0.30	SW_{12}	0.21	SW_{12}	0.04

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(Contd.....)

(Contd.....) Table 5·12

May '86		August '86		November '87	
Sample location	BOD$_5$/COD ratio	Sample location	BOD$_5$/COD ratio	Sample location	BOD$_5$/COD ratio
SW$_3$	0.26	SW$_3$	0.18	SW$_3$	0.28
SW$_5$	0.44	SW$_5$	0.09	SW$_5$	0.02
SW$_9$	–	SW$_9$	0.22	SW$_{22}$	0.13
SW$_{21}$	0.39	SW$_{21}$	0.18	SW$_{23}$	0.70
SW$_{19}$	0.27	SW$_{10}$	0.54	SW$_{24}$	0.19
SW$_{10}$	0.42	SW$_8$	0.12	SW$_9$	0.46
SW$_{18}$	0.30	SW$_{15}$	0.02	SW$_{21}$	0.10
SW$_{11}$	0.32	SW$_{16}$	0.13	SW$_{10}$	0.14
SW$_{13}$	0.30			SW$_{18}$	0.11
SW$_8$	0.18			SW$_{11}$	0.03
SW$_{15}$	0.25			SW$_{13}$	0.09
SW$_{16}$	0.34			SW$_{27}$	0.05
SW$_{17}$	–			SW$_{28}$	0.04
SW$_{12}$	0.26			SW$_8$	0.12
				SW$_{16}$	0.08
				SW$_{17}$	0.08
				SW$_{12}$	0.79

CHAPTER-6

ADSORPTION STUDY OF TRACE METALS ON SEDIMENTS

6.1 INTRODUCTION

The distribution and fate of most of the toxic metals and the effect they cause on environmental quality and aquatic life are strongly influenced by their reactions with particulate substances and the transport of these particles through aquatic system. The heavy metals can be associated with solid phase by direct adsorption on fine grained inorganic particles and in turn get associated with clays. Adsorption has been recognized as an important mechanism for controlling the concentration and transport of trace constituents through natural water bodies, soil/ground water systems and waste treatment operations.

The greater part of the dissolved heavy metals transported by natural system, under normal physio-chemical conditions, gets rapidly adsorbed on to the particulate material. However, the heavy metals immobilized in bottom sediments do not necessarily stay in that condition for long and are gradually released as a result of chemical change in the aquatic environment. This state of affairs is maintained until there is remobilization from the sediment due to changing state in the system and this results from:

(1) the elevated salt concentrations, whereby the alkali and alkaline earth cations can compete with metal ions sorbed onto solid particles.

(2) the change in the redox conditions, usually in conjunction with a decrease in oxygen potential due to advanced eutrophication.

(3) the lowering of pH which leads to a dissolution of carbonates and hydroxides, as well as to increased desorption of metal cations due to competition with H^+ ions.

(4) the increased use of natural and synthetic complexing agents, which can form soluble metal complexes (sometimes of high stability) with heavy metals that are otherwise adsorbed to solid particles.

The heavy metals are either transferred from the sediment to animal or plant organism possibly to be further enriched along the food chain or are discharged directly or via decomposition products into water. In the natural condition of river water, suspended load and sediments have the important function of buffering higher metal concentrations of water particularly by adsorption or precipitation (Forstner and Muller, 1973) and therefore a study of the sorptive properties of the sediments can provide valuable information relating to the tolerance of the system to the heavy metal loadings present in it.

6.2 NATURE OF SEDIMENTS

The sediments consist of inorganic and organic compounds both of which come from sources outside or within the river. The organic matter consists of micro-organisms (phytoplanktons, zooplanktons, benthos and bacteria), the remains of microphytes and large size organisms together with detritus derived from the decaying material. The inorganic matter consists of erosion products from the rock in the watershed (rock particles and clays), together with compounds such as FeOOH or [$Fe(OH)_3$], SiO_2 or $CaCO_3$ which may be brought into water from outside or are formed within it.

In general,the sediment composition is largely controlled by the composition of source rock and the influence of climatic regime (weathering and hydraulic conditions), landform, land use and time in transit.

6.3 CLASSIFICATION OF CHEMICAL PHASES IN SEDIMENTS

Despite the wide variability of composition of the sediments depending upon the prevailing conditions, these are characterised by some inherent structural and surface properties favouring heavy metal adsorption. A number of ingredients present in sediments are identified as surface active.

The mechanism of heavy metal uptake on hydrous oxides has been demonstrated by Hildebrand and Blum (1974). They have studied the uptake of Pb^{++} on iron hydroxide. Pb^{++} is incorporated in the stern layer of the hydroxide structure and hydrogen ions get exchanged. Thus it seems to exhibit a strong affinity for the hydroxyl group of the FeO(OH) crystal.

Jenne (1976) proposed that the hydroxide of aluminium, iron, and manganese, particularly the redox senstive Fe and Mn hydroxides and oxides under oxidizing conditions constitute significant sinks of heavy metals in aquatic system. These hydroxides and oxides readily sorb or co-precipitate cations and anions; even a low percentage of $Fe(OH)_3$ and MnO_2 has a controlling influence on the heavy metal distribution in an aquatic system. Stumm and Morgan (1970), for the sorption on micro-crystalline iron and manganese hydroxide, suggested that while these processes with group I and group II cations take place predominantly in the diffused part of the electrical double layer, the transition and heavy metal ions become specifically attached to the surface. The zero point of charge (pH_{zpc})values for α-$Al(OH)_3$(5.0), γ-Fe_2O_3(6.7), MnO_2 (2-4.5) indicate that these species in basic conditions will exhibit electrostatic affinity for heavy metal ions.

The zero point charge (pHzpc) of the clay minerals, kaolinite (4.6), and montmorillonite (2.5), indicate that at pH=8 the particles have negative charge and will exhibit electrostatic affinity for cations such as heavy metal ions (Jenne, 1976). Adsorption of heavy metal ions on oxides, another potential adsorber in sediments, have been studied extensively. Benjamin and Leckie (1980) reported the adsorption of Cd^{++},Zn^{++},Cu^{++} and Pb^{++} on γ-Al_2O_3, γ-FeooH and α-SiO_2 and indicated the surface sites for their uptake. Dempsey and Singer (1980) reported the uptake of zinc ion on hydrous ferric and manganese oxides. Loganathan and Burau (1973) reported the sorption of heavy metal ions by hydrous manganous oxides. Bourg and Filby (1974) studied the adsorption characteristics of zinc by montmorillonite, illite and kaolinite and found that Freundlich adsorption isotherm is satisfied. Griffin and Au (1977) reported the adsorption of lead from pure $Pb(NO_3)_2$ solution by Ca-montmorillonite at pH 5.0 and found it to be sensitive to the weight of clay sample. Reimer and Toth (1970) studied the adsorption of Cu^{++} on clay minerals, humic acid and bottom muds.

The references cited above exhibit the importance and role of sediments in the accumulation and transport of toxic heavy metal ions. As such it was considered necessary to observe the characteristics of bed sediments collected from various places. Investigations included in this section involve the surface uptake of Mn^{2+}, Pb^{2+} and Zn^{2+} on the sieved bed sediments of river Hindon. Different parameters which influence the sorption of metal ions viz. pH of the solution, optimum sediment and metal dose etc., have been evaluated and the data has been treated by Freundlich and Langmuir models to obtain the energy and other relevant parameters which indicate the probability and feasibility of the process.

6.4 MATERIAL AND METHODS

6.4.1 Collection of Samples

For studying the distribution of heavy metals in bed sediments and also for observing the sorption behaviour of freshly deposited sediments, a background sample was always collected from the nearby area for comparison purpose. The sediment samples were collected at different locations. One sample was collected at the confluence of Padli nala, Nagdeo nala and Indana nala; and three more were obtained from each drain. One sediment sample each was taken from the confluence of Nagdeo nala and river Hindon and another set was collected from the paper mill drain and after the confluence of paper mill waste and Hindon river. The location of the sediment sampling points are shown in Fig. 1.1.

The method of sampling was the same as suggested by Sakai et al. (1986) and Subramanian et al. (1987). Samples were kept in plastic bags. The sediment samples, collected from various locations, were wet material. These were air dried and passed through a 230 mesh sieve to separate the silt and clay fraction which was subsequently used for adsorption studies.

6.5 EXTRACTABLE METALS IN BED SEDIMENTS

For the determination of extractable metal concentration in the bed sediment samples, the HNO_3-H_2O_2 extraction method was used, as reported by Krishnamurthy et al. (1976).

6.6 SORPTION STUDIES

Batch studies were performed for the determination of optimum pH and sediment dose for the adsorption of metal ions. The sieved sediments were oven dried overnight at 100-105^{0}C and after cooling in dessicator were utilised for sorption study. Aqueous solutions of Pb^{2+}, Zn^{2+} and Mn^{2+} were prepared from lead nitrate, zinc sulphate and manganese dioxide respectively. The concentration of the solution taken for experimentation was 2000,4000, 6000,8000 and 10,000 μg/l (2.0,4.0,6.0,8.0 and 10 mg/l). 25 ml portions of the solution was added to 50 ml beaker containing weighed amount of the sediment and the contents were stirred in multiple stirrer fitted with polythene blades for fixed period of time. These were then filtered through Whatman filter paper No. 1 and the filterate was used for the determination of the concentration of metal ions after adsorption, with the help of Atomic Absorption Spectrophotometer (Model IL 751).

The pH for optimum adsorption of each metal was determined by running experiments at varying hydrogen ion concentrations. Optimum sediment dose was fixed by taking different amounts of sediment ranging from 0.2 gms to 0.8 gms per 25 ml solution of 10000 μg/l (10mg/l) concentration (Table 6.7).

6.7 X-RAY DIFFRACTION STUDIES OF SEDIMENTS

The X-ray diffractogram of the sediments (silt + clay fraction) were obtained by using X-ray diffracto meter (Model PW1140/90, Phillips, Holland). The target used was Cu (Kα) with Ni filter. The chart speed and genometer speed were 1 cm per min, and 1° per min respectively.

6.8 RESULTS AND DISCUSSION

X-ray diffractograms of different samples are shown in Fig. 6.1 to 6.9. The details of X-ray diffractograms in terms of intensity and d values are given in Table 6.1.

In order to identify the clay minerals, the X-ray diffraction of clay+silt fraction of representative sediment samples collected from the area, are shown in Fig. 1.1. These reveal the presence of illite and other mixed minerals viz., (chlorite-vermiculite, kaolinite-chlorite and quartz-illite). The presence of illite as the major constituent of clay and silt fraction is indicated by a strong reflection at $8.8^{0}(10\bar{A})$. The reflection of chlorite-vermiculite, kaolinite-chlorite and quartz-illite are also

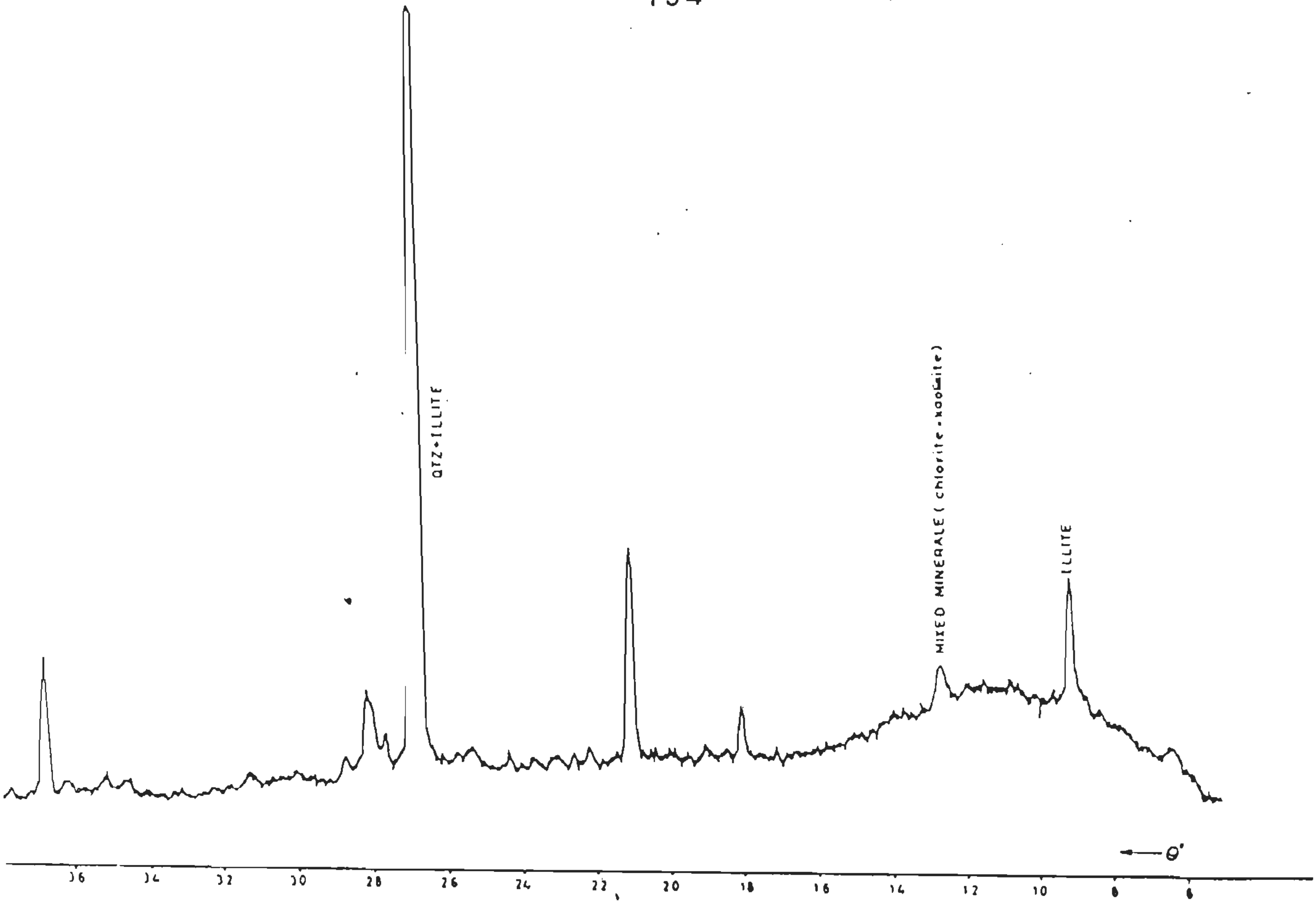


FIG.6·1 X- RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE(S-1)

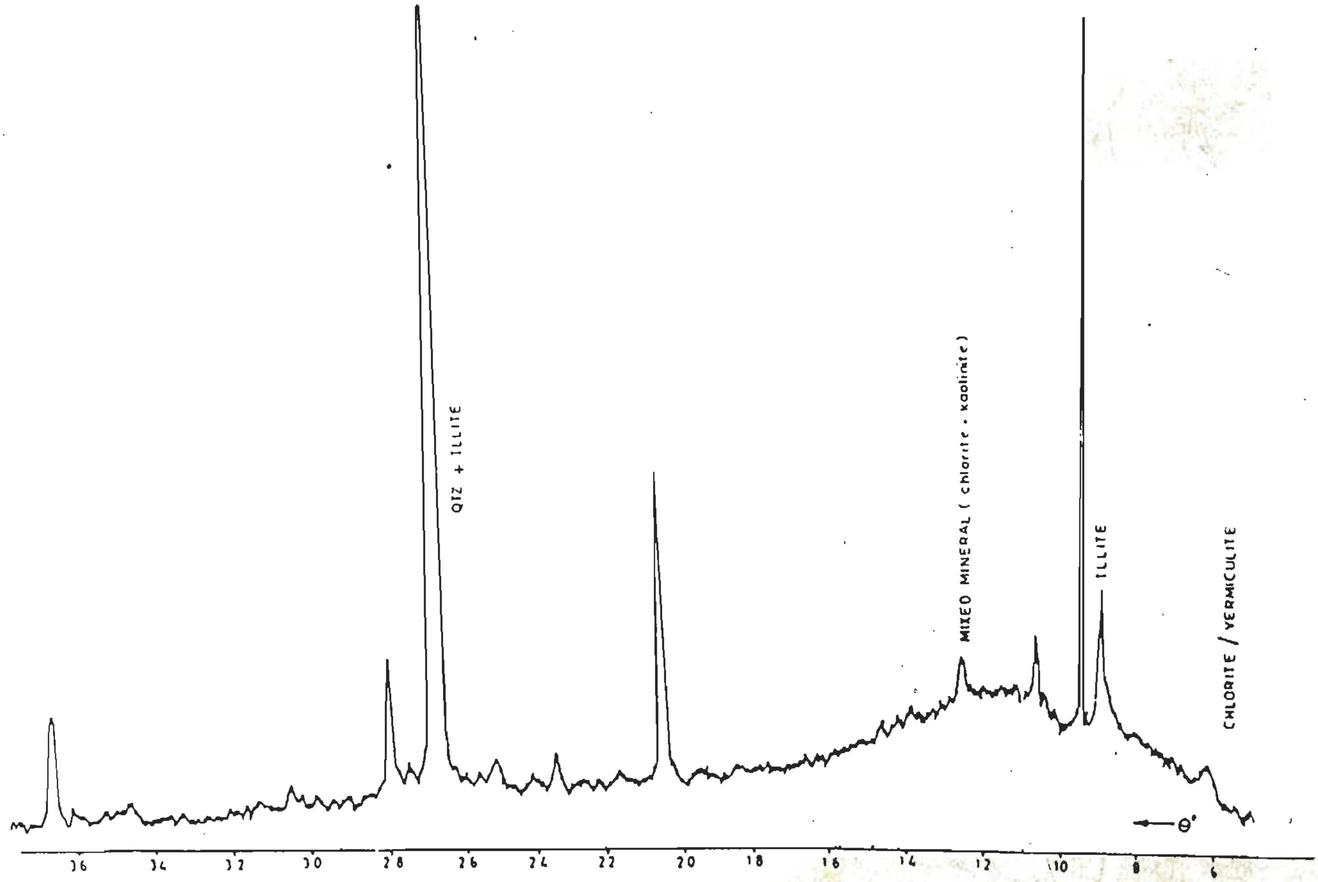


FIG.6·2 X-RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE(S-2)

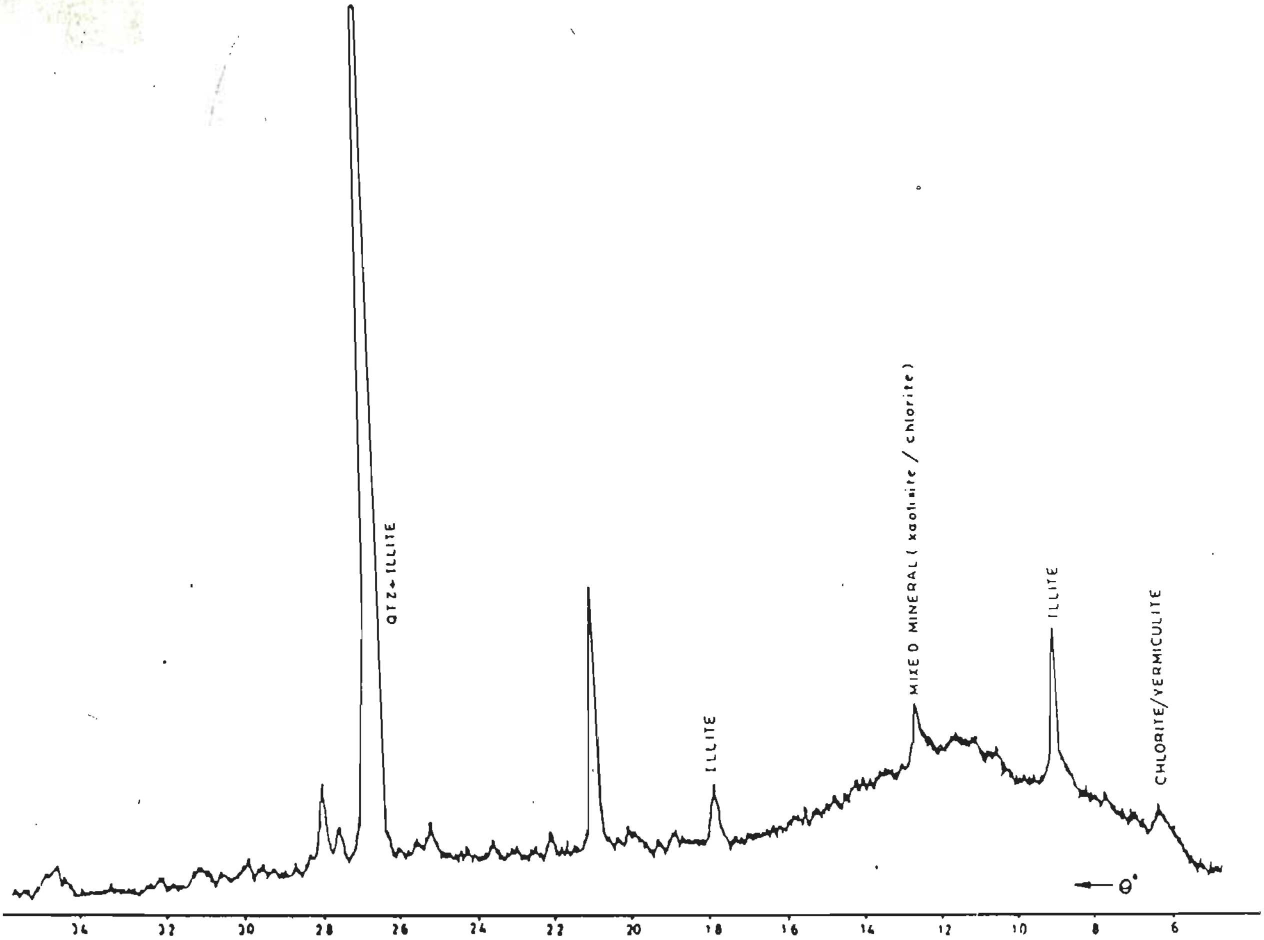


FIG.6.3 X-RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE (S-3)

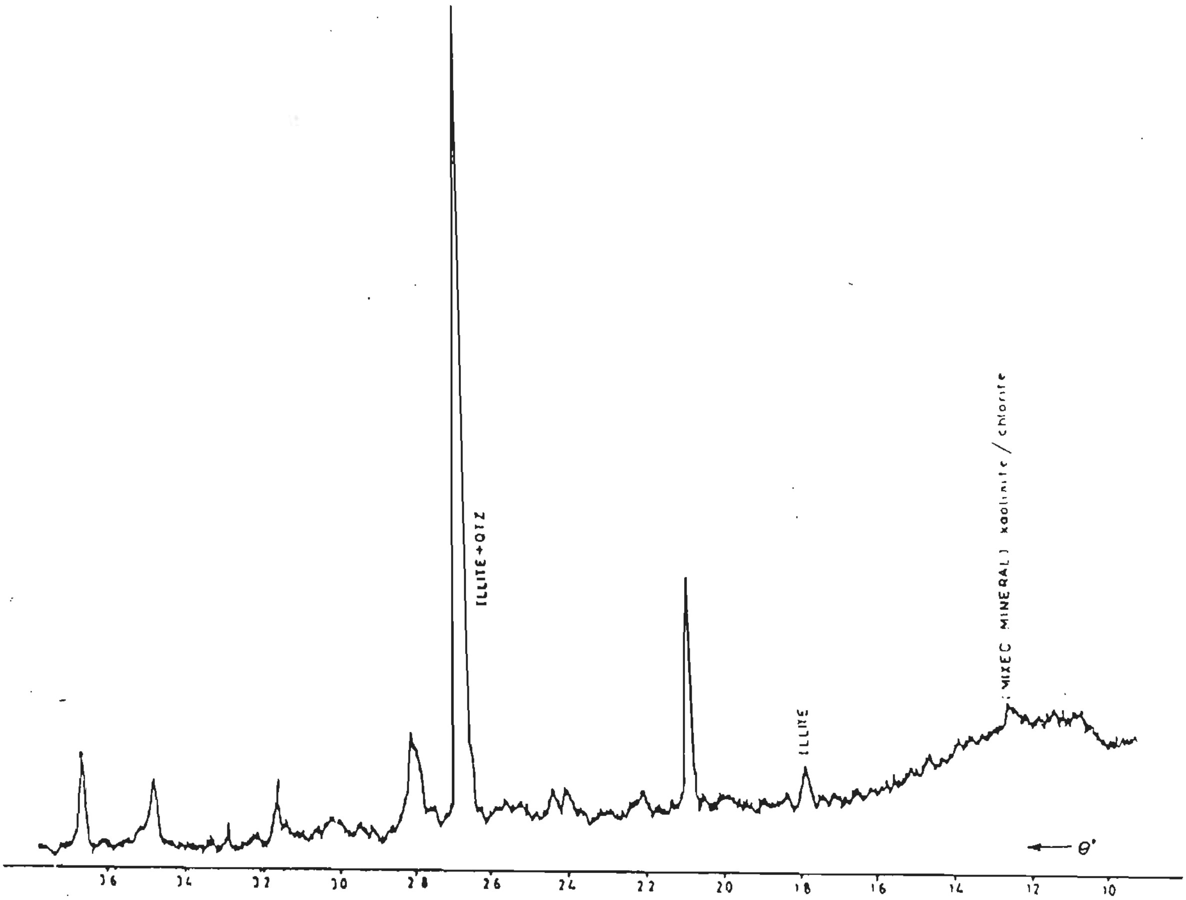


FIG6.4 X- RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE(S-4)

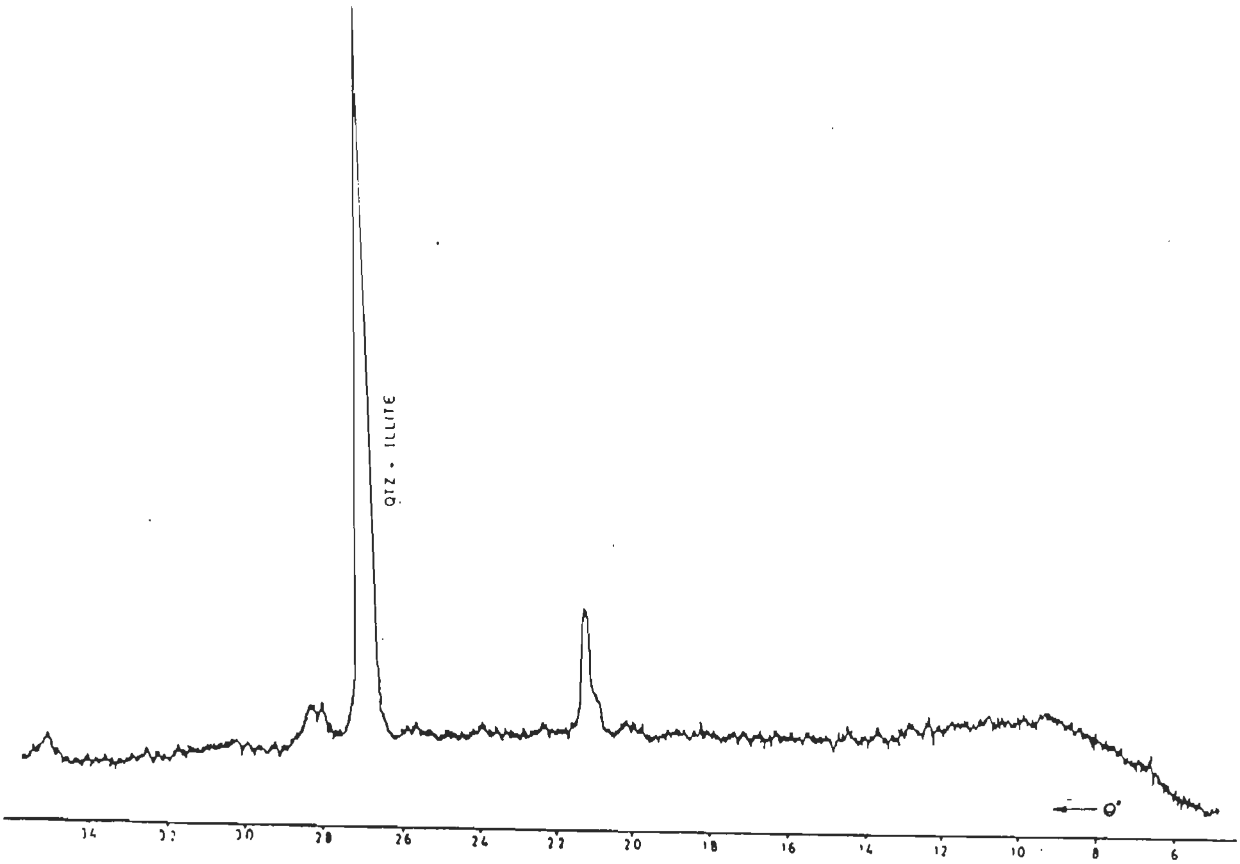


FIG.6.5 X-RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE (S-5)

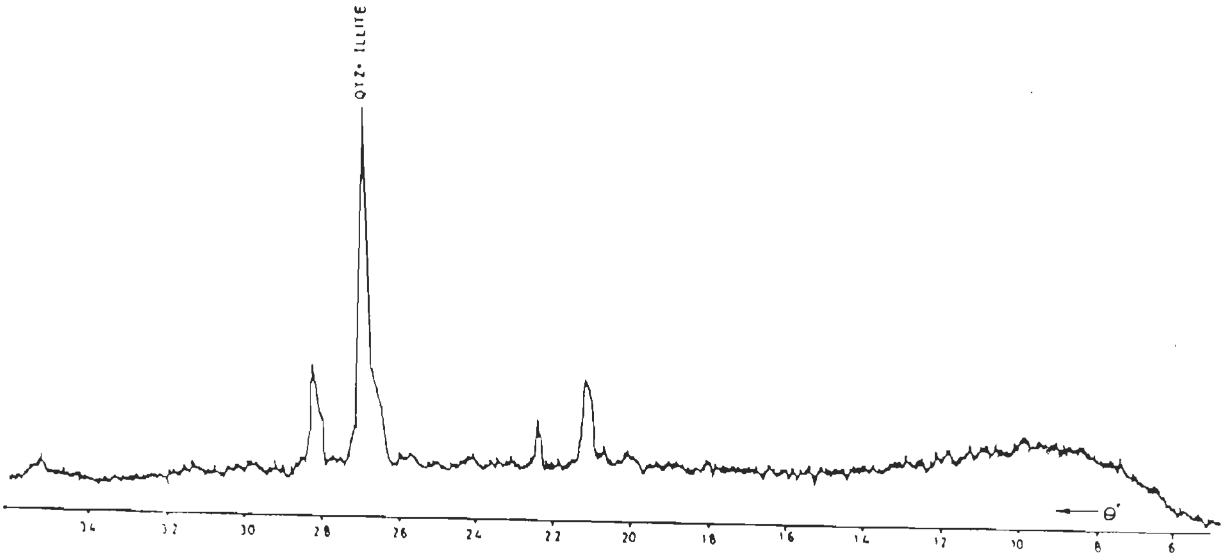


FIG.6.6 X-RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE(S-6)

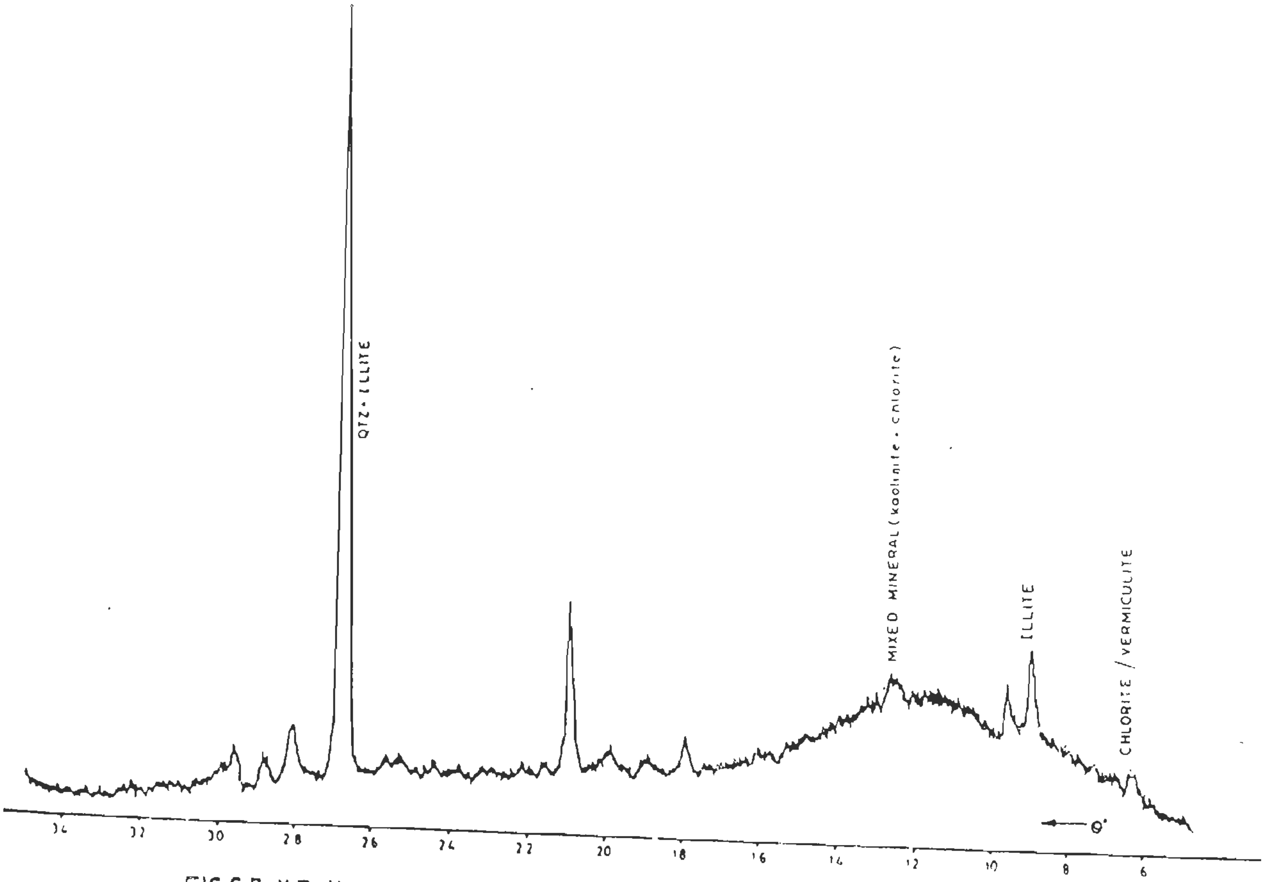


FIG.6.7 X-RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE (S-7)

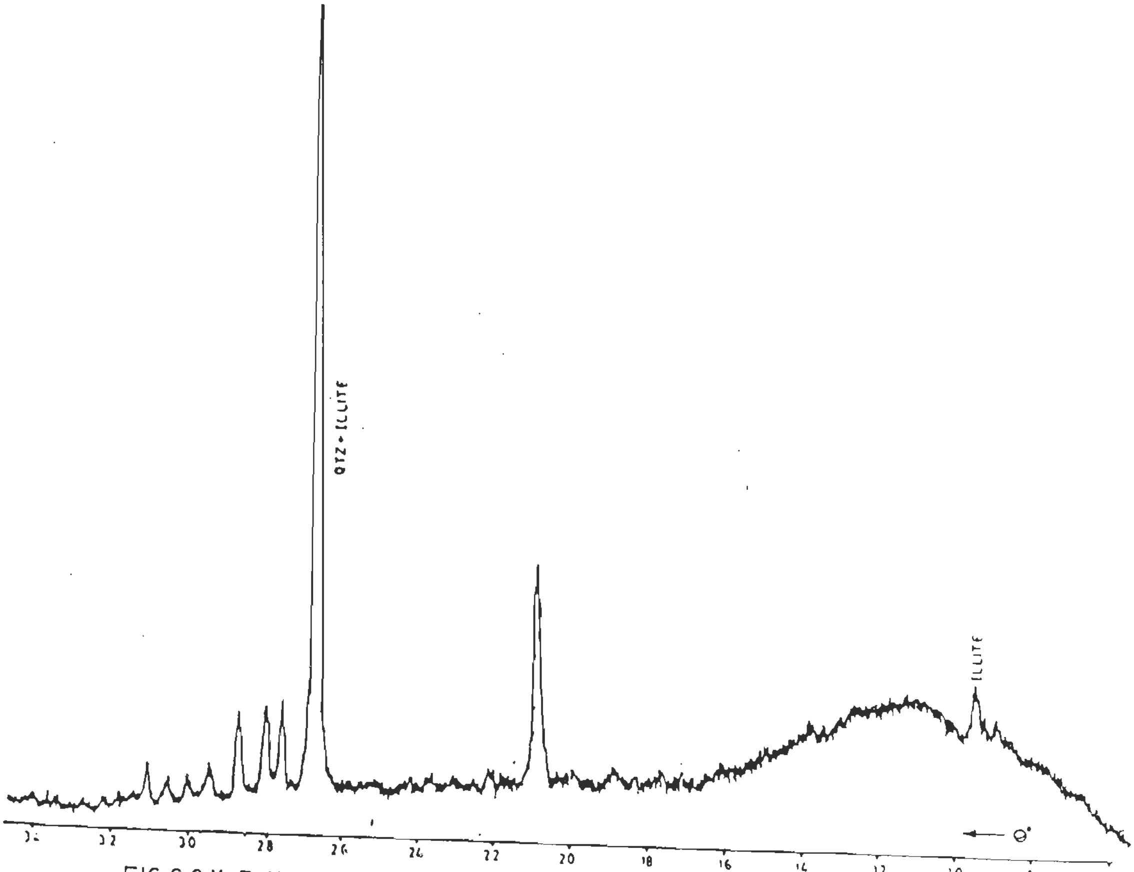


FIG.6.8 X-RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE (S-8)

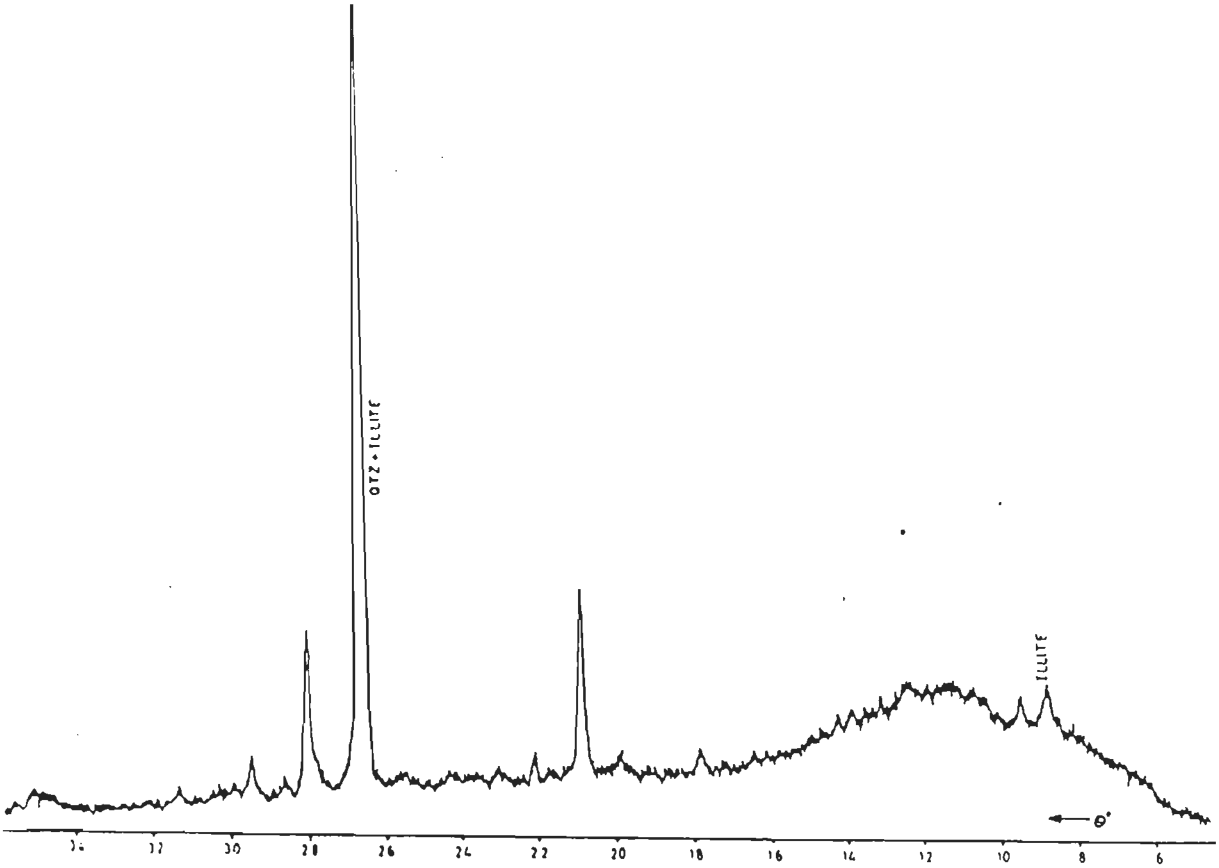


FIG.6.9 X-RAY DIFFRACTOGRAMS OF SEDIMENT SAMPLE (S-9)

observed at 6^0, 12.3^0 and 26.6^0.

The values of the total concentration of two metals, determined in river water at different locations (Fig. 1.1) from May, 1985 to November, 1987, are given in Table 6.2. It is observed that the values of Pb^{2+} range from 0.105 mg/l to 0.605 mg/l and that of Zn^{2+} are in the range of 0.080 mg/l to 0.147 mg/l. The reason for the higher values of Pb^{2+} and Zn^{2+}, observed in the downstream of the confluence of river Hindon and Paper mill effluent, are already mentioned in chapter 4.

Table 6.1: Values of d-Spacing as Calculated from X-ray diffraction Patterns of Sediment Samples (A^0)

S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
9.827	9.827	9.827	4.983	4.231	4.191	10.052	9.216	9.827
(19)	(19)	(25)	(6)	(18)	(23)	(10)	(7)	(6)
6.917	8.272	7.028	4.231	3.327	3.970	9.216	4.251	4.271
(7)	(9)	(7)	(30)	(100)	(15)	(8)	(28)	(25)
5.216	7.028	4.983	3.327		3.303	5.291	3.327	3.327
(10)	(5)	(11)	(100)		(100)	(4)	(100)	(100)
4.441	4.231	4.231	3.165		3.165	4.956	3.232	3.165
(32)	(40)	(40)	(12)		(32)	(6)	(10)	(22)
3.453	3.739	3.327	2.831			9.231	3.187	3.018
(100)	(5)	(100)	(7)			(22)	(9)	(5)
3.279	3.533	3.187	2.578			3.327	3.122	
(12)	(100)	(11)	(7)			(100)	(10)	
2.508	3.187		2.455			3.176	3.038	
(20)	(16)		(11)			(6)	(5)	
	2.455					3.100	2.885	
	(15)					(4)	(5)	
						3.018		
						(4)		

The relative intensity values are given in parenthesis.

Table 6.2: Mean Values of Pb^{2+} and Zn^{2+} Content in Water Samples. (Period: May, 1985 to November, 1987)

Sampling location	pH	Pb^{2+} mg/l	Zn^{2+} mg/l
Padli <u>nala</u> (SW_2)	6.5-8.8	0.587	0.121
Nagdeo <u>nala</u> (SW_3)	7.3-8.8	0.365	0.094
Indana <u>nala</u> (SW_4)	7.2-9.1	0.105	0.087
Mixture (SW_5)	6.8-9.1	0.228	0.080
Hindon at RKE-SRE Rly Bridge (SW_9)	7.7-8.7	0.346	0.096
Star Paper Mill effluent (SW_{20})	7.5-9.1	0.368	0.137
D/S of Star Paper Mill (SW_{21})	7.3-8.9	0.605	0.147

The values of extractable heavy metal contents present in nine bed sediment samples are given in table 6.3. It is observed that Pb^{2+}, Zn^{2+} and Mn^{2+} vary in the range of 21 to 42; 1.2 to 148.3 and 37.6 to 406.2 μg/g; respectively. Even in the sediments the maximum amount of Zn^{2+} and Mn^{2+} are found in the samples collected from paper mill drains (S-6). The maximum value of Pb^{2+} is observed in the sample collected from Padli <u>nala</u> (S-2).

It is further observed that total concentration of Pb^{2+} and Zn^{2+} in water samples decreases just after the confluence of three <u>nalas</u> viz. Padli <u>nala</u> (SW_2), Nagdeo <u>nala</u> (SW_3) and Indana <u>nala</u> (SW_4). The discharge from Padli <u>nala</u> is quite rich in metal concentration. The decrease in the concentration of metals after the confluence may be attributed to the dilution of water in Nagdeo <u>nala</u> but the concentration of lead again increases along the course of Nagdeo nala and also after the addition of both the water from river Hindon as well as the paper mill effluent. In general, a comparison of the heavy metal contents (Lead and Zinc) of water and sediment collected from different locations indicates a higher concentration of Pb^{2+}, Zn^{2+} and also of Mn^{2+} at or near the confluence of Hindon river and paper mill drain.

Table 6.3 : Extractable metal (Pb^{2+}, Zn^{2+} and $Mn)^{2+}$ contents in Sediment Samples. (Period : May, 1985 to November, 1987).

Sampling Location	Pb^{2+}	Zn^{2+} (Unit: μg/g of sediment)	Mn^{2+}
Padli nala(S-1)	42.0	1.2	68.7
Nagdeo nala(S-2)	25.6	2.9	57.8
Indana nala (S-3)	21.0	2.6	37.6
Mixture (S-4)	29.2	2.0	54.7
Background(S-5)	2.87	0.57	6.51
Paper mill drain (S-6)	36.3	148.3	406.2
Nagdeo nala + Rly bridge(S-7)	26.0	100.2	132.5
D/S of Paper Mill (S-8)	36.9	140.0	301.2
Background (S-9)	3.79	12.24	28.6

The pH of the river water at different locations is found to be in the alkaline range (Table 6.2). The minimum and maximum values observed are 6.5 and 9.1 respectively. The prevailing conditions of pH of river water do not favour a higher concentration of dissolved metal as the divalent metals like Pb^{2+} and Zn^{2+} are expected to get hydrolysed under these conditions.

The pH range would however favour higher concentration of heavy metal ions in the sediments.

The adsorption data of Pb^{2+}, Zn^{2+} and Mn^{2+} ions for nine sediment samples are presented in tables 6.4 to 6.6 and the same has also been shown in Fig.6.10 to 6.18.The uptake has been observed at the original pH(4.0) of various metal salts and also at pH 3.0 and 6.0. The studies indicate that there is a general increase in the sorption rate with increasing concentration of the metallic solution applied on the sediment without adjusting the pH value. At the highest concentration of the metal solution 10 mg/l (10000 µg/l) in contact with sediment samples, maximum uptake of Pb^{2+}ion observed at pH 3.0 and 6.0 is 1100 µg/g(Table 6.4) and the same at pH 4.0 is 1170 µg/g. From the table 6.4 and 6.6 it is observed that the maximum uptake of Zn^{2+} is 1170 µg/g at pH 3.0 and 6.0 while at pH 4.0 the amount is 1200 µg/g. For Mn^{2+} the maximum uptake of the ion is 960 µg/g and 980 µg/g at pH 3.0 and 6.0 while at pH 4.0 it is 1150 µg/g.

Table 6.4: Adsorption of Pb^{2+} on Sediment

size of Sediment-<63 micron
Amount of Sediment added - 0.2 gms
Total Volume - 25ml, Temperature- 23^{0}C, pH-4.0, original

Initial Concn. µg/l	Amount Adsorbed(µg/g)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	141	193	210	126	170	220	170	213	145
4000	413	475	468	380	475	475	373	443	393
6000	587	699	729	654	738	688	565	700	606
8000	974	838	937	870	878	800	750	938	840
10000	1170	1150	1170	950	1150	1000	900	1100	950

Size of Sediment - < 63 micron
Amount of Sediment added - 0.2 gms
Total volume - 25 ml
Temperature - 23^{o}C, pH 3.0

Initial concn. $\mu g/l$	Amount Adsorbed($\mu g/g$)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	123	173	228	243	236	175	244	228	150
4000	480	431	488	331	450	410	481	484	466
6000	713	678	649	718	668	650	731	714	685
8000	943	934	888	985	766	925	895	898	896
10000	1100	1075	1050	1100	1050	1070	1100	1100	1040

Size of Sediment - < 63 micron
Amount of Sediment added - 0.2 gms
Total Volume - 25 ml.
Temperature 23^{o}C pH 6.0

Initial Concn. ($\mu g/l$)	Amount Adsorbed ($\mu g/g$)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	161	170	168	151	198	231	196	238	234
4000	419	441	390	300	466	325	498	395	484
6000	680	630	590	456	726	673	671	703	734
8000	826	831	800	700	894	850	826	913	976
10000	980	1100	910	850	1100	1030	1020	1100	1050

Table 6.5: Adsorption of Zn^{2+} on Sediment
Size of Sediment - <63 micron
Amount of Sediment added - 0.2 gms
Total Volume - 25 ml, Temp. 25^{o}C, pH-4.0, original

Initial Concn. ($\mu g/l$)	Amount Adsorbed ($\mu g/g$)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	248	249	249	246	241	249	249	249	249
4000	495	494	496	496	499	499	496	498	499
6000	713	646	719	738	748	738	744	748	748
8000	854	738	885	995	984	985	944	995	998
10000	1060	1020	1100	1150	1200	1180	1150	1200	1150

Size of Sediment - < 63 micron
Amount of Sediment added - 0.2 gms
Total Volume - 25 ml. Temp.25°C, pH - 3.0

Initial Concn. (μg/l)	Amount Adsorbed (μg/g)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	246	243	243	245	245	248	246	249	249
4000	496	493	496	495	495	498	495	499	495
6000	736	711	700	734	739	748	748	746	749
8000	954	840	874	949	984	994	993	991	995
10000	1100	1050	980	1060	1110	1140	1130	1170	1160

Size of Sediment - <63 micron
Amount of Sediment added - 0.2 gms
Total Volume - 25 ml
Temp - 25°C, pH - 6.0

Initial Concn. (μg/l)	Amount Adsorbed (μg/g)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	246	243	243	246	246	248	248	249	249
4000	495	494	496	495	494	499	496	499	496
6000	736	593	700	735	739	746	748	746	749
8000	956	836	874	949	985	993	993	993	995
10000	1080	980	1100	1050	1120	1170	1170	1150	1160

Table 6.6: Adsorption of Mn^{2+} on Sediment

Size of Sediment - < 63 micron
Amount of Sediment added - 0.2 gms
Total Volume - 25 ml, Temp 24°C, pH-4.0,Original

Initial Concen. (μg/l)	Amount Adsorbed (μg/g)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	238	238	243	239	249	246	245	238	244
4000	328	460	471	478	490	485	495	471	498
6000	714	688	723	725	733	720	733	700	738
8000	954	903	940	935	962	944	973	934	979
10000	1140	1100	1100	1150	1100	1070	1100	1070	1100

Size of Sediment - < 63 micron
Amount of Sediment added - 0.2 gms
Total Volume - 25 ml, pH-3.0, Temp. - 24°C

Initial Concen. (μg/l)	Amount Adsorbed (μg/g)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	168	125	168	159	238	131	191	130	180
4000	345	293	359	438	414	406	429	368	454
6000	532	383	706	534	540	581	639	630	664
8000	738	478	845	678	719	798	795	712	855
10000	860	580	950	800	860	900	960	815	1020

Size of Sediment - <63 micron
Amount of Sediment added - 0.2 gms
Total volume - 25 ml, pH-6.0, Temp-24°C

Initial Concn. (μg/l)	Amount Adsorbed (μg/g)								
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
2000	163	119	156	225	231	125	181	125	175
4000	325	275	351	406	404	350	425	356	441
6000	579	388	688	521	594	570	625	613	641
8000	716	488	848	800	775	613	763	744	838
10000	840	600	900	950	950	800	950	830	980

Considering the extent of adsorption at different pH values for the metals Pb^{2+}, Zn^{2+} and Mn^{2+} the optimum pH at which maximum uptake of the Pb^{2+}, Zn^{2+} and Mn^{2+} takes place is 4.0. Samples of sediment at Paper mill drain which are already rich in metal ions due to the discharge from the mill, have been taken in varying dosages to have an idea of its bearing or the loading capacity for the metal ions under consideration. Experiments were carried out at

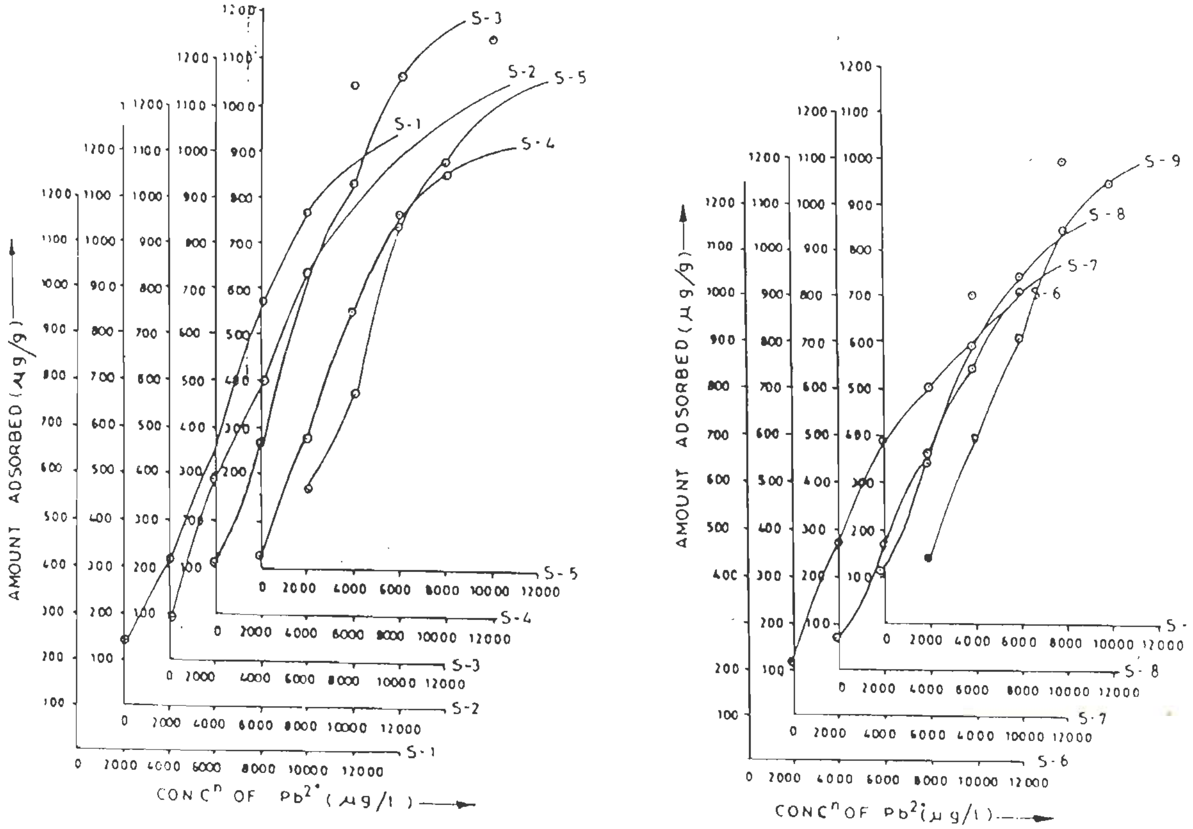


FIG.6.10 ADSORPTION ISOTHERM OF Pb^{2+} ON SEDIMENTS

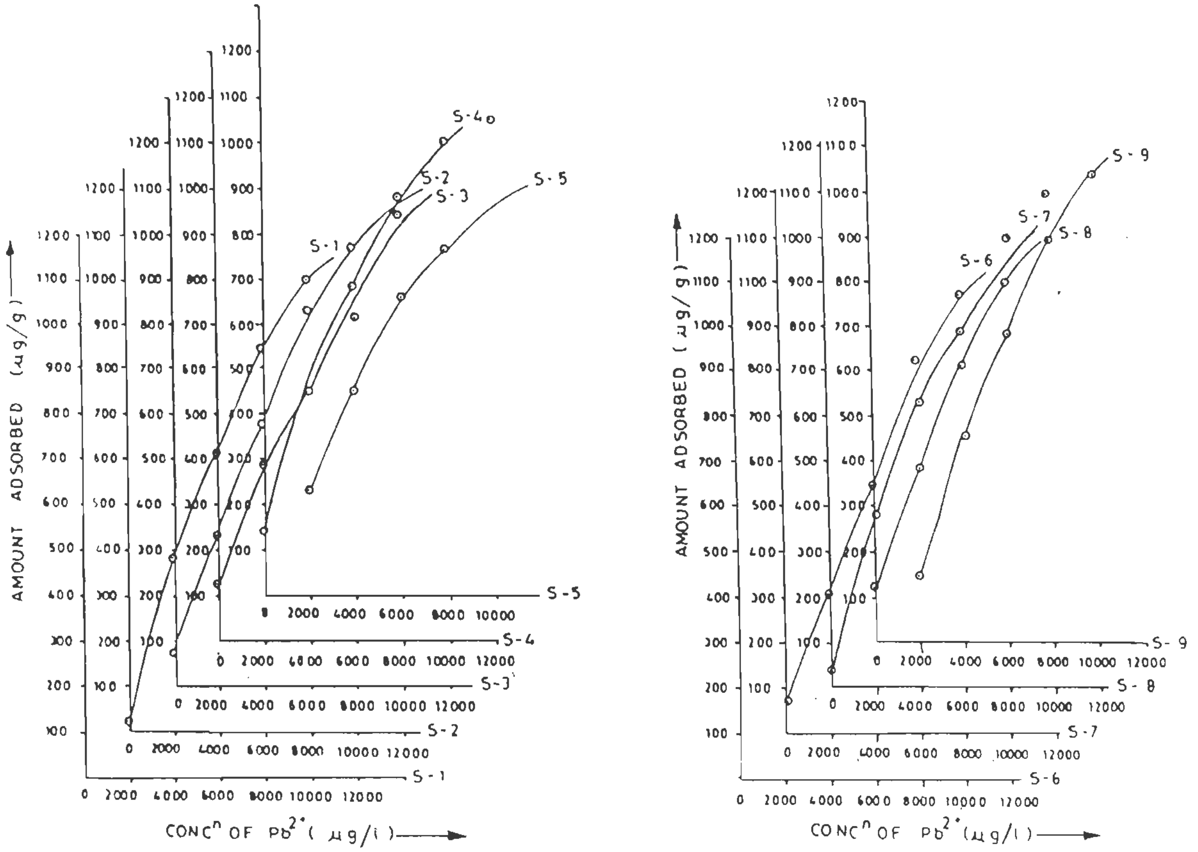


FIG. 6.11 ADSORPTION ISOTHERM OF Pb^{2+} ON SEDIMENTS AT pH 3.0

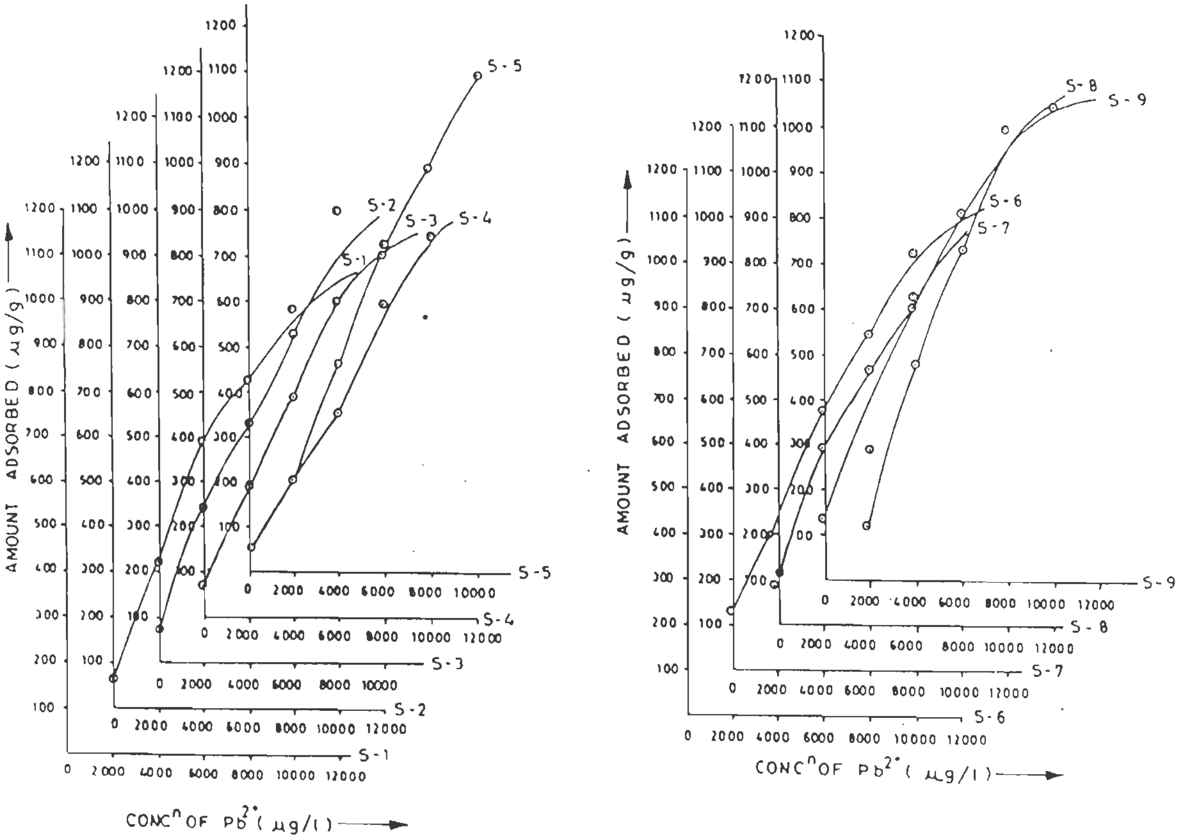


FIG 6·12 ADSORPTION ISOTHERM OF Pb^{2+} ON SEDIMENTS AT pH 6·0

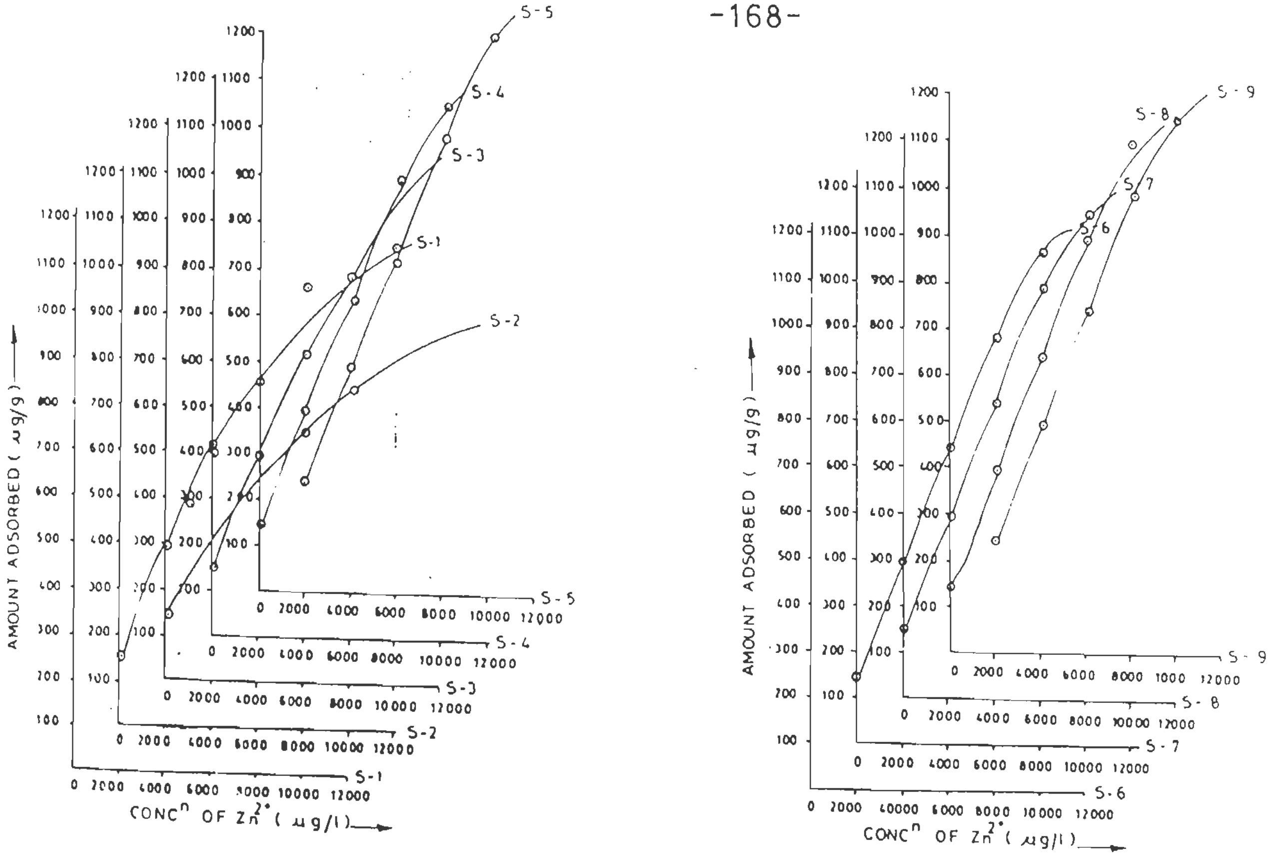


FIG 6·13 ADSORPTION ISOTHERM OF Zn^{2+} ON SEDIMENTS

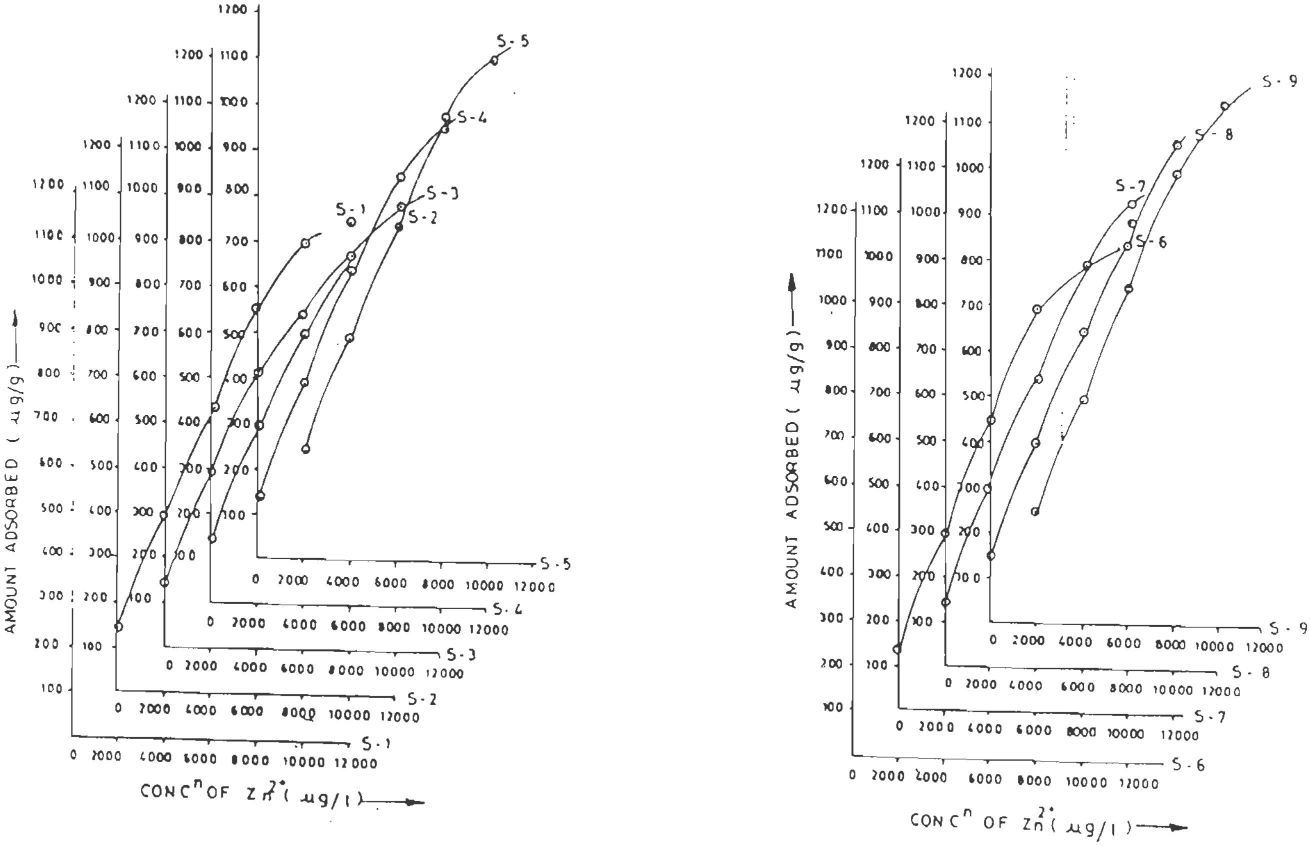


FIG.6·14 ADSORPTION ISOTHERM OF Zn^{2+} ON SEDIMENT AT pH 3·0

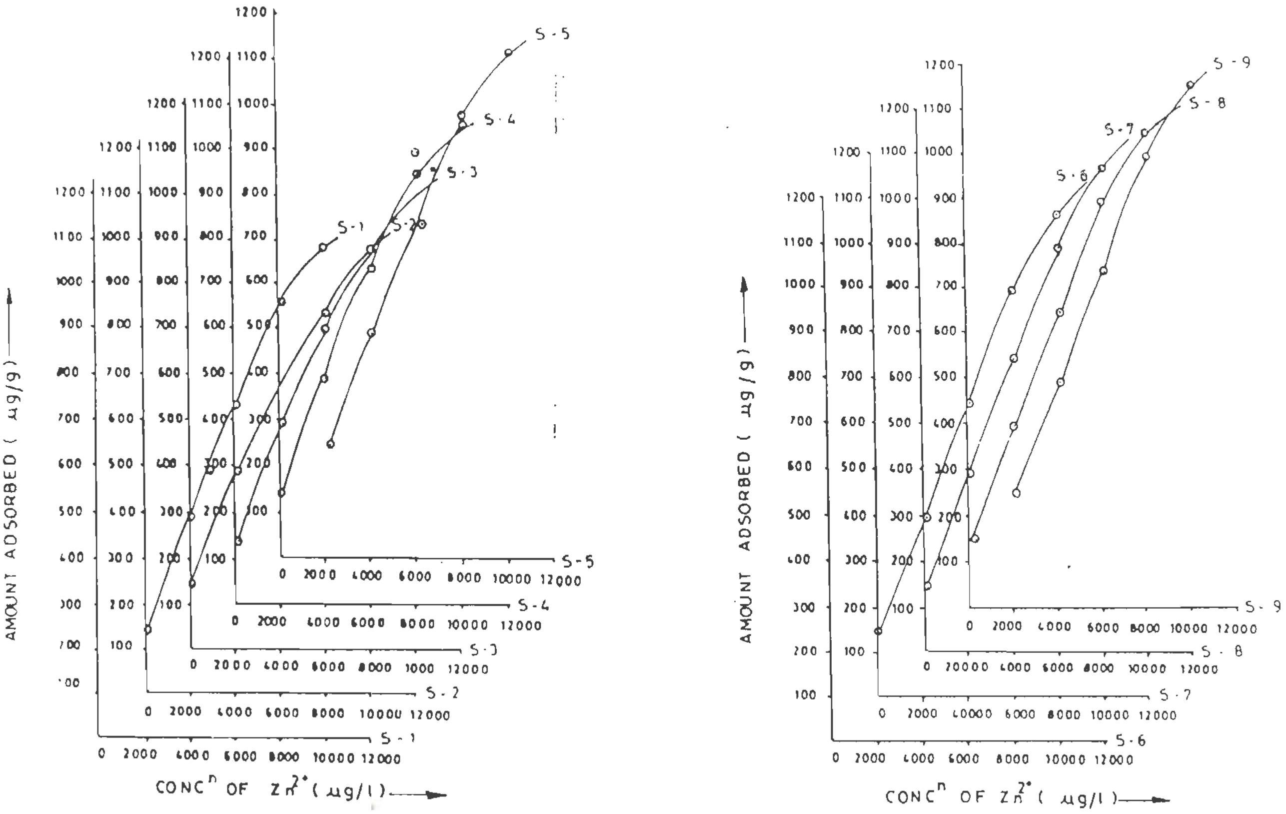


FIG.6.15ADSORPTION ISOTHERM OF Zn^{2+} ON SEDIMENTS AT pH 6.0

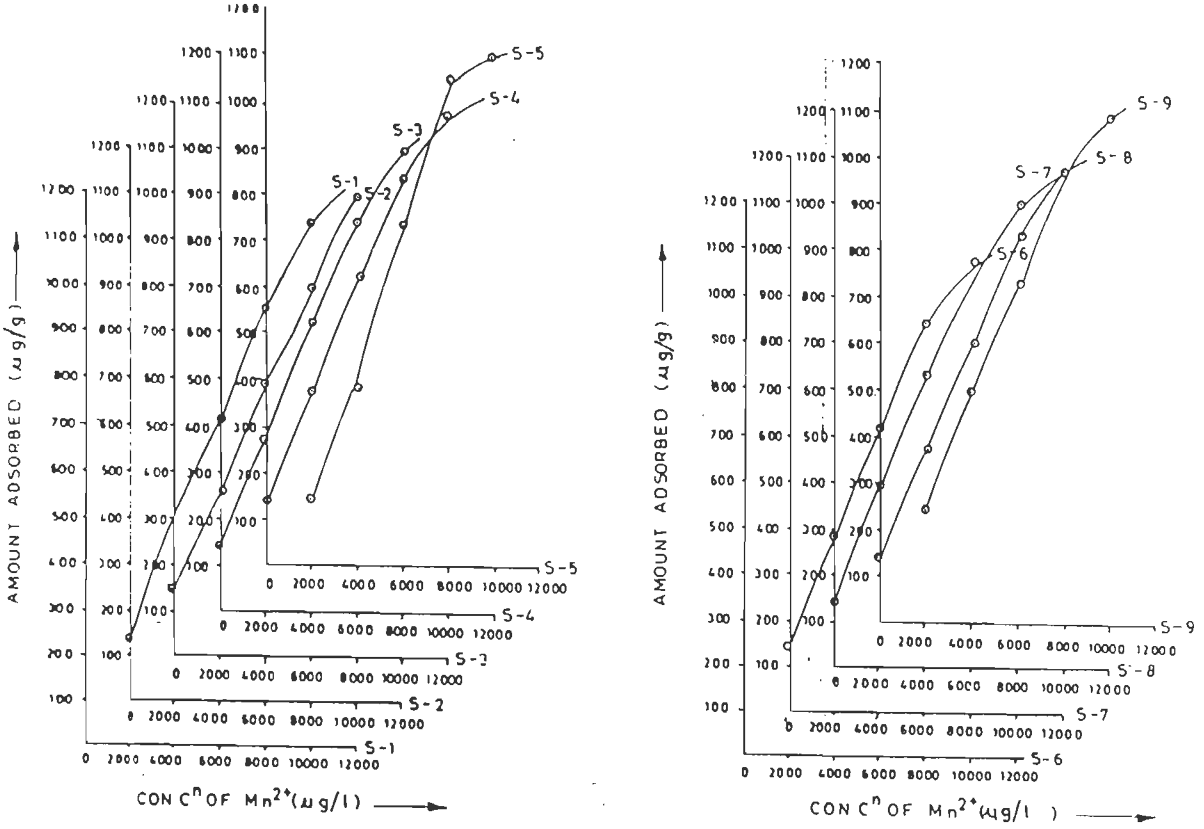


FIG. 6·16 ADSORPTION ISOTHERM OF Mn^{2+} ON SEDIMENTS

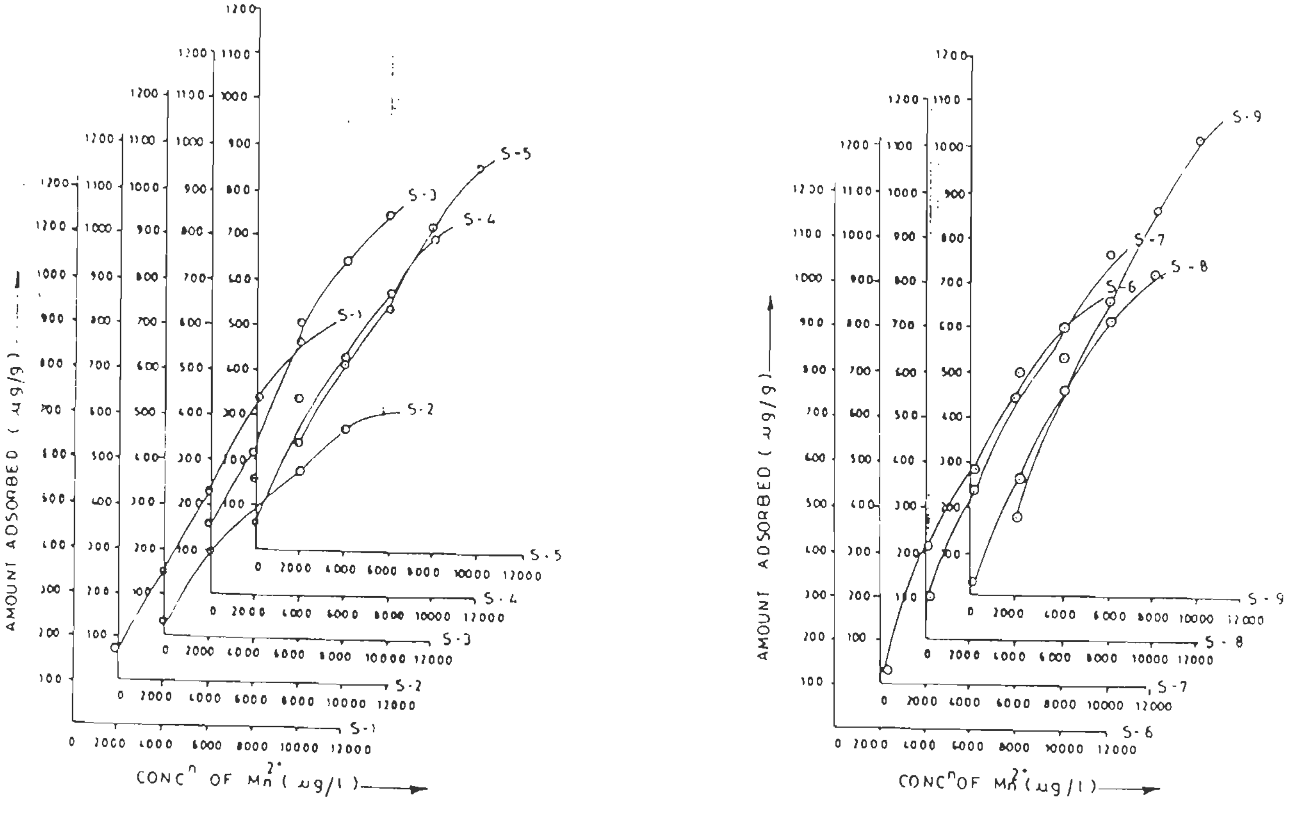


FIG.6·17 ADSORPTION ISOTHERM OF Mn^{2+} ON SEDIMENTS AT pH 3·0

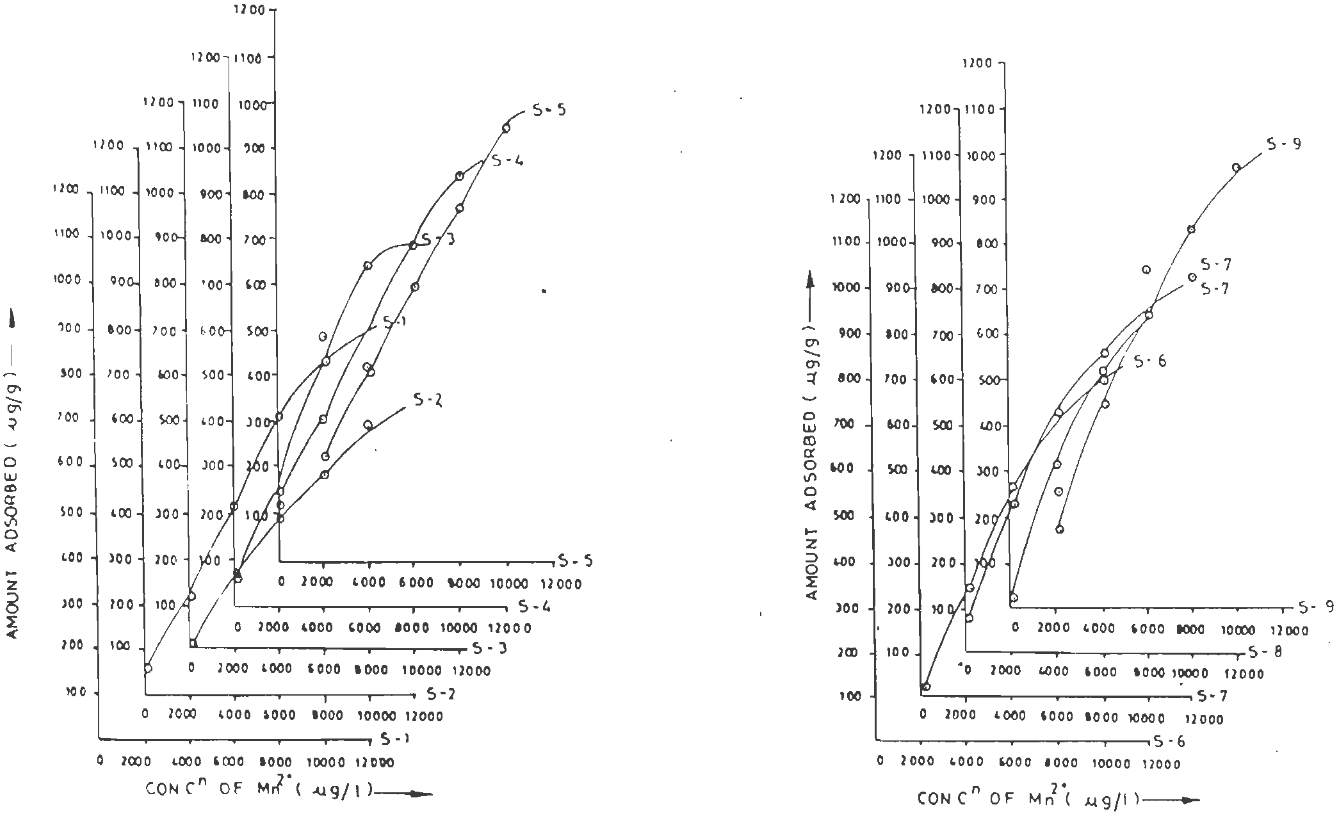


FIG6·18ADSORPTION ISOTHERM OF Mn^{2+} ON SEDIMENTS AT pH 6·0 pH 3.0 with different dose of sediments viz, 0.2, 0.4, 0.6 and 0.8g for a solution volume of 25ml and metal concentration 10 mg/l (1000μg/l) in case of Pb^{2+}, Zn^{2+} and Mn^{2+} at 25^0C. The results reflect a maximum removal at sediment dose of 0.2g for Pb^{2+}, Zn^{2+} and Mn^{2+} and the same are given in table 6.7. It is observed that at higher sediment dose some leaching or negative sorption may occur.

Table 6.7: Amount Adsorbed **(μg/g)** by Sediment Dose

Ions	0.2 gms	0.4 gms	0.6 gms	0.8gms	Optimum dose
Pb^{2+}	945	778	718	856	0.2 gms
Zn^{2+}	1087	973	1000	981	0.2 gms
Mn^{2+}	1015	956	851	816	0.2 gms

6.9 ADSORPTION ISOTHERM

The adsorption data of the three metal ions by sediment samples has been analysed with the help of Langmuir and Freundlich models to evaluate the mechanisitic parameters associated with the adsorption process.

6.9.1 Langmuir Isotherm

Langmuir isotherm has been extensively used for this purpose by many authors specially for the sorption of heavy metals on clays, metal oxides and soil etc.

In these investigations the adsorption data of Pb^{2+}, Zn^{2+} and Mn^{2+} has been tried on the linear form of Langmuir equation.

$$C_e/q_e = C_e/Q^0 + \frac{1}{bQ^0} \qquad \ldots(6.1)$$

where q_e is the amount of solute adsorbed per unit weight of solidadsorbent and C_e is the concentration of solute remaining in solution at equilibrium. When C_e/q_e is plotted against C_e values, a straight line with slope $1/Q^o$ and intercept $1/b.Q^o$ is obtained.

The Langmuir parameters (i) maximum sorption capacity Q^o (monolayer capacity) and (ii) parameter related to energy of adsorption 'b' are calculated from the Fig. 6.19 to 6.24. These values (Table 6.8) are used for comparison and correlation of the sorptive properties of various sediments samples.

6.9.2 Freundlich Isotherm

The Freundlich isotherm in its logarithmic form

$$\log q_e = \log K_f + 1/n \log C \qquad \ldots(6.2)$$

is also extensively used for data description.

The intercept of the line, log K_f is roughly an indication of sorption capacity and the slope 1/n of adsorption intensity (Webber, 1972). The adsorption data of Pb^{2+}, Zn^{2+} and Mn^{2+} on the sediments of river Hindon has been treated to see if Freudlich model is obeyed (Fig.6.25 to 6.30). The value for the sorption capacity K_f and the adsorption intensity 1/n are recorded in Table 6.9.

Table 6.8: Langmuir Parameters for Adsorption of Mn^{2+}, Zn^{2+} and Pb^{2+} on Sediment (<63 micron)

Sample Location	Adsorbate	$Q^{o}(mgg^{-1})$	Energy parameter b (lmg^{-1})
S-1	Mn^{2+}	-	-
	Zn^{2+}	-	-
	Pb^{2+}	-	-
S-2	Mn^{2+}	2.00	1.10
	Zn^{2+}	0.800	41.66
	Pb^{2+}	10.00	0.50
S-3	Mn^{2+}	-	-
	Zn^{2+}	-	-
	Pb^{2+}	-	-
S-4	Mn^{2+}	2.00	1.75
	Zn^{2+}	1.25	83.33
	Pb^{2+}	-	-
S-5	Mn^{2+}	1.35	7.40
	Zn^{2+}	1.19	2.38×10^{-3}
	Pb^{2+}	1.33	7.70
S-6	Mn^{2+}	1.00	8.33
	Zn^{2+}	1.42	17.85
	Pb^{2+}	0.833	6.00
S-7	Mn^{2+}	1.30	15.50
	Zn^{2+}	-	-
	Pb^{2+}	-	-
S-8	Mn^{2+}	2.00	1.42
	Zn^{2+}	-	-
	Pb^{2+}	-	-
S-9	Mn^{2+}	0.909	0.227
	Zn^{2+}	-	-
	Pb^{2+}	-	-

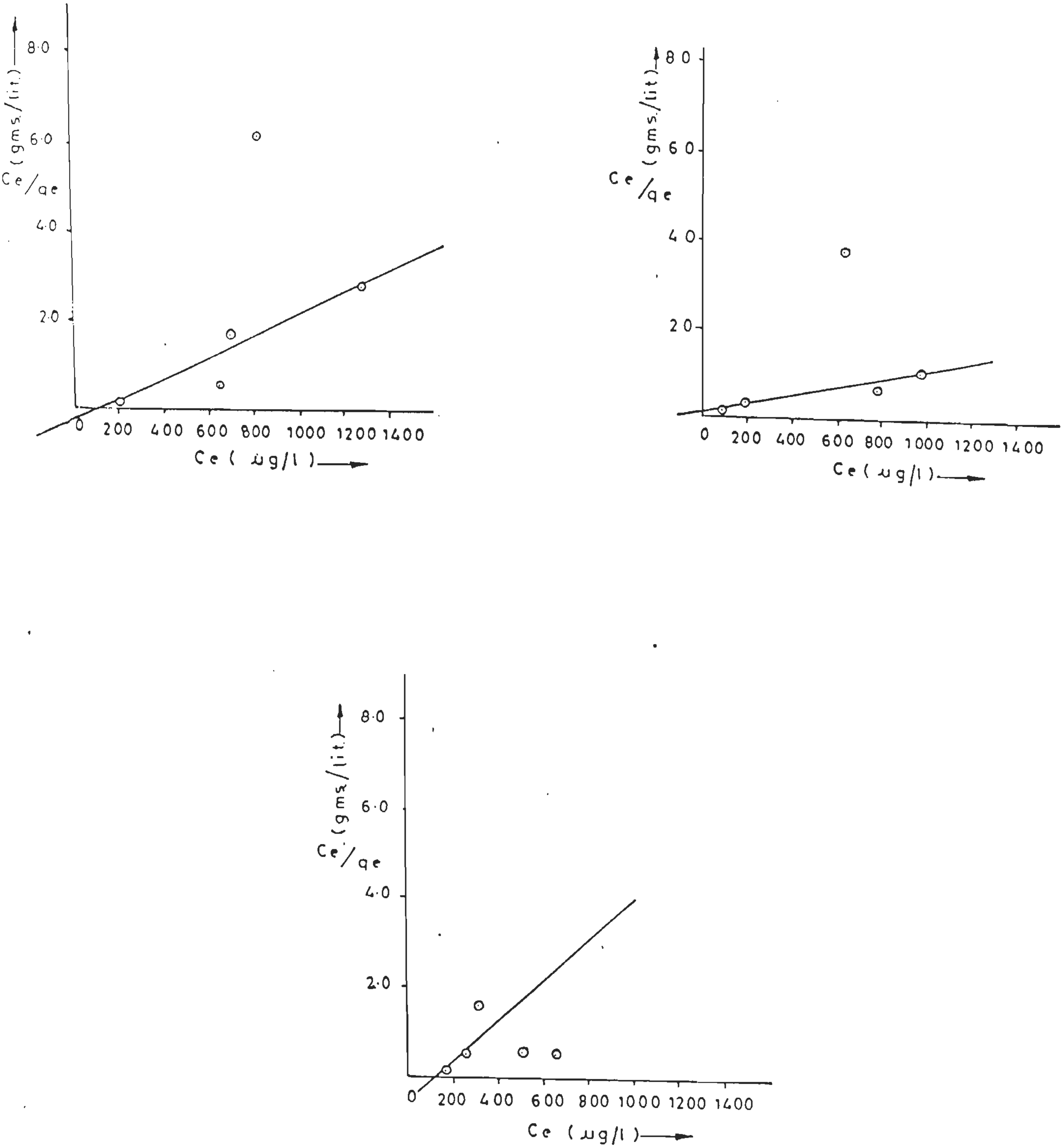


FIG.6·19 LANGMUIR ISOTHERM FOR ADSORPTION OF Pb^{2+} BY SEDIMENT(< 63 MICRON FRACTION)

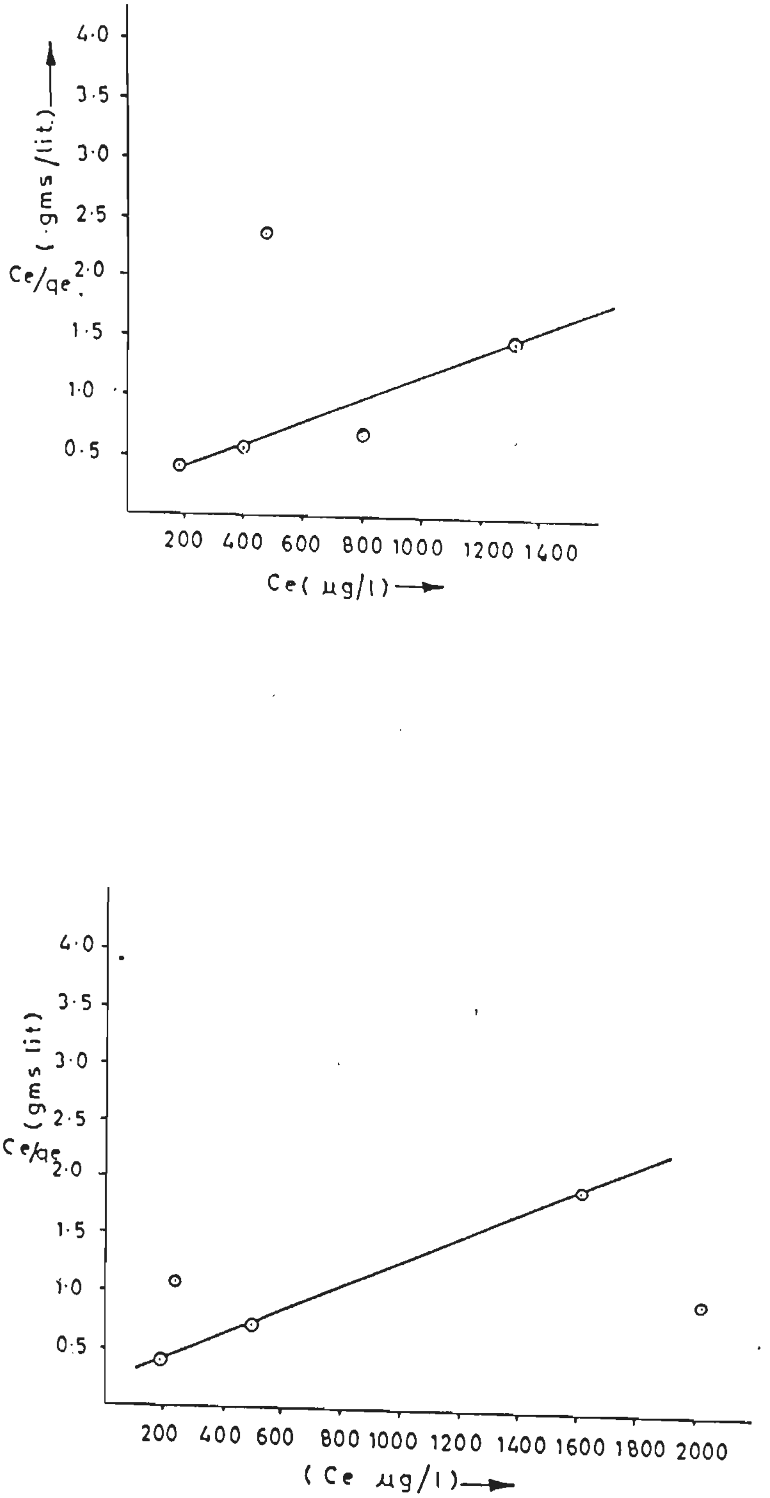


FIG. 6·20 LANGMUIR ISOTHERM FOR ADSORPTION OF Pb^{2+} BY SEDIMENT(< 63 MICRON FRACTION)

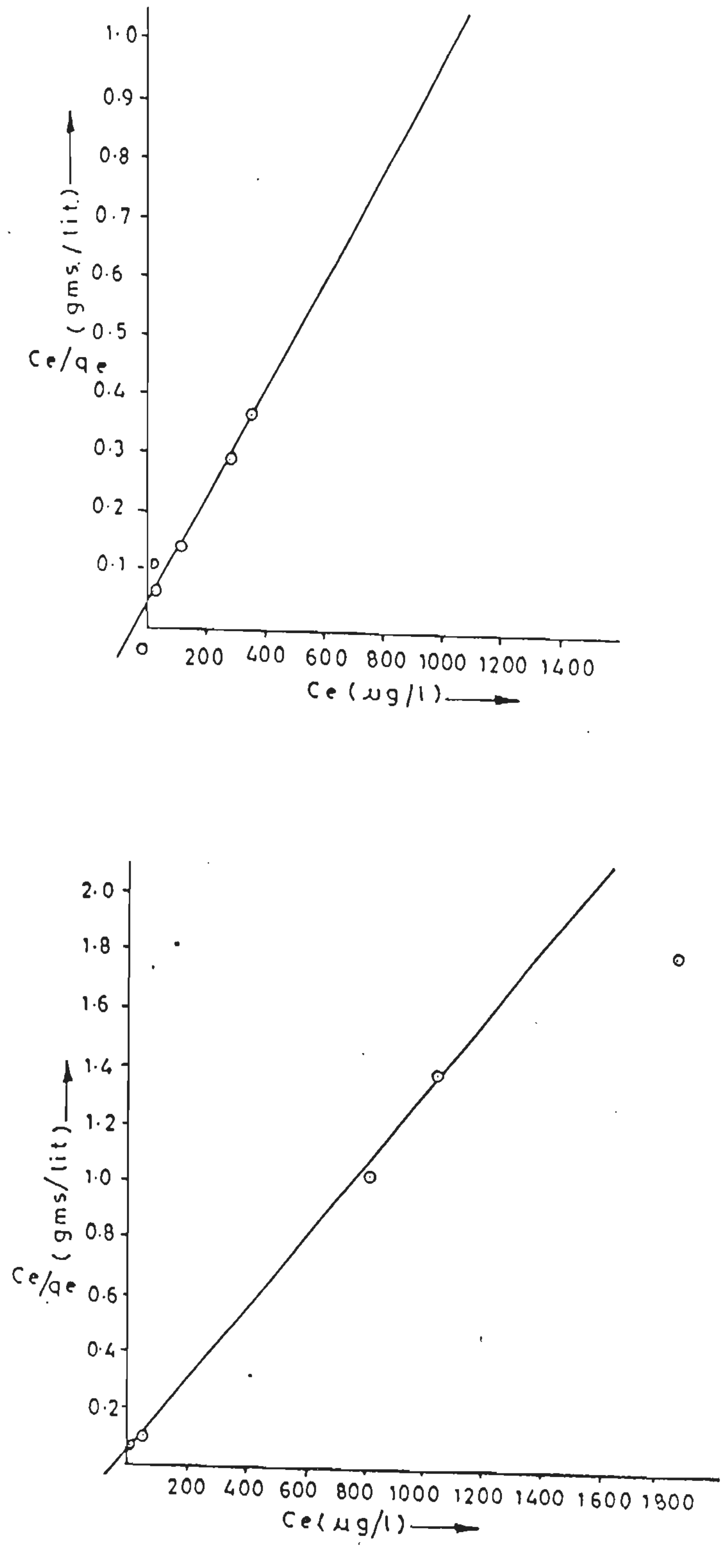
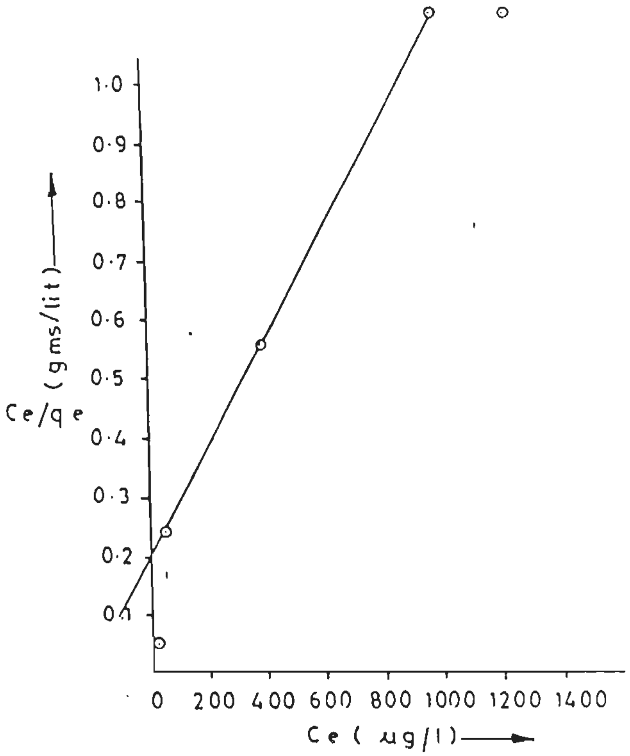


FIG.6.21 LANGMUIR ISOTHERM FOR ADSORPTION OF Zn^{2+} BY SEDIMENT (< 63 MICRON FRACTION)



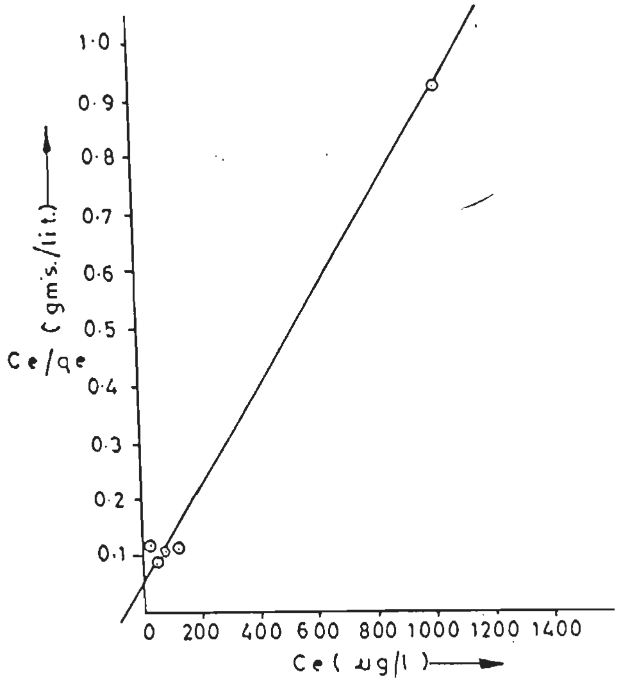


FIG. 6·22 LANGMUIR ISOTHERM FOR ADSORPTION OF Zn^{2+} BY SEDIMENT(< 63 MICRON FRACTION)

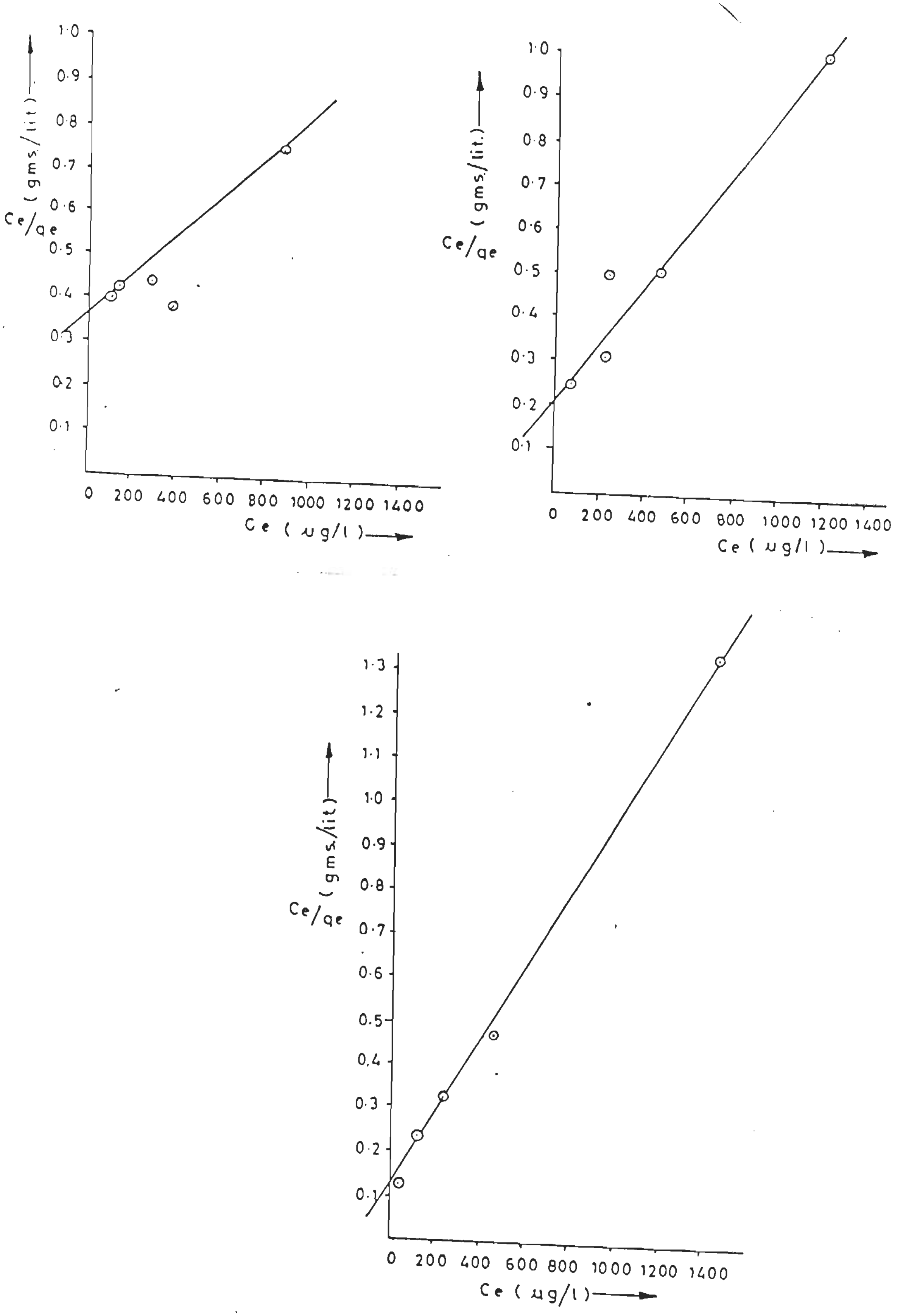


FIG. 6·23 LANGMUIR ISOTHERM FOR ADSORPTION OF Mn^{2+} BY SEDIMENT(< 63 MICRON)

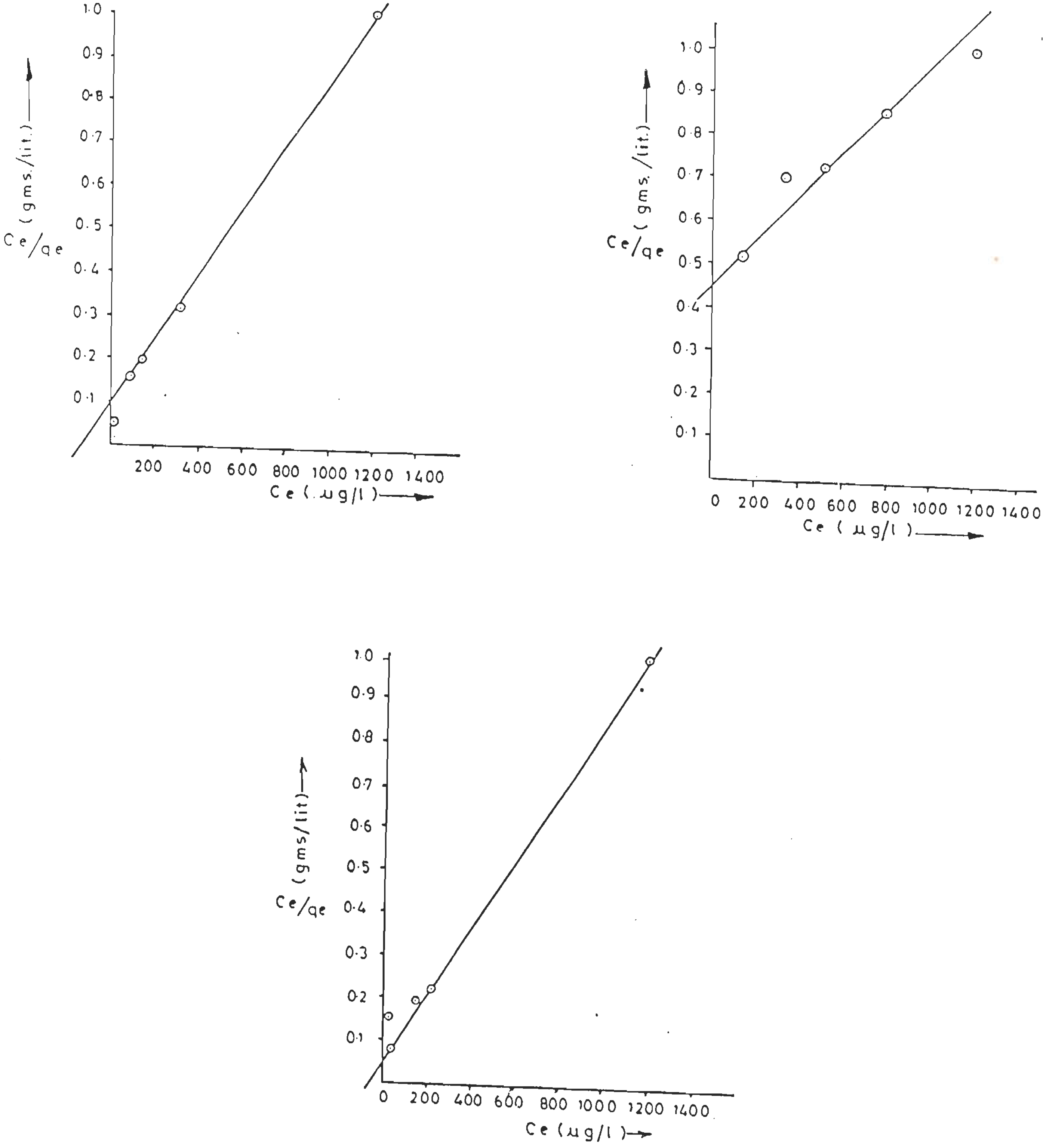


FIG.6.24 LANGMUIR ISOTHERM FOR ADSORPTION OF Mn^{2+} BY SEDIMENT(< 63 MICRON FRACTION)

Table 6.9: Freundlich Constants of Mn^{2+}, Zn^{2+} and Pb^{2+} on Sediment (<63 micron)

Sample location	Absorbate	Sorption Capacity K_f ($\mu g/g$)	Adsorption Intensity 1/n
S-1	Mn^{2+}	-	-
	Zn^{2+}	-	-
	Pb^{2+}	-	-
S-2	Mn^{2+}	1.25	0.680
	Zn^{2+}	0.476	0.370
	Pb^{2+}	0.769	0.550
S-3	Mn^{2+}	0.704	0.110
	Zn^{2+}	0.606	0.220
	Pb^{2+}	6.66	1.04
S-4	Mn^{2+}	1.42	0.840
	Zn^{2+}	0.909	0.860
	Pb^{2+}	0.769	0.480
S-5	Mn^{2+}	0.555	0.500
	Zn^{2+}	1.00	1.00
	Pb^{2+}	0.526	0.150
S-6	Mn^{2+}	0.420	0.420
	Zn^{2+}	0.416	0.300
	Pb^{2+}	0.588	0.400
S-7	Mn^{2+}	-	-
	Zn^{2+}	-	-
	Pb^{2+}	-	-
S-8	Mn^{2+}	1.66	0.880
	Zn^{2+}	0.454	0.420
	Pb^{2+}	-	-
S-9	Mn^{2+}	-	-
	Zn^{2+}	-	-
	Pb^{2+}	-	-

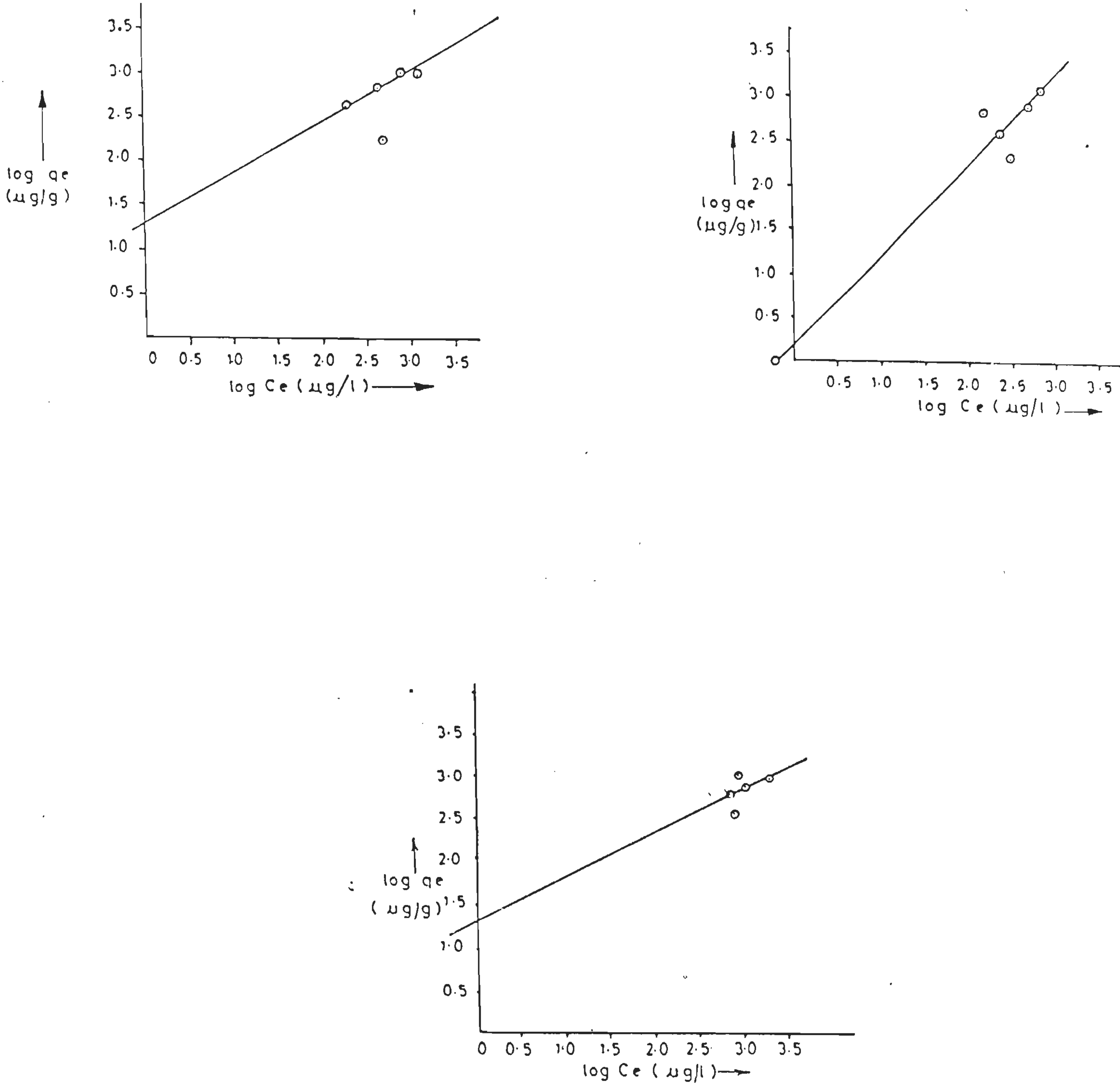


FIG.6.25 FREUNDLICH ISOTHERM FOR ADSORPTION OF Pb^{2+} BY SEDIMENT(< 63MICRON FRACTION)

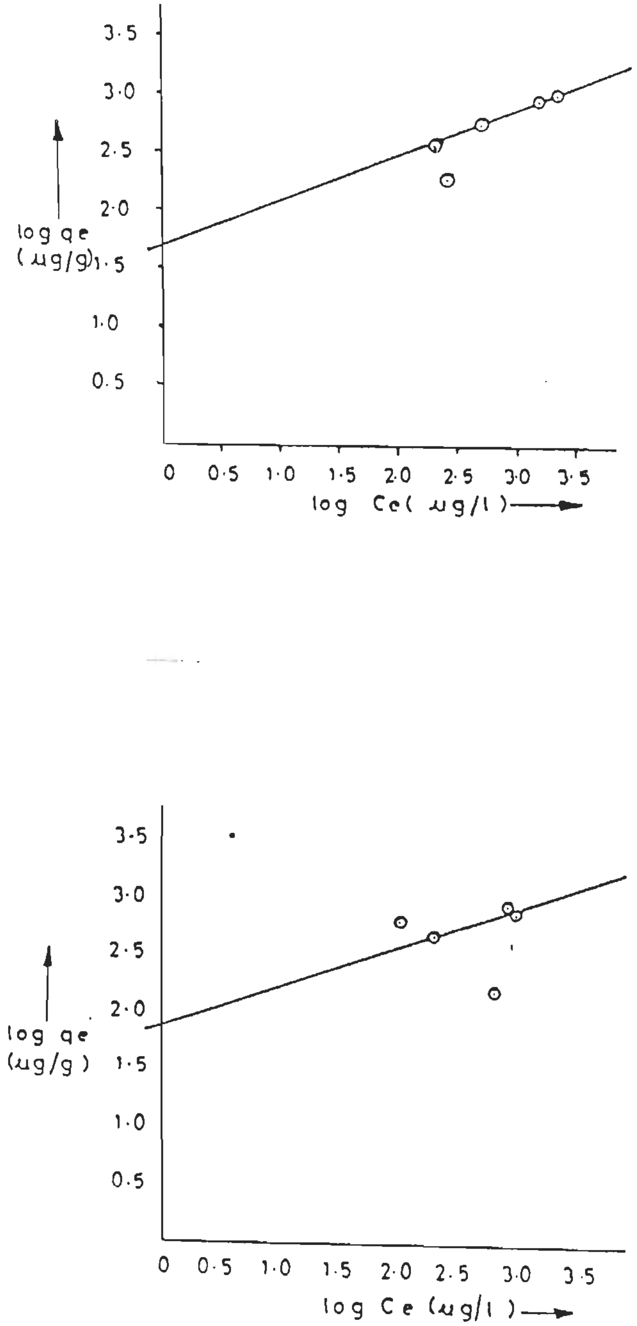


FIG.6·26 FREUNDLICH ISOTHERM FOR ADSORPTION OF Pb^{2+} BY SEDIMENT(< 63 MICRON FRACTION)

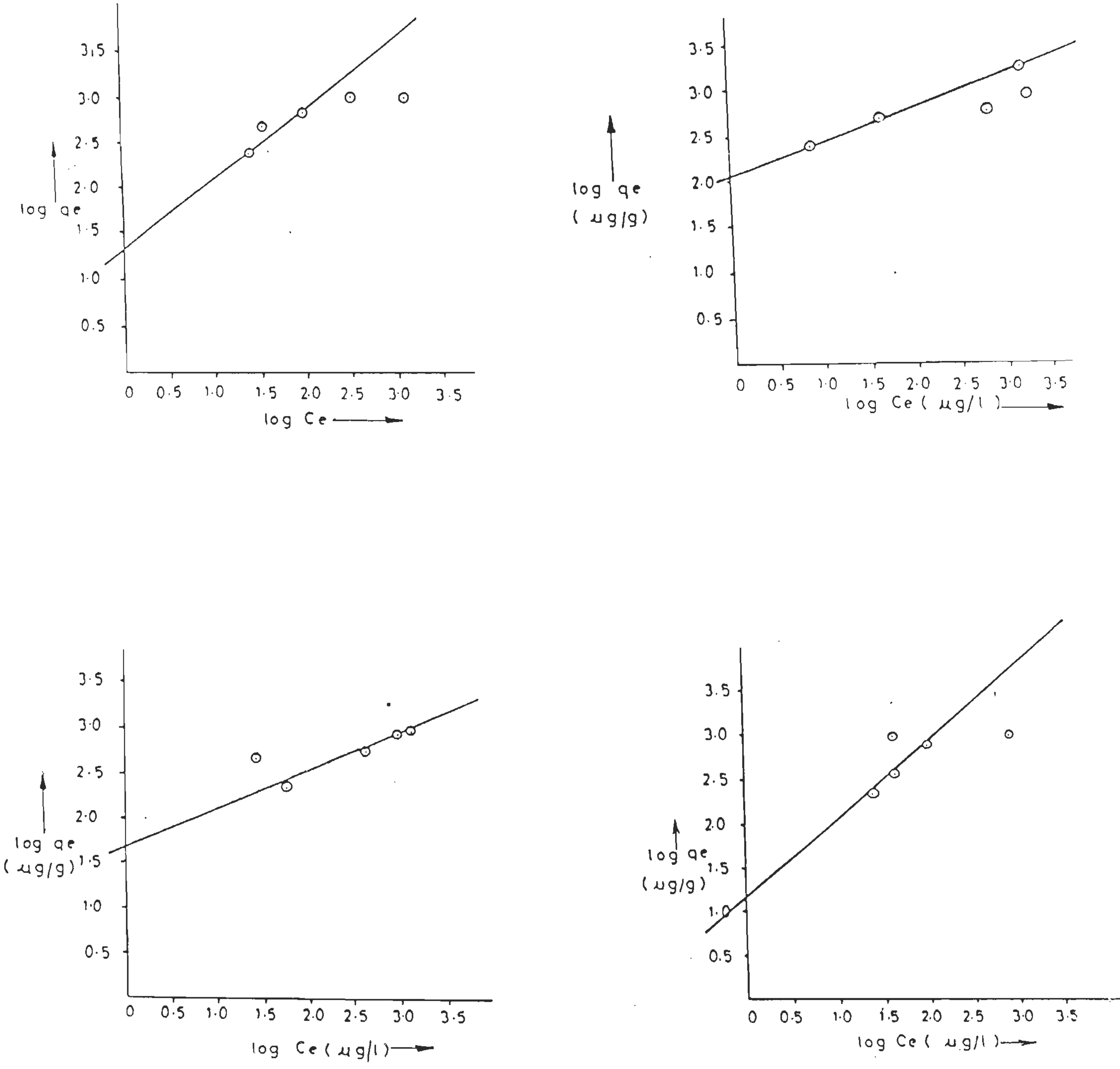


FIG.6.27 FREUNDLICH ISOTHERM FOR ADSORPTION OF Zn^{2+} BY SEDIMENT(< 63 MICRON FRACTION)

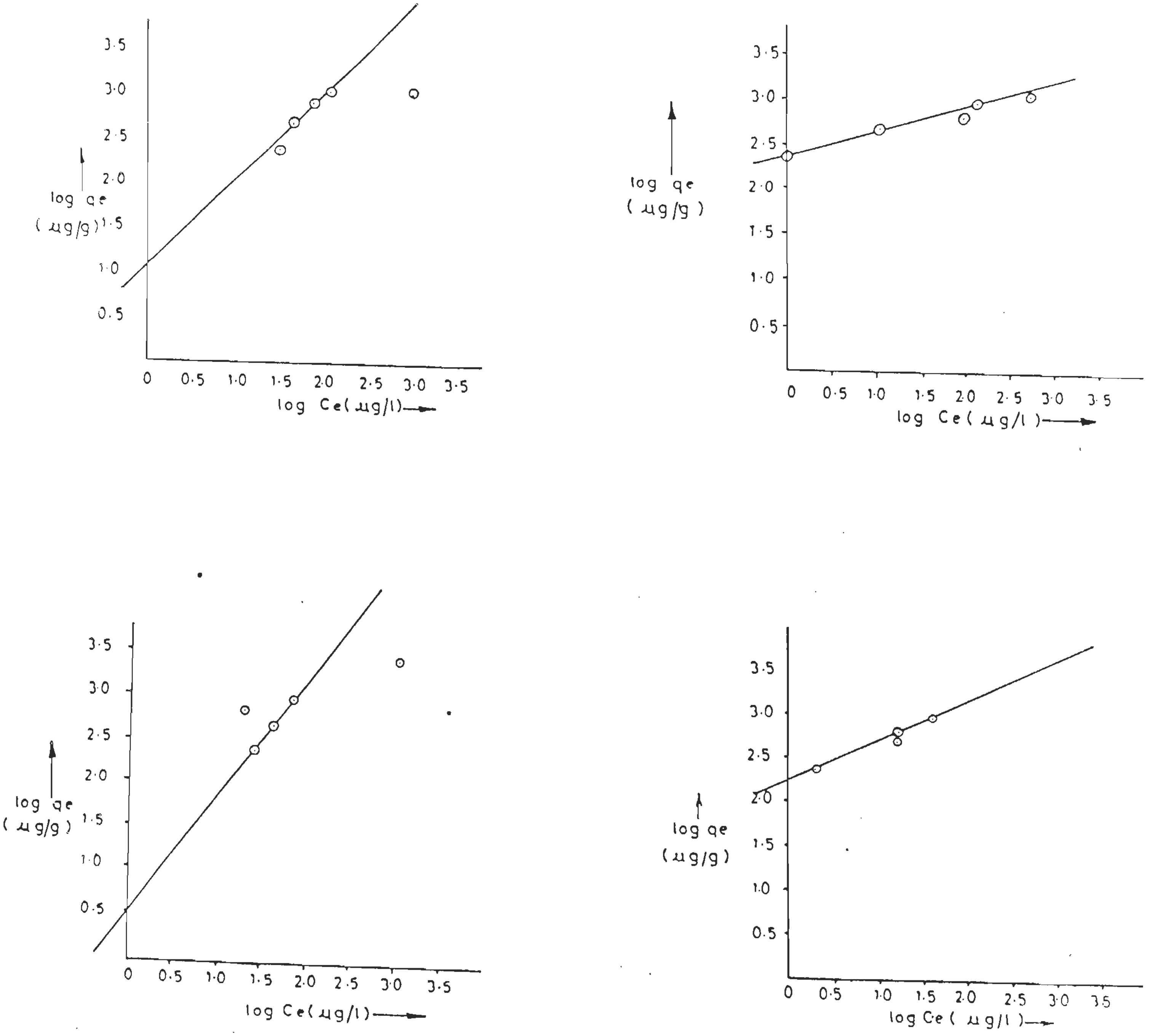


FIG. 6·28 FREUNDLICH ISOTHERM FOR ADSORPTION OF Zn^{2+} BY SEDIMENTS(< 63 MICRON FRACTION)

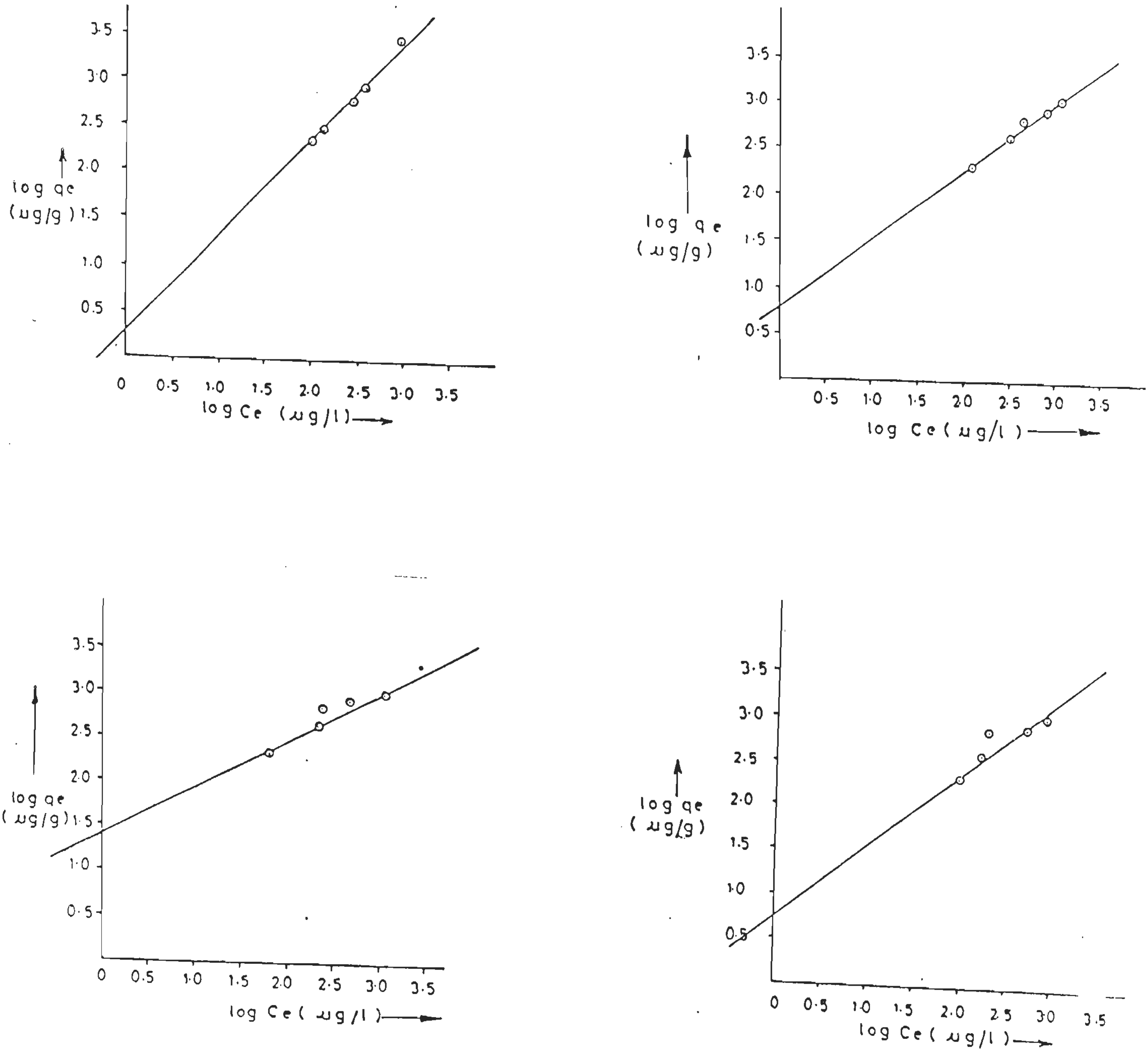


FIG. 6·29 FREUNDLICH ISOTHERM FOR ADSORPTION OF Mn^{2+} BY SEDIMENT (<63 MICRON FRACTION)

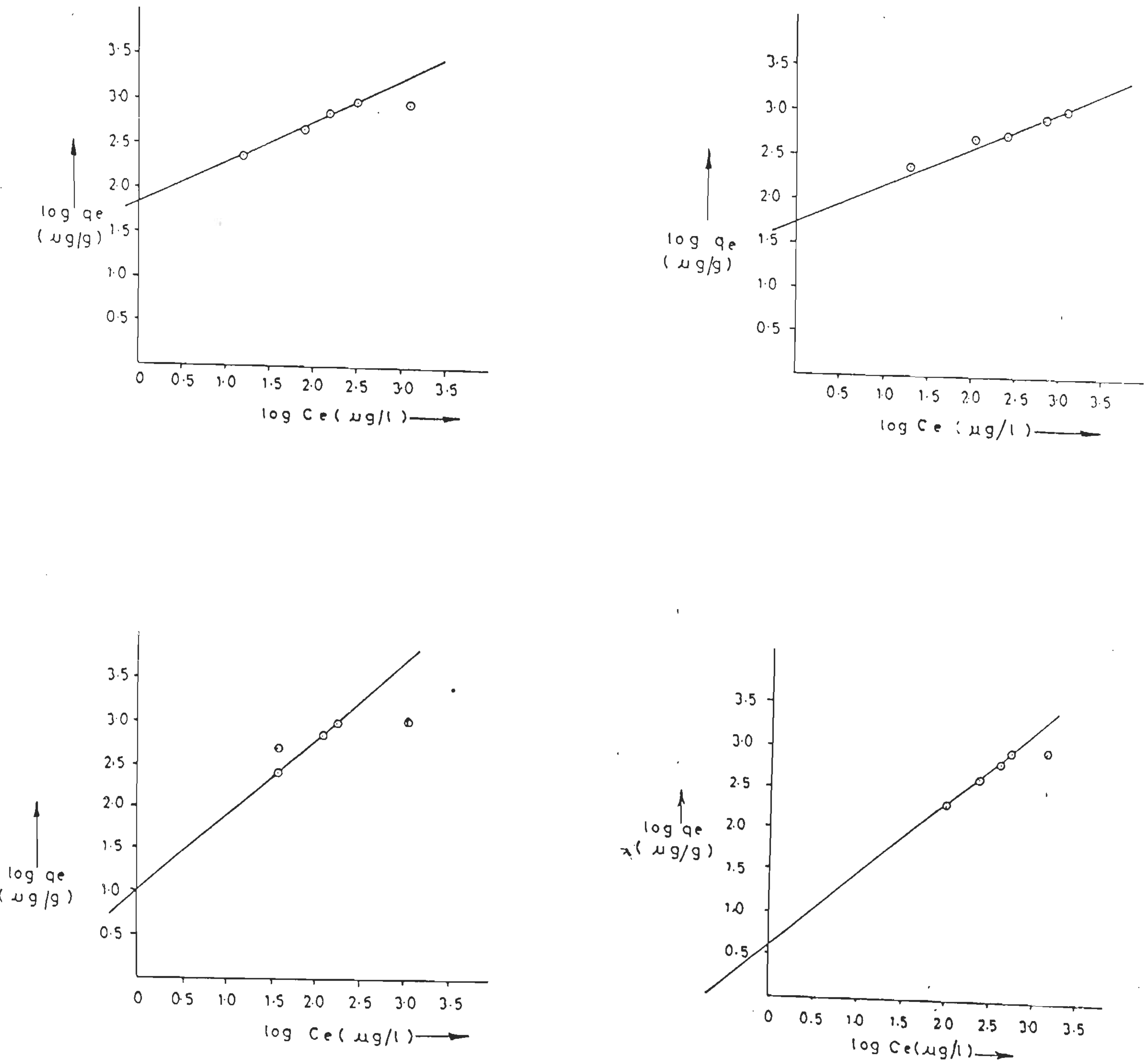


FIG. 6.30 FREUNDLICH ISOTHERM FOR ADSORPTION OF Mn^{2+} BY SEDIMENT (< 63 MICRON FRACTION)

Various parameters for the three metal ions, as obtained from Langmuir or Freundlich models do not show any particular gradation. Maximum adsorption values recorded practically are quite divergent from the one calculated on the basis of Langmuir or Freundlich model. The fact that the Langmuir or Freundlich model is not valid, for the entire concentration range of the adsorbates studied may be a reason for the above mentioned disparity. Besides this, the heterogeneous nature of the systems under investigation is also responsible for the same.

A survey of the analysis data of water (Table 6.2) and sediments (Table 6.3) for the two metal ions Pb^{2+} and Zn^{2+} exhibit a good correlation between the metal contents in water and corresponding sediment samples. The adsorption data shows the metal bearing capacity of the sediment samples and the same is found to be quite high (compared to the amount already present as determined by analysis). As such the metal content of the aqueous discharge is taken up by the sediment and presently the chances of the reverse process seem to be remote. In terms of pollution, the dangers from the discharged water are much less in comparison to the sediments which in course of time may start transporting the toxic metals to nearby fields etc.

CHAPTER-7

SUMMARY AND CONCLUSIONS

The surface and ground waterin Hindon basin of Saharanpur district are reported to have been affected adversely by the diverse types of industrial units which release various kinds of wastes into the drainage system of the area.

The Hindon river, the main stream of the basin, is fed by two main rivulets viz., Nagdeo nala and Dhamola nala.

Major industries in the area are Foremost Dairies and Star Paper Mill. Other small scale industries and hidden drains also exist in the area but locations of their outfalls are not clearly known or their discharge are insignificant.

The effluent from the Foremost dairies which is released into the nearby Nagdeo drain contains high BOD & COD as well as excessive concentration of total dissolved solids, Ca^{++}, Mg^{++}, Na^{++} and K^{+} alongwith the trace elements like Cd^{++}, Pb^{++} and total chromium. The effluents from the Star paper mill also have high concentration of organic matter, dissolved solids, Na^{++},. K^{+} and low values of dissolved oxygen. Thus, both the dairy and paper mill effluents are unsuitable for direct discharge on land or into the water bodies.

During the field monitoring programme, eight sets of surface water and six sets of ground water samples were collected from various sampling locations for different periods between May 1985 to November, 1987 and April, 1985 to August 1986. In addition, four sets of surface water samples were collected for studying DO-BOD relationship of surface water using DOSAG-I water quality routing model. Further, few sediment samples were collected from the river bed and nearby area for metal adsorption studies.

The Stiff polygon maps prepared for ground water and surface water for premonsoon and postmonsoon periods indicate that the total ionic concentration in the ground water is less in postmonsoon samples due to dilution by rain water. The Stiff polygon maps for surface water reveal that along the Hindon river there is no marked variation in total dissolved solids from the upstream to downstream parts. Along the Nagdeo nala, water is of poorer quality, as compared to the upper stretches of the Hindon river. This seems to be due to the discharge of effluents from the dairy and a card board factory. The concentration of different ions in waters of Pandhoi and Dhamola nalas increases in the downstream part due to the addition of municipal effluents. The quality of water in Dhamola nala is generally better than Hindon river.

The Piper Trilinear diagrams for ground water indicate the dominance of carbonate hardness. However, in the months of April, June and November 1985, the ground water showed presence of secondary salinity. The remaining ground water samples have no cation-anion pair exceeding fifty percent. Thus, a common chemical attribute of the ground water of the area is dominance of alkaline earths (Ca^{++} and Mg^{++}). In an area of relatively high rainfall where evapotranspiration is low, the chlorides and sulphate are leached off and therefore ground water will be of alkaline earth bicarbonate type.

In terms of hydrochemical facies, ground waters mainly belong to $Ca^{++} + Mg^{++} - Na^{+} + K^{+} - HCO_3^{-} - Cl^{-} + SO_4^{--}$ hydrochemical facies.

The trace metals viz.Cd^{++}, Pb^{++} and total chromium in surface water and ground water are in high concentrations at several places. The reasons for such high values of the trace metals are not well understood. However, one of the reasons for high concentration of these elements in surface water could be from the release of effluents from industrial units. The concentration of the trace metals in ground water is also high which makes it unsuitable for drinking purposes.

The profiles of Horton based water quality indices along the course of Nagdeo - Hindon river indicate that overall quality of water gets deteriorated just downstream of outfalls of Dairy/Paper effluents. The water quality improves further down stream as reflected in the decrease of W.Q.I. but again gets deteriorated by another waste outfall from Paper mill.

The computed water quality indices for surface waters of the study area for eight different periods between May, 1985 to November, 1987 vary between 117.00 to 307.57. The maximum value is near the waste outfall of paper mill effluent in the month of May, 1986. The lowest values of the water quality indices are found in the upstream areas of river Hindon/Nagdeo nala in the monsoon month of August, 1985.

It may also be noted that the quality of water in Dhamola nala is better than Nagdeo nala as indicated by the overall lower values of W.Q.I.

The Ambient water quality indices profile based on two distinct sub-indices developed for the Nagdeo - Hindon river, indicate that the nature of Ambient W.Q.I profiles is generally similar to that of Horton based index.

The relationship between BOD_5 and COD for various periods between May, 1985 to November, 1987 has also been studied. The values of BOD_5/COD are in the range of 0.02 to 0.70. The low values in the samples point probably to the presence of smaller fractions of biodegradable wastes. The maximum ratio is observed in the month of November, 1987 at location SW_{23} (downstream of the confluence of Nagdeo nala, SW_5). Most of the lower values are observed in Dhamola nala in November, 1987.

The dissolved oxygen sag curves were computed for the surface waters for four periods between September, 1986 to November, 1987 using DOSAG-I water quality routing model given by the Texas Water Development Board, USA. The computation of BOD and DO involved evaluation of reaeration constant (K_2') from a discretizd form of Streeter - Phelps (1925) equation and from the approach used by Bhargava (1983b, 1986). The values of BOD rate constant were calculated from the equation based on the work of Streeter - Phelps (1944) taking into consideration the early K_1' (for settleable BOD) and late BOD rate constant (at exponential rate).

The DO sag curves developed by ignoring settleable BOD show a distinctly divergent match between observed and computed DO values. It is also observed that the computed DO decreases just downstream of the point of major waste outfalls into the streams. This disagreement can be explained due to the extremely fast BOD removal caused due to sudden increase in settleable BOD load at these locations. However, by considering bioflocculation and settleable BOD, the computed and observed DO sag curves show a better match at many places though some deviation is still discernible at other points.

The DO sag curves for Dhamola nala show higher DO levels as compared to Hindon - Nagdeo stretches indicating there by better organic quality of the Dhamola waters. This fact is also corroborated by the continuing rise in dissolved oxygen downstream of the confluence of Dhamola nala with the Hindon river.

Studies on the occurrence and movement of Pb^{++}, Zn^{++} and Mn^{++} in the upper part of Hindon basin and their sorption on sediments lead to the following conclusion : The three heavy metals studied viz Lead, Zinc and Manganese are present in water as well as in sediment samples.

The incidence of heavy metals in water and sediment may be attributed to the increasing industrial activity.

The concentration of Zinc does not exceed the permissible WHO limits for drinking water but Lead is higher than the safe prescribed limit.

At the prevailing pH of the river water, which remains alkaline throughout the stretch, the uptake of Zn^{++}, Pb^{++} and Mn^{++}

ions by the sediment is favourable, the order of adsorption being Zn>Pb>Mn.

The metal bearing capacity of sediment samples is quite large: Whatever amount is being discharged in water is taken up by the sediments and in course of time this may not cause any considerable damage till, however, the sorption capacity of sediments gets exhausted.

The hydrochemical studies carried out in the south-eastern part of Saharanpur district of Upper Hindon basin Uttar Pradesh have brought out the levels of concentration of conservative (including selected trace metals) constituents in the surface water and ground water. Besides,the non-conservative (organic) constituents have also been estimated highlighting the levels of depletion of dissolved oxygen in the surface water along the different streams of the area. These studies show that the surface waters of the area are unsuitable for drinking and fish culture. Such studies can also be useful in other river systems.

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Table:4·10 Determination of Surface Water Quality Index (May, 1985)

Sample station	Q_i	Q_{TDS}	Q_{pH}	Q_{DO}	Q_{BOD}	$Q_{A.N.}$	Q_{Cl}	Q_{SO_4}	Q_{Cd}	Q_{Cr}	Q_{PO_4}	Q_{COD}	Q_{NO_3}	W.Q.I.
	Weighting Factor	3.0	4.0	5.0	5.0	3.0	2.0	2.0	5.0	4.0	3.0	5.0	3.0	
SW_2		536	6.5	6.20	203	4.5	48	12	ND	0.315	0.58	720	0.35	254.5
		100	100	347	400	400	148	103	100	327	187	400	231	
SW_3		312	7.3	32.2	12.5	0.8	18	24	ND	0.068	0.17	56	0.04	127.2
		100	100	124	129	211	110	118	100	115	126	172	115	
SW_4		358	7.1	17.3	51.3	1.2	60	7	ND	ND	0.24	180	0.09	184.1
		100	100	252	249	274	163	100	100	100	136	368	134	
SW_5		414	6.8	2.60	43.4	1.0	0.0	28	0.060	0.148	0.34	176	0.13	231.7
		100	100	400	225	242	100	123	350	184	151	362	149	
SW_6		346	7.4	2.60	31.3	0.7	82	14	0.050	0.076	1.20	125	0.07	214.2
		100	100	400	188	195	190	105	300	122	280	281	126	
SW_7		332	7.3	23.20	2.6	0.2	75	14	0.016	0.068	0.88	9.3	0.00	130.2
		100	100	201	100	116	181	105	130	115	232	100	100	
SW_8		492	6.9	4.10	19.4	0.8	100	23	0.070	0.126	1.18	97	0.11	207.4
		100	100	400	151	211	213	116	400	165	277	238	141	
SW_9		482	7.7	89.00	6.2	0.5	30	15	0.016	0.095	0.03	28.0	0.04	124.6
		100	100	100	100	163	125	106	130	139	105	128	115	
SW_{10}		403	7.2	20.30	461.0	5.0	182	16	0.008	ND	0.02	158	0.07	207.4
		100	100	226	400	400	315	108	100	100	103	333	126	
SW_{11}		510	7.1	13.7	92.8	2.5	228	18	0.002	0.055	0.41	464	0.13	227.7
		100	100	283	378	400	373	110	100	104	161	400	149	
SW_{12}		394	7.8	0.0	9.2	0.9	117	10	0.046	0.054	1.12	37	0.18	186.0
		100	100	400	119	226	234	100	280	103	162	143	168	
SW_{13}		370	7.2	0.0	6.2	0.4	96	18	ND	ND	1.21	28	0.04	160.4
		100	100	400	110	147	208	110	100	100	268	128	115	
SW_{14}		351	7.7	20.0	44.0	0.9	110	20	ND	ND	1.06	176	0.22	190.2
		100	100	229	227	226	225	113	100	100	259	362	183	

Note:- (i) ND = Not Detected
(ii) Detection limits of the used AAS instrument
Cd^{**}: 0·001-2 mg/l; Pb^{**}: 0·002-15 mg/l; Cr (total): 0·007-5 mg/l

Table: 4·11 Determination of Surface Water Quality Index (August, 1985)

Sample station	$\bar{Q}_i$ Weighting Factor	Q_{TDS}	Q_{pH}	Q_{DO}	Q_{BOD}	$Q_{A.N.}$	Q_{Cl}	Q_{SO_4}	Q_{Cd}	Q_{Pb}	Q_{Cr}	Q_{PO_4}	Q_{COD}	Q_{NO_3}	WQI
		3.0	4.0	5.0	5.0	3.0	2.0	2.0	5.0	5.0	4.0	3.0	5.0	3.0	
SW_1		152	8.3	93.4	4.6	0.8	15	24	ND	0.02	0.031	0.52	16	0.13	117.0
		100	100	100	105	211	106	118	100	100	100	178	109	149	
SW_2		168	7.8	68.1	5.8	1.2	12	ND	0.002	0.05	0.003	0.31	20	0.27	122.4
		100	100	100	109	274	103	100	100	100	100	147	116	201	
SW_3		176	7.7	67.9	4.3	0.2	30	12	0.003	0.12	0.016	0.71	20	0.13	117.0
		100	100	100	104	116	125	103	100	132	100	207	116	149	
SW_5		155	7.7	8.1	9.8	0.4	ND	24	0.002	0.04	ND	0.39	48	0.09	145.4
		100	100	373	121	147	100	118	100	100	100	159	160	134	
SW_6		210	7.7	32.5	6.2	0.4	18	24	ND	0.14	ND	0.71	40	ND	127.2
		100	100	164	110	147	110	118	100	142	100	207	147	100	
SW_7		190	7.7	65.6	3.7	0.5	15	60	0.008	0.15	0.009	1.26	16	0.04	124.9
		100	100	100	102	163	106	163	100	146	100	289	109	115	
SW_8		222	7.8	63.8	4.1	1.0	17	36	ND	0.20	ND	0.87	16	ND	126.7
		100	100	100	103	242	109	133	100	169	100	231	109	100	
SW_{10}		170	7.7	60.2	7.2	0.3	13	12	ND	0.14	ND	1.19	24	0.09	123.0
		100	100	100	113	132	104	103	100	142	100	279	122	134	

Note: (i) ND = Not Detected
(ii) Detection limits of the used AAS instrument
Cd^{++}: 0·001 - 2 mg/l; Pb^{++}: 0·02-15 mg/l; Cr (total): 0·007-5 mg/l

Table: 4·12 - Determination of Surface Water Quality Index (October, 1985)

Sample station	Q_i	Q_{TDS}	Q_{pH}	Q_{DO}	Q_{BOD}	$Q_{A.N.}$	Q_{Cl}	Q_{SO_4}	Q_{Cd}	Q_{Pb}	Q_{Cr}	Q_{PO_4}	Q_{COD}	Q_{NO_3}	W.Q.I.
	Weighting Factor	3.0	4.0	5.0	5.0	3.0	2.0	2.0	5.0	5.0	4.0	3.0	5.0	3.0	
SW_1		180 100	8.3 100	75.75 100	1.6 100	1.2 274	12 103	42 140	0.048 290	0.70 400	0.237 260	0.05 108	8 100	0.18 168	180.1
SW_2		156 100	7.7 100	76.2 100	1.0 100	2.5 400	15 106	30 125	0.012 110	0.42 270	0.098 141	0.08 112	40 147	0.40 250	156.0
SW_3		230 100	8.1 100	45.0 100	5.0 106	0.8 211	18 110	30 125	0.019 145	0.13 137	0.062 110	0.53 180	16 110	0.13 149	122.9
SW_4		288 100	7.5 100	3.86 400	36.0 202	0.0 100	16 108	90 175	0.004 100	ND 100	0.040 100	1.25 288	133 294	0.04 115	176.6
SW_5		332 100	7.7 100	60.5 100	4.0 103	0.8 211	45 144	78 185	0.004 100	0.30 215	ND 100	0.20 130	20 116	0.13 149	130.6
SW_6		266 100	7.9 100	31.5 173	7.0 112	0.1 100	25 119	66 170	ND 100	ND 100	0.009 100	0.39 159	32 135	0.09 134	121.6
SW_7		252 100	7.9 100	31.45 173	65 292	1.0 242	25 119	78 185	0.011 105	ND 100	ND 100	0.05 108	200 400	0.31 216	178.7
SW_8		282 100	7,5 100	15.7 308	7.0 112	1.2 274	18 110	66 170	0.013 115	0.35 238	0.000 100	0.80 220	24 122	0.31 216	168.7
SW_{20}		437 100	7.4 100	20.8 264	320 400	1.0 242	120 238	30 125	ND 100	0.42 270	0.109 150	ND 100	1360 400	0.13 149	219.7
SW_{10}		248 100	7.5 100	55.9 100	5.0 106	2.5 400	68 173	42 140	0.000 100	0.37 247	ND 100	ND 100	20 116	0.18 168	144.4
SW_{11}		380 100	7.6 100	47.9 100	35.0 199	1.0 242	12 103	42 140	0.047 285	ND 100	0.014 100	0.00 100	13 105	ND 100	132.1
SW_{12}		122 100	7.5 100	57.7 100	12.0 128	0.4 147	18 110	18 110	ND 100	0.12 137	0.007 100	0.09 136	40 147	0.22 183	122.4
SW_{13}		274 100	7.5 100	34.2 149	35.0 199	0.9 226	13 104	30 125	0.009 100	0.24 187	0.038 100	ND 100	160 337	0.40 250	166.2

Note:- (i) ND = Not Detected

(ii) Detection limits of the used AAS instrument

Cd^{++}: 0·001-2 mg/l; Pb^{++}: 0·002-15 mg/l; Cr (total): 0·007-5 mg/l

APPENDIX-I

Table:4.13 -Determination of Surface Water Quality Index
(January, 1986)

Sample station	Q_i	Q_{TDS}	Q_{pH}	Q_{DO}	Q_{BOD}	$Q_{A.N.}$	Q_{Cl}	Q_{SO_4}	Q_{Cd}	Q_{Pb}	Q_{Cr}	Q_{PO_4}	Q_{COD}	Q_{NO_3}	W.Q.I.
	Weighting Factor	3.0	4.0	5.0	5.0	3.0	2.0	2.0	5.0	5.0	4.0	3.0	5.0	3.0	
SW_2		450 100	7.9 100	66.7 100	11.0 125	4.0 400	40 138	20 113	0.003 100	0.20 169	0.183 214	0.54 181	40 147	0.35 231	157.1
SW_3		415 100	8.2 100	70.6 100	12.0 128	0.6 179	35 131	140 263	0.003 100	0.20 169	0.400 400	0.19 129	48 160	0.04 115	155.9
SW_4		470 100	7.4 100	22.7 100	41.0 218	1.0 242	20 113	60 163	0.003 100	0.29 211	0.142 179	0.26 139	131 291	0.04 115	179.5
SW_5		328 100	7.7 100	7.8 376	16.0 140	0.8 211	20 133	10 100	0.001 100	0.10 123	0.281 298	0.36 154	72 197	0.09 134	173.4
SW_6		375 100	7.5 100	42.3 100	4.2 104	0.5 163	50 150	35 132	ND 100	0.04 100	0.154 189	1.0 250	22 119	ND 100	126.0
SW_7		557 100	8.3 100	76.8 100	3.1 100	0.2 116	35 132	70 175	0.002 100	0.04 100	0.217 243	0.86 229	21 117	N.D 100	126.65
SW_8		442 100	7.5 100	22.9 247	3.8 102	0.7 195	30 125	20 113	ND 100	0.04 100	0.037 100	1.12 268	7 5 203	0.09 134	145.4
SW_9		378 100	8.0 100	66.7 100	21.0 156	0.4 147	35 132	50 150	0.002 100	0.09 118	0.180 211	0.02 103	59 177	ND 100	130.9
SW_{10}		495 100	7.6 100	11.3 346	49.0 243	4.6 400	72 178	80 188	0.004 100	0.07 109	ND 100	0.02 103	216 400	0.62 333	210.8
SW_{11}		445 100	7.5 100	37.4 122	19.0 149	2.0 400	35 132	50 150	0.003 100	ND 100	0.087 132	0.46 169	88 223	0.13 149	151.3
SW_{12}		439 100	7.7 100	37.1 125	9.3 119	0.8 211	28 123	80 188	0.002 100	ND 100	ND 100	1.06 259	43 152	0.13 149	133.8
SW_{13}		311 100	7.5 100	41.2 100	0.0 100	0.2 116	2.7 100	25 119	0.002 100	0.02 100	0.132 170	1.20 280	3.2 100	ND 100	118.5

Note:- (i) ND = Not Detected

(ii) Detection limits of the used AAS instrument
Cd^{++}: 0·001-2 mg/l; Pb^{++}: 0·02-15 mg/l; Cr (total): 0·007-5 mg/l

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Table:4·14 Determination of Surface Water Quality Index
(March, 1986)

	Q_i	Q_{TDS}	Q_{pH}	Q_{DO}	Q_{BOD}	$Q_{A.N.}$	Q_{Cl}	Q_{SO_4}	Q_{Cd}	Q_{Pb}	Q_{PO_4}	Q_{COD}	Q_{NO_3}	W.Q.I.
Sample station	Weighting Factor	3.0	4.0	5.0	5.0	3.0	2.0	2.0	5.0	5.0	3.0	5.0	3.0	
SW_2		1064 178	7.3 100	88.8 100	160 400	1.0 242	32 128	20 113	0.003 100	0.66 382	0.27 141	666 400	0.31 216	224.9
SW_3		528 100	8.1 100	50.9 100	32 190	0.2 116	20 113	0.0 100	0.000 100	0.04 100	1.25 288	133 294	0.07 126	143.4
SW_4		546 100	7.2 100	0.0 400	60 276	0.5 163	16 108	12 103	0.013 115	ND 100	0.30 145	222 400	0.22 183	201.1
SW_5		538 100	7.3 100	21.1 262	72 313	0.6 179	20 113	12 103	0.030 200	ND 100	0.10 115	287 400	0.35 231	201.8
SW_6		782 118	7.5 100	4.7 400	30 184	0.8 211	56 158	36 133	ND 100	0.06 105	1.0 250	176 362	0.18 168	198.3
SW_7		418 100	7.5 100	66.8 100	10 122	1.0 242	24 118	24 118	0.003 100	ND 100	0.35 153	47 158	0.13 149	123.3
SW_8		640 100	7.2 100	26.9 212	15 137	1.2 274	36 133	60 163	ND 100	0.08 114	1.26 279	55 171	0.27 201	160.5
SW_9		466 100	7.7 100	87.9 100	12 128	0.4 147	16 108	60 163	0.013 115	ND 100	0.15 123	47 158	0.09 134	121.3
SW_{20}		1248 217	7.1 100	0·0 400	80 338	0.3 132	104 218	ND 100	0.015 125	0.20 169	0.10 115	470 400	0.18 168	224.2
SW_{21}		1182 203	7.3 100	2.6 400	70 307	0.4 147	76 183	0.0 100	0.011 105	0.49 303	0.08 112	431 400	0.27 201	234.0
SW_{10}		782 118	7.4 100	8.8 367	65 292	0.5 163	52 153	144 268	0.071 400	0.29 211	0.20 230	261 400	0.22 183	259.4
SW_{11}		954 154	7.4 100	0.0 400	50 245	0.5 163	60 163	24 118	0.022 160	0.18 160	0.50 175	235 400	ND 100	208.9
SW_{12}		480 100	7.5 100	16.7 300	5 106	0.9 226	32 128	60 163	ND 100	0.09 119	0.48 172	24 122	0.35 231	153.4
SW_{13}		556 100	7.9 100	45.45 100	10 122	1.0 242	36 133	24 118	ND 100	ND 100	1.7 355	24 122	0.18 168	138.2

Note: (i) ND = Not Detected
(ii) Detection limits of the used AAS instrument; Cd^{++}: 0·001-2 mg/l; Pb^{++}: 0·02-15 mg/l; Cr (total): 0·007-5mg/l

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Table: 4.15 Determination of Surface Water Quality Index (May, 1986)

	Q_i	Q_{TDS}	Q_{pH}	Q_{DO}	Q_{BOD}	$Q_{A.N.}$	Q_{Cl}	Q_{SO_4}	Q_{Cd}	Q_{Pb}	Q_{PO_4}	Q_{COD}	Q_{NO_3}	W.Q.I.
Sample station	Weighting Factor	3.0	4.0	5.0	5.0	3.0	2.0	2.0	5.0	5.0	3.0	5.0	3.0	
SW_2		828 127	8.8 100	0.0 400	75.5 324	0.05 100	80 188	120 238	0.015 125	1.89 400	0.15 123	314 400	2.70 400	261.0
SW_3		300 100	8.8 100	98.2 100	13.3 132	0.01 100	10 100	12 103	ND 100	1.13 400	0.04 106	51 165	0.61 329	159.9
SW_4		418 100	8.3 100	38.6 112	35.2 200	0.01 100	22 115	60 163	ND 100	0.16 151	1.72 358	34 138	0.90 400	163.0
SW_5		548 100	8.8 100	14.4 319	71.5 312	0.04 100	19 111	48 148	0.058 100	0.48 298	0.37 156	161 339	0.60 325	217.8
SW_6		466 100	8.2 100	13.1 330	16.4 141	0.02 100	35 131	72 178	0.124 400	0.50 308	1.08 262	119 272	0.90 400	241.3
SW_7		500 100	8.0 100	13.3 329	76.5 327	0.02 100	43 141	24 118	ND 100	ND 100	0.78 217	225 400	0.64 340	210.4
SW_8		578 100	8.2 100	0.0 400	45.5 231	0.03 100	35 131	180 313	0.097 400	0.23 183	1.08 262	246 400	0.16 160	249.4
SW_9		388 100	8.7 100	8.1 373	87.2 360	0.04 100	14 105	108 223	0.111 400	1.31 400	0.67 201	59 178	0.08 130	248.9
SW_{20}		1052 175	9.0 100	0.0 400	105.4 400	0.34 138	155 281	72 178	0.076 400	0.58 345	0.64 196	424 400	0.29 209	293.2
SW_{21}		1118 190	8.9 100	0.0 400	176.3 400	0.27 127	218 360	12 103	0.144 400	0.79 400	0.42 163	452 400	ND 100	290.3
SW_{10}		1102 186	8.7 100	0.0 400	207.0 400	0.38 144	136 258	24 118	0.155 400	0.37 248	0.70 205	497 400	0.52 295	286.2
SW_{11}		982 160	8.8 100	0.0 400	116.0 400	0.57 165	134 255	36 133	0.043 265	0.10 123	0.31 147	367 400	ND 100	240.7
SW_{12}		530 100	8.5 100	0.0 400	17.8 146	0.02 100	48 148	60 163	0.185 400	0.74 300	1.17 276	68 191	0.81 400	251.8

Contd......

(Contd.4.15)

Sample station	Q_i Weighting Factor	Q_{TDS} 3.0	Q_{pH} 4.0	Q_{DO} 5.0	Q_{BOD} 5.0	$Q_{A.N.}$ 3.0	Q_{Cl} 2.0	Q_{SO_4} 2.0	Q_{Cd} 5.0	Q_{Pb} 5.0	Q_{PO_4} 3.0	Q_{COD} 5.0	Q_{NO_3} 3.0	W.Q.I.
SW_{13}		500 100	8.5 100	0.0 400	20.4 154	0.07 100	56 158	120 238	ND 100	ND 100	1.13 270	68 191	0.83 400	196.1
SW_{14}		536 100	8.7 100	0.0 400	43.5 225	0.09 100	56 158	60 163	0.100 400	0.37 248	1.29 294	155 330	3.13 400	260.8
SW_{15}		448 100	8.1 100	0.0 400	19.5 151	0.06 100	35 131	96 208	0.175 400	1.28 400	1.39 400	76 308	0.66 205	236.7
SW_{16}		418 100	8.1 100	0.0 400	40.6 216	0.02 100	34 130	48 148	ND 100	1.25 400	1.34 301	119 272	0.72 370	233.5
SW_{17}		480 100	8.4 100	0.0 400	218.0 400	0.03 100	47 146	36 133	ND 100	0.40 262	1.40 310	93 231	0.86 400	236.7
SW_{18}		912 145	8.6 100	0.0 400	136.0 400	0.27 127	115 231	60 163	0.099 400	0.47 294	0.91 237	452 400	0.12 145	280.4
SW_{19}		1070 179	8.6 100	0.0 400	134.2 400	0.35 139	184 317	96 208	0.145 400	1.96 400	0.93 240	495 400	0.37 239	307.5

Note:- (i) ND = Not Detected

(ii) Detection limits of the used AAS instrument
Cd^{++}: 0·001-2 mg/l; Pb^{++}: 0·02-15 mg/l Cr (total): 0·007-5 mg/l

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Table:4.16- Determination of Surface Water Quality Index
(August, 1986)

Sample station	Q_i	Q_{TDS}	Q_{pH}	Q_{DO}	Q_{BOD}	$Q_{A.N.}$	Q_{Cl}	Q_{SO_4}	Q_{Cd}	Q_{Pb}	Q_{PO_4}	Q_{COD}	Q_{NO_3}	W.Q.I.
	Weighting Factor	3.0	4.0	5.0	5.0	3.0	2.0	2.0	5.0	5.0	3.0	5.0	3.0	
SW_1		136 100	8.0 100	89.1 100	6.8 112	ND 100	12 103	12 103	ND 100	ND 100	0.19 129	39 146	1.02 400	128.6
SW_2		154 100	7.4 100	65.6 100	30.5 185	0.01 100	48 148	96 208	0.005 100	0.17 155	0.20 130	188 381	2.35 400	175.7
SW_3		158 100	7.4 100	81.0 100	24.0 165	0.01 100	12 103	12 103	ND 100	ND 100	0.20 130	133 294	0.50 288	143.5
SW_4		526 100	7.7 100	12.0 340	74.3 320	0.03 100	112 228	48 148	0.007 100	0.11 128	0.20 130	102 245	0.75 381	198.8
SW_5		134 100	7.6 100	74.5 100	10.4 123	0.02 100	4.0 100	24 118	ND 100	0.08 114	0.24 136	114 264	0.53 299	138.8
SW_6		218 100	7.3 100	45.9 100	6.8 112	0.02 100	8.0 100	60 163	ND 100	0.35 238	0.26 139	125 282	0.85 400	162.2
SW_7		138 100	7.5 100	58.6 100	6.8 112	0.04 100	8.0 100	24 118	0.067 385	0.14 142	0.15 123	117 270	0.60 325	175.8
SW_8		164 100	7.5 100	78.5 100	6.9 112	0.03 100	8.0 100	96 208	0.007 100	ND 100	0.15 123	55 171	0.10 137	118.0
SW_9		72 100	7.5 100	89.2 100	16.0 140	0.24 122	12 103	72 178	0.070 400	0.06 105	0.24 136	71 196	0.05 119	157.7
SW_{20}		746 110	7.5 100	8.1 373	43.8 226	0.30 132	80 188	60 163	0.025 175	ND 100	0.23 135	235 400	0.21 179	200.8
SW_{21}		290 100	8.6 100	54.6 100	20.0 155	0.19 114	20 113	12 103	0.068 390	0.33 229	0.25 138	10 250	0.01 104	173.7
SW_{10}		204 100	7.7 100	71.7 100	25.5 170	0.26 125	12 103	12 103	0.080 400	ND 100	0.27 141	47 148	0.43 261	161.8
SW_{15}		216 100	8.6 100	36.5 130	2.20 100	0.05 100	60 163	60 163	ND 100	ND 100	0.27 141	78 208	0.46 272	132.4
SW_{16}		200 100	7.4 100	20.5 267	9.20 119	0.01 100	36 133	36 133	0.036 230	ND 100	0.28 142	71 196	0.60 325	165.1

Note:- (i) ND = Not Detected
(ii) Detection limits of the used AAS instrument Cd^{++}: 0·001-2 mg/l; Pb^{++}: 0·02-15 mg/l; Cr (total): 0·007-5 mg/l

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Table:4.17 Determination of Surface Water Quality Index
(November, 1987)

Sample station	Q_i Weighting Factor	Q_{TDS} 3.0	Q_{pH} 4.0	Q_{DO} 5.0	Q_{BOD} 5.0	$Q_{A.N.}$ 3.0	Q_{Cl} 2.0	Q_{SO_4} 2.0	Q_{Cd} 5.0	Q_{Pb} 5.0	Q_{PO_4} 3.0	Q_{COD} 5.0	Q_{NO_3} 3.0	W.Q.I.
SW_2		910 145	8.0 100	0.0 400	134 400	1.00 242	30 125	24 130	0.036 200	0.89 400	0.54 181	900 400	0.35 231	273.4
SW_3		256 100	8.5 100	68.9 100	18 146	0.50 163	4 100	36 133	0.010 100	0.76 400	0.18 127	64 185	0.02 108	155.8
SW_5		800 121	9.1 400	25.2 226	7.3 316	0.80 210	22 115	48 148	0.025 175	0.53 322	0.46 169	480 400	0.03 111	247.8
SW_{22}		510 100	7.6 100	35.7 136	16 140	0.20 116	12 103	60 163	0.006 100	0.42 171	0.20 130	120 274	0.01 104	141.9
SW_{23}		485 100	7.5 100	45.3 100	17 143	0.25 124	16 108	30 125	0.011 105	0.35 238	0.18 127	24 122	0.01 104	128.2
SW_{24}		480 100	7.6 100	27.4 205	30 183	0.30 131	18 110	60 163	0.037 235	0.30 215	0.10 115	160 337	ND 100	181.2
SW_9		500 100	7.9 100	22.2 252	11 124	0.40 147	36 133	60 163	0.035 225	0.27 202	0.00 100	24 122	ND 100	154.6
SW_{20}		515 100	8.0 100	0.00 400	109 400	2.00 400	168 298	36 133	0.034 220	0.64 372	0.10 115	480 400	0.42 258	285.3
SW_{21}		715 103	7.8 100	13.8 324	64 228	1.20 273	90 200	24 118	0.004 100	0.81 400	0.08 112	620 400	0.32 220	231.5
SW_{10}		675 100	7.8 100	27.0 211	61 279	0.80 210	116 233	36 133	ND 100	0.46 289	0.06 109	440 400	0.10 138	204.4
SW_{26}		780 117	7.7 100	28.3 200	51 248	0.45 155	110 225	24 118	0.003 100	0.35 238	0.04 106	133 294	0.10 138	178.5
SW_6		440 100	8.0 100	3.57 400	17 143	0.40 143	30 125	24 118	ND 100	0.50 308	0.80 220	80 210	0.01 104	186.4
SW_7		450 100	7.9 100	6.19 390	11 124	0.35 139	38 135	48 148	0.004 100	0.12 132	0.52 178	184 375	0.01 104	180.9
SW_4		850 132	9.1 400	0.0 400	192 400	1.0 242	20 113	12 103	0.026 180	0.18 160	0.26 139	680 400	0.02 108	257.6

Contd.....

(Contd .4.17.)

Sample station	Q_i Weighting Factor	Q_{TDS} 3.0	Q_{pH} 4.0	Q_{DO} 5.0	Q_{BOD} 5.0	$Q_{A.N.}$ 3.0	Q_{Cl} 2.0	Q_{SO_4} 2.0	Q_{Cd} 5.0	Q_{Pb} 5.0	Q_{PO_4} 3.0	Q_{COD} 5.0	Q_{NO_3} 3.0	W.Q.I.
SW_8		470 100	7.9 100	11.1 347	100.0 122	0.35 139	30 125	24 118	0.038 240	0.62 363	0.68 202	80 210	0.02 108	182.6
SW_{16}		340 100	7.9 100	5.6 394	8.0 125	0.15 108	18 110	48 148	0.005 100	0.11 128	0.42 163	96 236	0.02 106	161.3
SW_{17}		358 100	7.9 100	11.5 344	8.0 125	0.10 100	18 110	48 148	0.042 260	0.46 289	0.40 160	96 236	0.40 104	190.6
SW_{18}		874 100	7.7 100	19.6 274	43.0 223	0.20 116	108 223	24 118	0.002 100	0.49 303	0.30 145	392 400	0.11 141	204.4
SW_{12}		417 100	8.0 100	13.9 323	19.0 149	0.25 124	32 128	72 178	ND 100	0.65 377	0.85 228	24 122	0.11 141	181.0
SW_{11}		798 121	8.1 100	35.3 140	8.0 125	1.00 242	94 205	60 163	0.012 210	0.11 128	0.55 183	280 400	0.08 130	181.7
SW_{13}		448 100	7.9 100	26.9 212	10.0 122	0.60 179	36 134	48 148	ND 100	0.20 169	0.75 213	112 261	0.03 111	157.6
SW_{27}		473 100	7.9 100	24.7 230	6.0 109	0.40 147	34 130	72 178	ND 100	0.10 123	0.42 163	120 274	0.01 104	149.7
SW_{28}		426 100	8.1 100	26.7 213	3.0 109	0.20 116	46 145	60 163	0.004 100	0.08 114	0.30 145	72 199	ND 100	134.9
SW_{14}		457 100	7.8 100	38.7 111	1.0 100	0.10 100	56 158	48 148	0.019 145	ND 100	0.12 118	72 199	ND 100	123.1

Note:- (i) ND = Not Detected
(ii) Detection limits of the used AAS instrument
cd^{**}: 0·001-2 mg/l; Pb^{**}: 0·02-15 mg/l; Cr(total): 0·007-5 mg/l

APPENDIX - II

TABLE : 4.18 - Determination of Ambient Water Quality Index (May, 1985)

Sample No.	I_{TOX}	Total Hardness	$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}}$	% DO_D	BOD	AN	$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})^2}{4}}$
SW_2	0.0	0.2	0.14	1.560	101.50	9.0	50.955
SW_3	0.0	0.2	0.14	1.130	6.25	0.16	3.177
SW_5	6.0	0.2	4.24	1.620	21.70	2.0	11.129
SW_{4*}	0.0	0.2	0.14	1.380	25.65	2.4	12.900
SW_9	1.6	0.2	1.14	0.180	3.10	1.0	1.727
SW_{10}	0.8	0.2	0.58	1.320	230.50	10.0	115.360
SW_6	5.0	0.2	3.53	1.620	15.65	1.4	8.092
SW_7	1.6	0.2	1.14	1.280	1.30	0.4	1.093
SW_8	7.0	0.2	4.95	1.590	9.70	1.6	5.560
SW_{11}	0.2	0.2	0.20	1.430	46.40	5.0	23.345
SW_{12}	4.6	0.2	3.25	0.000	4.60	1.8	2.956
SW_{13}	0.0	0.2	0.14	0.000	3.10	0.8	1.620

* SW_4 : Dairy effluent ; SW_{20} : Paper & pulp effluent.

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TABLE : 4.19- Determination of Ambient Water Quality Index (Aug, 1985)

Sample No.	I_{TOX}	Total Hardness	$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}}$	% DO_D	BOD	AN	$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})}{4}}$
SW_2	1.2	0.2	0.86	0.532	2.90	2.0	1.832
SW_3	2.7	0.2	1.91	0.535	0.23	0.4	1.075
SW_5	1.0	0.2	0.72	1.532	4.90	0.8	2.622
SW_6	2.8	0.2	1.98	1.125	3.10	0.8	1.964
SW_7	3.8	0.2	2.20	0.573	1.85	1.0	1.548
SW_8	4.0	0.2	2.83	0.603	2.05	2.0	2.022

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TABLE:4.20 - Determination of Ambient Water Quality Index (Oct., 1985)

Sample No.	I_{TOX}	Total Hardness	$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}}$	% DO_D	BOD	AN	$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})^2}{4}}$
SW_2	9.6	0.2	6.78	0.396	0.50	5.0	4.223
SW_3	4.5	0.2	3.18	0.916	2.50	1.6	2.222
SW_5	6.4	0.2	4.52	0.658	2.00	1.6	2.618
SW_{4*}	0.4	0.2	0.32	1.600	18.00	0.0	9.036
SW_{10}	7.4	0.2	5.23	0.734	2.50	5.0	3.845
SW_{20*}	8.4	0.2	5.94	1.320	160.00	2.0	80.064
SW_6	0.0	0.2	0.14	1.142	3.50	0.2	1.844
SW_7	1.1	0.2	0.79	1.142	32.50	2.0	16.295
SW_8	8.3	0.2	5.03	1.400	3.50	2.4	3.599
SW_{11}	4.7	0.2	3.33	0.868	17.50	2.0	8.973
SW_{12}	2.4	0.0	1.69	0.708	6.00	0.8	3.161
SW_{13}	5.7	0.2	4.03	1.096	17.50	1.8	9.040

* SW_4 : Dairy effluent; SW_{20} : Paper & pulp effluent.

APPENDIX - II

TABLE: 4.21- Determination of Ambient Water Quality Index (Jan , 1986)

Sample No.	I_{TOX}	Total Hardness	$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}}$	% DO_D	BOD	AN	$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})^2}{4}}$
SW_2	4.3	0.2	3.04	0.550	5.50	8.0	5.093
SW_3	4.3	0.2	3.04	0.490	6.00	1.2	3.424
SW_5	2.1	0.2	1.49	1.530	8.00	1.6	4.216
SW_4*	6.1	0.2	4.31	1.280	20.50	2.0	10.541
SW_9	2.0	0.2	1.42	0.550	10.50	0.8	5.319
SW_{10}	1.8	0.2	1.28	1.470	24.50	9.2	13.121
SW_6	0.8	0.2	0.58	0.962	2.10	1.0	1.291
SW_7	0.8	0.2	0.60	0.386	1.55	0.4	0.876
SW_8	0.8	0.2	0.58	1.280	1.90	1.4	1.373
SW_{11}	0.3	0.2	0.25	1.040	9.50	4.0	5.181
SW_{12}	0.2	0.2	0.20	1.040	4.65	1.6	2.485
SW_{13}	0.6	0.2	0.44	0.900	0.00	4.0	0.573

* SW_4 : Dairy effluent

APPENDIX - II

TABLE:4.22- Determination of Ambient Water Quality Index (March, 86)

Sample No.	I_{TOX}	Total Hardness	$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}}$	% DO_D	BOD	AN	$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})^2}{4}}$
SW_2	13.5	0.2	9.54	0.186	80.00	2.0	40.295
SW_3	0.8	0.2	0.58	0.818	16.00	0.4	8.018
SW_5	3.0	0.2	2.12	1.315	36.00	1.2	18.053
SW_4*	1.3	0.2	0.93	0.000	30.00	1.0	15.010
SW_9	1.3	0.2	0.93	0.200	6.00	0.8	3.100
SW_{21}	10.9	0.2	7.70	1.620	35.00	0.8	17.940
SW_{10}	12.9	0.2	9.12	1.520	32.50	1.0	16.900
SW_{20}*	5.5	0.2	3.89	0.000	40.00	0.6	20.090
SW_6	1.2	0.2	0.86	0.078	15.00	1.6	7.554
SW_7	0.3	0.2	0.25	1.113	5.00	2.0	2.751
SW_8	1.6	0.2	1.82	0.449	7.50	2.4	4.046
SW_{11}	5.8	0.2	4.10	0.000	25.00	1.0	12.680
SW_{12}	1.8	0.2	1.28	0.278	2.50	1.8	1.673
SW_{13}	0.0	0.2	0.14	0.909	5.00	2.0	2.731

* SW_4 : Dairy effluent; SW_{20} : Paper & pulp effluent.

TABLE: 4·23-Determination of Ambient Water Quality Index (May, 1986)

Sample No.	I_{TOX}	Total Hardness	$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}}$	% DO_D	BOD	AN	$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})^2}{4}}$
SW_2	39.4	0.2	27.87	0.000	37.75	0.10	23.460
SW_3	22.6	0.2	15.98	1.630	6.65	0.02	8.690
SW_5	15.4	0.2	10.89	0.240	35.75	0.08	18.690
SW_{4*}	3.2	0.2	2.26	0.646	17.60	0.02	8.870
SW_9	37.3	0.2	26.37	0.140	43.60	0.08	25.470
SW_{21}	30.2	0.2	21.35	0.000	88.15	0.54	45.350
SW_{10}	22.9	0.2	16.19	0.000	103.50	0.76	52.390
SW_{20*}	19.2	0.2	13.57	0.000	52.70	0.68	27.210
SW_6	22.4	0.2	11.26	0.218	8.20	0.04	6.965
SW_7	0.0	0.2	0.14	0.221	38.25	0.04	19.125
SW_8	14.3	0.2	7.59	0.000	22.75	0.06	11.992
SW_{11}	6.3	0.2	4.45	0.000	58.00	1.14	29.090
SW_{12}	33.3	0.2	23.54	0.000	8.90	0.04	12.600
SW_{13}	0.0	0.2	0.14	0.000	10.20	0.14	5.100

* SW_4 : Dairy effluent; SW_{20} : Paper & pulp effluent.

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TABLE: 4.24 - Determination of Ambient Water Quality Index (Aug., 86)

Sample No.	I_{TOX}	Total Hardness	$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}}$	% DO_D	BOD	AN	$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})^2}{4}}$
SW_2	3.9	0.0	2.75	1.486	15.25	0.2	7.784
SW_3	0.0	0.0	0.00	1.352	11.95	0.2	6.013
SW_4*	2.9	0.2	2.05	0.200	37.15	0.6	18.610
SW_5	1.6	0.0	1.13	1.242	5.20	0.4	2.730
SW_9	2.2	0.0	1.55	1.487	8.00	4.8	4.780
SW_{20}*	2.5	0.2	1.77	0.140	21.90	6.0	11.380
SW_{21}	13.4	0.0	9.47	0.910	10.00	3.8	7.158
SW_{10}	8.0	0.0	5.65	1.195	12.75	5.2	7.465
SW_6	7.0	0.2	4.94	0.900	3.40	0.4	3.038
SW_7	9.5	0.0	5.13	0.690	3.40	0.8	3.122
SW_8	0.7	0.0	0.495	0.260	3.45	0.6	1.777

* SW_4 : Dairy effluent; SW_{20} : Paper & pulp effluent.

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ABLE: 4.25-Determination of Ambient Water Quality Index (Nov., 1987)

ample o.	I_{TOX}	Total Hardness	$I_{TM} = \sqrt{\frac{(I_{TOX})^2 + (I_H)^2}{2}}$	$\% DO_D$	BOD	AN	$I_{amb} = \sqrt{\frac{(I_{DO_D})^2 + (I_{BOD})^2 + (I_{AN})^2 + (I_{TM})^2}{4}}$
SW_2	21.4	0.2	15.13	0.000	66.80	2.0	34.260
SW_3	16.3	0.2	11.52	1.150	9.00	1.0	7.349
SW_4*	6.2	0.2	4.38	0.000	114.25	2.0	57.175
SW_5	15.2	0.2	10.74	0.390	42.32	1.6	21.840
SW_9	8.9	0.2	6.29	0.371	5.73	0.8	4.270
SW_{20}*	16.2	0.2	11.45	0.000	54.50	4.0	27.910
SW_{21}	16.6	0.2	11.73	0.228	18.95	2.4	11.200
SW_{10}	9.2	0.2	6.50	0.451	30.70	1.6	15.710
SW_6	10.0	0.2	7.07	0.059	8.55	0.8	5.561
SW_7	2.8	0.2	1.72	0.102	5.65	0.7	2.974
SW_8	16.2	0.2	9.17	0.185	7.95	0.7	6.070
SW_{11}	3.4	0.2	2.40	0.590	3.85	2.0	2.500
SW_{12}	13.0	0.2	9.19	0.348	9.40	0.5	6.578
SW_{13}	4.0	0.2	2.83	0.466	3.20	1.2	2.230

* SW_4 : Dairy effluent; SW_{20} : Paper & pulp effluent.

Table: 5·7 : Field Data and Related Rate Constants for DOSAG-I Model (September - October, 1986)

Sample No.	DISCHARGE DATA						D O	D O sat at t°C	D O Deficit	BOD DATA	
	Temp. (°C)	Width (m)	Depth (m)	Surface velocity (m/sec)	Mean velocity (m/sec)	Discharge (m^3/sec)	(mg/l)	(mg/l)	(mg/l)	BOD_5 (mg/l)	BOD_{ult} (mg/l)
SW_1	28	7.30	0.549	0.243	0.206	0.828	7.1	7.92	0.82	15.20	15.77
SW_2	30	3.25	0.112	0.118	0.100	0.036	2.6	7.63	5.03	39.30	40.77
SW_3	31	5.30	0.348	0.526	0.447	0.825	0.7	7.51	6.81	29.40	30.50
SW_4	33	0.95	0.151	0.292	0.248	0.035	0.0	7.30	7.30	158.60	164.54
SW_5	31	6.52	0.271	0.560	0.476	0.841	4.4	7.51	3.10	10.76	11.16
SW_{22}	34	2.95	0.448	0.588	0.499	0.661	1.2	7.20	6.00	14.29	14.83
SW_{23}	33	5.40	0.469	0.385	0.327	0.827	1.2	7.30	6.10	36.30	37.66
SW_{24}	33	6.20	0.430	0.385	0.327	0.872	6.6	7.30	0.70	12.40	12.86
SW_{25}	36	12.00	0.442	0.500	0.425	2.254	1.3	7.00	5.70	2.00	2.07
SW_9	32	8.70	0.382	0.213	0.181	0.601	1.1	7.39	6.29	9.80	11.72
SW_{20}	-	-	-	-	-	-	-	-	-	-	-
SW_{21}	31	13.00	0.185	0.333	0.283	0.681	6.4	7.51	1.11	9.10	11.66
SW_{10}	32	17.00	0.244	0.250	0.212	0.882	6.0	7.39	1.39	10.00	12.82
SW_{18}	30	10.00	0.256	0.333	0.283	0.724	5.2	7.63	2.43	13.90	17.82
SW_{26}	31	16.00	0.175	0.375	0.319	0.891	6.5	7.51	1.01	9.40	12.05
SW_{11}	28	16.00	0.208	0.400	0.340	1.132	5.7	7.92	2.22	6.51	11.05
SW_6	27	9.00	0.106	0.937	0.796	0.765	1.1	8.07	6.97	42.80	151.11
SW_7	26	13.70	0.287	0.500	0.425	1.665	6.3	8.22	1.92	6.00	21.18
SW_8	26	15.00	0.206	0.925	0.786	2.430	4.8	8.22	3.42	21.20	74.85
SW_{16}	26	19.00	0.326	0.500	0.425	2.638	2.6	8.22	5.62	25.70	90.74
SW_{17}	28	14.00	0.384	0.650	0.552	2.972	4.8	7.92	3.12	12.10	42.72
SW_{12}	27	18.00	0.286	0.909	0.772	3.986	4.9	8.07	3.17	8.00	20.11
SW_{13}	27	30.00	0.241	0.833	0.708	5.118	4.5	8.07	3.57	12.50	44.13

(Contd......)

	K_1		K_1'	K_1'		K_2		K_2'	Coefficient	Exponent
				Based on Bhargava (1986)		From equation 5·8				
	at 20°C	at t°C	Base e	K_1'(early)	K_1'(late)	at 20°C	at t°C	Base e	(A_1)	(B_1)
SW_1	1.172	1.943	4.479	21.40	-	2.295	3.051	7.031	0.218	0.335
SW_2	1.172	1.943	4.479	21.40	-	2.295	3.051	7.031	0.302	0.315
SW_3	1.172	1.943	4.479	21.40	-	2.295	3.051	7.031	0.474	0.335
SW_4	1.172	1.943	4.479	21.40	-	2.295	3.051	7.031	0.758	0.335
SW_5	1.172	1.943	4.479	21.40	-	2.295	3.051	7.031	0.501	0.335
SW_{22}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.569	0.335
SW_{23}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.346	0.335
SW_{24}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.340	0.335
SW_{25}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.321	0.335
SW_9	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.213	0.335
SW_{20}	-	-	-	-	-	-	-	-	-	-
SW_{21}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.320	0.335
SW_{10}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.219	0.335
SW_{18}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.313	0.335
SW_{26}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.329	0.335
SW_{11}	1.172	1.943	4,479	-	0.19	2.295	3.051	7.031	0.324	0.335
SW_6	3.837	5.293	12.196	-	-	55.079	65.026	149.83	0.865	0.335
SW_7	3.837	5.293	12.196	-	-	55.079	65.026	149.83	0.356	0.335
SW_8	3.837	5.293	12.196	-	-	55.079	65.026	149.83	0.580	0.335
SW_{16}	3.837	5.293	12.196	-	0.19	55.079	65.026	149.83	0.305	0.335
SW_{17}	3.837	5.293	12.196	-	0.19	55.079	65.026	149.83	0.380	0.335
SW_{12}	3.837	5.293	12.196	-	-	55.079	65.026	149.83	0.482	0.335
SW_{13}	1.172	1.943	4.479	-	0.19	2.295	3.051	7.031	0.407	0.335

Table : 5·8 : Field Data and Related Rate Constants for DOSAG-I Model (January 1987)

Sample No.	DISCHARGE DATA						D O	D O sat at t°C	D O Deficit	BOD DATA	
	Temp. (°C)	Width (m)	Depth (m)	Surface velocity (m/sec)	Mean velocity (m/sec)	Discharge (m^3/sec)	(mg/l)	(mg/l)	(mg/l)	BOD_5 (mg/l)	BOD_{ult} (mg/l)
SW_2	19	2.60	0.132	0.056	0.048	0.016	6.5	9.35	2.85	29.00	31.03
SW_3	20	4.60	0.213	0.333	0.283	0.279	8.4	9.17	0.77	20.10	21.51
SW_4	23	1.00	0.145	0.272	0.231	0.033	0.0	8.68	8.68	284.00	265.35
SW_5	20	3.60	0.153	0.704	0.598	0.330	7.2	9.17	1.97	6.80	7.27
SW_{22}	21	2.50	0.162	0.789	0.670	0.271	5.9	8.99	3.09	17.70	18.94
SW_{23}	22	5.50	0.281	0.416	0.354	0.546	5.5	8.83	3.33	29.60	31.67
SW_{24}	22	6.00	0.221	0.357	0.303	0.403	4.7	8.83	4.13	11.60	12.41
SW_{25}	-	-	-	-	-	-	-	-	-	-	-
SW_9	22	7.20	0.125	0.375	0.319	0.287	5.3	8.83	3.53	13.10	15.26
SW_{20}	30	0.95	0.474	0.833	0.708	0.320	0.0	7.63	7.63	147.60	175.95
SW_{21}	26	9.00	0.272	0.291	0.247	0.607	2.8	8.22	5.42	51.40	61.27
SW_{10}	21	7.00	0.212	0.242	0.206	0.305	0.5	8.99	8.49	22.70	27.06
SW_{18}	22	7.60	0.230	0.333	0.283	0.495	0.7	8.83	8.13	21.60	25.75
SW_{26}	21	7.00	0.255	0.288	0.245	0.437	0.7	8.99	8.29	16.40	19.55
SW_{11}	20	11.00	0.284	0.750	0.638	1.993	4.0	9.17	5.17	22.50	28.35
SW_6	20	9.00	0.108	0.750	0.638	0.619	1.9	9.17	7.27	8.90	10.74
SW_7	19	11.00	0.240	0.405	0.344	0.913	7.5	9.35	1.85	14.80	17.85
SW_8	19	13.50	0.183	0.729	0.620	1.532	4.7	9.35	4.65	6.40	7.72
SW_{16}	18	17.50	0.268	0.428	0.364	1.710	1.2	9.54	8.34	19.00	22.92
SW_{17}	20	12.80	0.287	0.319	0.271	0.998	6.4	9.17	2.77	6.60	7.96
SW_{12}	19	13.00	0.230	0.555	0.472	1.410	5.5	9.35	3.85	14.30	15.83
SW_{13}	20	18.50	0.303	0.714	0.607	3.403	1.0	9.17	8.17	2.00	2.41

(Contd......)

	K_1		K_1'	K_1'		K_2		K_2'	Coefficient	Exponent
				Based on Bhargava (1986)		From equation 5·8				
	at 20°C	at t°C	Base e	K_{1}'(early)	K_{1}'(late)	at 20°C	at t°C	Base e	(A_1)	(B_1)
SW_2	1.066	1.168	2.693	3.12	-	4.851	5.086	11.720	1.190	0.335
SW_3	1.066	1.168	2.693	3.12	-	4.851	5.086	11.720	0.431	0.335
SW_4	1.066	1.168	2.693	3.12	-	4.851	5.086	11.720	0.719	0.335
SW_5	1.066	1.168	2.693	3.12	-	4.851	5.086	11.720	0.861	0.335
SW_{22}	1.066	1.168	2.693	3.12	-	4.851	5.096	11.720	1.031	0.335
SW_{23}	1.066	1.168	2.693	-	1.19	4.851	5.086	11.720	0.430	0.335
SW_{24}	1.066	1.168	2.693	-	1.19	4.851	5.086	11.720	0.408	0.335
SW_{25}	-	-	-	-	-	-	-	-	-	-
SW_9	1.066	1.168	2.693	-	1.19	4.851	5.086	11.720	1.031	0.335
SW_{20}	1.066	1.168	2.693	2.10	-	4.851	5.086	11.720	1.031	0.335
SW_{21}	1.066	1.168	2.693	2.10	-	4.851	5.086	11.720	0.290	0.335
SW_{10}	1.066	1.168	2.693	2.10	-	4.851	5.086	11.720	0.305	0.335
SW_{18}	1.066	1.168	2.693	-	1.90	4.851	5.086	11.720	0.356	0.335
SW_{26}	1.066	1.168	2.693	-	1.90	4.851	5.086	11.720	0.321	0.335
SW_{11}	1.066	1.168	2.693	-	1.90	4.851	5.086	11.720	0.503	0.335
SW_6	0.871	0.832	1.918	-	-	1.442	1.408	3.245	0.744	0.335
SW_7	0.871	0.832	1.918	-	-	1.442	1.408	3.245	0.352	0.335
SW_8	0.871	0.832	1.918	-	-	1.442	1.408	3.245	0.534	0.335
SW_{16}	0.871	0.832	1.918	-	1.90	1.442	1.408	3.245	0.269	0.335
SW_{17}	0.871	0.832	1.918	-	1.90	1.442	1.408	3.245	0.269	0.335
SW_{12}	0.871	0.832	1.918	-	-	1.442	1.408	3.245	0.418	0.335
SW_{13}	1.066	1.168	2.693	-	1.90	4.851	5.086	11.720	0.400	0.335

Table : 5·9 : Field Data and Related Rate Constants for DOSAG-I Model (July 1987)

Sample No.	DISCHARGE DATA						D O	D O sat at t°C	D O Deficit	BOD DATA	
	Temp. (°C)	Width (m)	Depth (m)	Surface velocity (m/sec)	Mean velocity (m/sec)	Discharge (m^3/sec)	(mg/l)	(mg/l)	(mg/l)	BOD_5 (mg/l)	BOD_{ult} (mg/l)
SW_2	32	2.50	0.108	0.133	0.113	0.030	0.0	7.39	7.39	109.29	110.29
SW_3	36	3.50	0.077	0.270	0.229	0.062	7.0	7.00	0.00	6.87	6.93
SW_4	33	1.50	0.394	0.159	0.135	0.020	0.0	7.30	7.30	278.70	281.24
SW_5	34	3.25	0.165	0.246	0.209	0.112	1.0	7.20	6.20	53.60	54.08
SW_{22}	35	17.50	0.170	0.311	0.264	0.082	0.0	7.17	7.17	30.60	30.88
SW_{23}	33	5.40	0.459	0.125	0.106	0.219	0.2	7.30	7.10	45.10	45.51
SW_{24}	33	4.50	0.098	0.370	0.314	0.138	0.0	7.30	7.30	35.10	34.42
SW_{25}	-	-	-	-	-	-	-	-	-	-	-
SW_9	34	3.50	0.083	0.175	0.149	0.043	2.2	7.20	5.00	16.40	18.32
SW_{20}	33	1.00	0.400	0.375	0.319	0.127	0.0	7.30	7.30	44.70	48.84
SW_{21}	33	5.00	0.415	0.096	0.082	0.170	1.8	7.30	5.50	7.90	8.63
SW_{10}	-	-	-	-	-	-	-	-	-	-	-
SW_{18}	-	-	-	-	-	-	-	-	-	-	-
SW_{26}	-	-	-	-	-	-	-	-	-	-	-
SW_{11}	32	10.00	0.236	0.750	0.637	0.152	3.8	7.39	3.59	5.60	7.32
SW_6	35	8.00	0.101	0.700	0.595	0.482	0.0	7.17	7.10	31.40	39.07
SW_7	35	8.50	0.188	0.250	0.212	0.341	5.2	7.17	1.97	25.20	31.35
SW_8	35	9.00	0.087	1.236	1.050	0.823	3.5	7.17	3.67	25.10	31.23
SW_{16}	32	15.00	0.200	0.333	0.283	0.850	0.0	7.39	7.39	11.20	13.94
SW_{17}	33	15.50	0.222	0.200	0.170	0.585	0.0	7.30	7.30	5.20	6.47
SW_{12}	32	13.00	0.270	0.604	0.513	1.802	0.0	7.39	7.39	15.90	21.54
SW_{13}	32	16.50	0.420	0.331	0.281	1.954	3.8	7.39	3.59	2.90	3.61

(Contd.....)

	K_1		K'_1	K'_1 Based on Bhargava (1986)		K_2 From equation 5.8		K'_2	Coefficient	Exponent
	at 20°C	at t°C	Base e	K'_1(early)	K'_1(late)	at 20°C	at t°C	Base e	(A_1)	(B_1)
SW_2	2.397	4.560	10.507	7.00	-	11.633	16.214	37.359	0.363	0.335
SW_3	2.397	4.560	10.507	7.00	-	11.633	16.214	37.359	0.577	0.335
SW_4	2.397	4.560	10.507	7.00	-	11.633	16.214	37.359	0.497	0.335
SW_5	2.397	4.560	10.507	7.00	-	11.633	16.214	37.359	0.432	0.335
SW_{22}	2.397	4.560	10.507	7.00	-	11.633	16.214	37.359	0.606	0.335
SW_{23}	2.397	4.560	10.507	-	9.00	11.633	16.214	37.359	0.175	0.335
SW_{24}	2.397	4.560	10.507	-	9.00	11.633	16.214	37.359	0.606	0.335
SW_{25}	-	-	-	-	-	-	-	-	-	-
SW_9	2.397	4.560	10.507	-	9.00	11.633	16.214	37.359	0.425	0.335
SW_{20}	2.397	4.560	10.507	-	9.00	11.633	16.214	37.359	0.633	0.335
SW_{21}	2.397	4.560	10.507	-	9.00	11.633	16.214	37.359	0.147	0.335
SW_{10}	-	-	-	-	-	-	-	-	-	-
SW_{18}	-	-	-	-	-	-	-	-	-	-
SW_{26}	-	-	-	-	-	-	-	-	-	-
SW_{11}	2.397	4.560	10.507	-	9.00	11.633	16.214	37.359	1.190	0.335
SW_6	1.078	1.871	4.312	-	-	3.190	4.241	9.772	0.755	0.335
SW_7	1.078	1.871	4.312	-	-	3.190	4.241	9.772	0.302	0.335
SW_8	1.078	1.871	4.312	-	-	3.190	4.241	9.772	1.114	0.335
SW_{16}	1.078	1.871	4.312	-	9.00	3.190	4.241	9.772	0.297	0.335
SW_{17}	1.078	1.871	4.312	-	9.00	3.190	4.241	9.772	0.202	0.335
SW_{12}	1.078	1.871	4.312	-	-	3.190	4.241	9.772	0.418	0.335
SW_{13}	2.397	4.560	10.507	-	9.00	11.633	16.214	37.359	0.223	0.335

Table : 5.10 : Field Data and Related Rate Constants for DOSAG-I Model (November 1987)

Sample No.	DISCHARGE DATA Temp. (°C)	Width (m)	Depth (m)	Surface velocity (m/sec)	Mean velocity (m/sec)	Discharge (m^3/sec)	D O (mg/l)	D O sat at t° C (mg/l)	D O Deficit (mg/l)	BOD DATA BOD_5 (mg/l)	BOD_{ult} (mg/l)
SW_1	-	-	-	-	-	-	-	-	-	-	-
SW_2	26	3.00	0.058	0.194	0.165	0.0286	0.0	8.22	8.22	133.60	133.60
SW_3	21	4.30	0.133	0.083	0.070	0.0404	6.2	8.99	2.79	18.00	18.00
SW_4	29	1.50	0.080	0.166	1.141	0.0169	0.0	7.77	7.77	191.83	213.59
SW_5	24	4.00	0.184	0.140	0.119	0.0875	2.0	8.53	6.53	73.15	79.43
SW_{22}	25	2.00	0.150	0.233	0.198	0.059	3.0	8.38	5.38	15.86	15.86
SW_{23}	25	4.00	0.350	0.200	0.170	0.238	3.8	8.38	4.58	17.00	17.00
SW_{24}	25	4.20	0.080	0.189	0.160	0.054	2.3	8.38	6.08	38.80	38.80
SW_{25}	-	-	-	-	-	-	-	-	-	-	-
SW_9	24	4.50	0.030	0.200	0.170	0.0227	1.9	8.53	6.63	11.46	14.66
SW_{20}	35	1.00	0.350	0.395	0.336	0.117	0.0	7.17	7.17	10.90	117.85
SW_{21}	33	12.00	0.154	0.089	0.076	0.140	1.0	7.30	6.30	64.15	73.46
SW_{10}	32	6.00	0.180	0.325	0.276	0.298	2.0	7.39	5.39	61.40	61.40
SW_{18}	30	9.00	0.155	0.344	0.292	0.407	1.5	7.63	6.13	42.90	42.92
SW_{26}	29	7.00	0.256	0.333	0.283	0.507	2.2	7.77	5.57	51.00	51.00
SW_{11}	28	6.00	0.250	0.181	0.154	0.231	2.8	7.92	5.12	7.70	7.70
SW_6	25	7.50	0.082	0.280	0.238	0.146	0.3	8.38	8.08	17.10	17.10
SW_7	29	8.30	0.170	0.272	0.231	0.328	0.5	7.77	7.27	11.30	11.30
SW_8	28	9.00	0.074	0.837	0.711	0.474	0.9	7.92	7.02	9.90	13.22
SW_{16}	22	15.00	0.250	0.200	0.170	0.637	0.5	8.83	8.33	7.60	7.76
SW_{17}	29	16.00	0.225	0.227	0.235	0.847	0.9	7.77	6.87	7.50	7.66
SW_{12}	25	16.50	0.206	0.277	0.235	0.802	1.0	8.38	7.38	18.80	19.20
SW_{13}	26	17.60	0.251	0.312	0.265	1.175	2.3	8.22	5.92	97.60	15.04
SW_{27}	25	17.60	0.144	0.370	0.314	0.801	2.0	8.38	6.38	6.40	6.75
SW_{28}	26	16.00	0.152	0.200	0.170	0.414	2.2	8.22	6.02	2.53	2.67
SW_{14}	26	10.00	0.069	0.285	0.242	0.168	3.2	8.22	5.02	1.04	1.09

(Contd .....)

	K_1		K'_1	K'_1		K_2		K'_2	Coefficient	Exponent
				Based on Bhargava (1986)		From equation 5.8				
	at 20°C	at t°C	Base e	K'_1(early)	K'_1 (late)	at 20°C	at t°C	Base e	(A_1)	(B_1)
SW_1	-	-	-	-	-	-	-	-	-	-
SW_2	0.155	0.195	0.451	4.00	-	0.412	0.464	1.070	0.539	0.335
SW_3	0.155	0.195	0.451	4.00	-	0.412	0.464	1.070	0.204	0.335
SW_4	0.155	0.195	0.451	4.00	-	0.412	0.464	1.070	0.549	0.335
SW_5	0.155	0.195	0.451	4.00	-	0.412	0.464	1.070	0.267	0.335
SW_{22}	0.155	0.195	0.451	4.00	0.22	0.412	0.464	1.070	0.507	0.335
SW_{23}	0.155	0.195	0.451	-	0.22	0.412	0.464	1.070	0.273	0.335
SW_{24}	0.155	0.195	0.451	-	-	0.412	0.464	1.070	0.423	0.335
SW_{25}	-	-	-	-	0.22	-	-	-	-	-
SW_9	0.155	0.195	0.451	-	10.40	0.412	0.464	1.070	0.598	0.335
SW_{20}	0.155	0.195	0.451	13.70	10.40	0.412	0.464	1.070	0.684	0.335
SW_{21}	0.155	0.195	0.451	13.70	10.40	0.412	0.464	1.070	0.146	0.335
SW_{10}	0.155	0.195	0.451	13.70	10.40	0.412	0.464	1.070	0.411	0.335
SW_{18}	0.155	0.195	0.451	-	10.40	0.412	0.464	1.070	0.392	0.335
SW_{26}	0.155	0.195	0.451	-	10.40	0.412	0.464	1.070	0.353	0.335
SW_{11}	0.155	0.195	0.451	-	-	0.412	0.464	1.070	0.250	0.335
SW_6	1.832	2.008	4.628	-	-	1.916	2.009	4.630	0.451	0.335
SW_7	1.832	2.008	4.628	-	-	1.916	2.009	4.630	0.333	0.335
SW_8	1.832	2.008	4.628	-	10.40	1.916	2.009	4.630	0.907	0.335
SW_{16}	1.832	2.008	4.628	-	10.40	1.916	2.009	4.630	0.196	0.335
SW_{17}	1.832	2.008	4.628	-	-	1.916	2.009	4.630	0.296	0.335
SW_{12}	1.832	2.008	4.628	-	10.40	1.916	2.009	4.630	0.251	0.335
SW_{13}	1.832	2.008	4.628	-	10.40	1.916	2.009	4.630	0.249	0.335
SW_{27}	1.832	2.008	4.628	-	10.40	1.916	2.009	4.630	0.336	0.335
SW_{28}	1.832	2.008	4.628	-	10.40	1.916	2.009	4.630	0.227	0.335
SW_{14}	0.155	0.195	0.451	-	10.40	0.412	0.464	1.070	0.437	0.335

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