

CHARACTERISATION OF HUBLI-DHARWAD URBAN SEWAGE AND ITS IMPACT ON SOIL PROPERTIES

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**In
SOIL SCIENCE**

By

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DECEMBER, 1999

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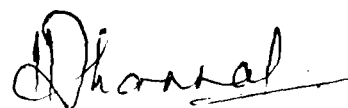
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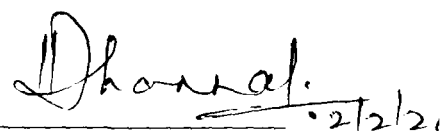
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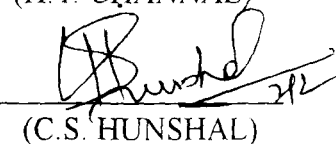
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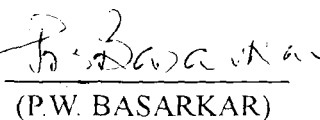


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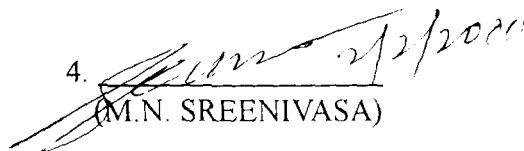
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INTRODUCTION

I. INTRODUCTION

The time of extreme alteration of the landscape being accepted without protest, and development of any kind regardless of its environmental impact being universally condoned in the name of the progress does not exist no more. This frontier attitude is being gradually modified during the first half of the century, and in the past two decades there is a rapid evolution of wide spread public concern over the progressive deterioration of the environment. Increasing public awareness of the need for preserving the quality of our surface water is one among them.

Surface waters are being polluted by means of disposal of wastes or effluents of the factories from urban cities, sewage wastes *etc.* Moreover increased population growth, massive urbanisation, rapid rate of industrialisation, inculcation of modern technology in agriculture and animal husbandry have accelerated water pollution and have lead to gradual deterioration of its quality. The above problem occurred mainly due to the usual method of disposal of these wastes to natural water bodies. Recent regulations governing wastewater discharge into surface water and increasing cost for wastewater treatment have encouraged the development of irrigation system for recycling of wastewater in crop production. Land application of wastewater is now becoming one of the most economically and ecologically viable method of disposal of these waters.

Water is one of the most valuable resources available to man for his domestic, agriculture and industrial uses, out of which agriculture claims lion's share accounting for about two-thirds of the water demand. With

population growing at an annual rate of 1.6 per cent, while irrigation is expanding at rate of about one per cent per year (Sandra,1995). Shortage of water is being experienced in many parts of the world especially in arid and semi-arid regions. Since intensive agriculture cannot depend on rainfall alone, sewage water as well as other low quality water resources may become important sources of water in areas where other sources are inadequate.

In India, total waste water generated per annum from the 200 cities is about 2600 Mm³. The quality of which varies with the type of industry and use. About 65 to 70 per cent of water does not get any treatment (Kaul et al, 1989), which can be thought of one of the sources of water for irrigation purpose.

The Hubli-Dharwad Municipal Corporation which is second largest in Karnataka is only partially provided with underground drainage system. Wastewater is generated largely from domestic properties and also from industrial sources. About 15 million gallons of wastewater is generated per day in these cities and could cause problems for which user as it is not being treated.

The sewage system for Dharwad city is divided into four drainage divisions, determined by topography of the city; Madihal, Hirekeri, Narendra and Lakamanhalli. Untreated sewage water of Dharwad joins to number of small streams on its way to Tupari, a large stream which ultimately joins Malaprabha river, a main potable water source for Hubli - Dharwad cities. Thus, if farmers let it unused may continue to pollute all water source on its course.

This raw sewage is being utilized by the farmers in near by villages of Hubli-Dharwad for the last 30 to 35 years to grow various *rabi* and *summer* crops like vegetables, wheat, sorghum, cotton, pulses *etc.* The small farmers reserve their entire land for intensive vegetable cultivation as it sustains their economy.

Irrigation through sewage is as old as agriculture itself (Singh, 1996) and it is being practiced over a long period (Pound and Crites, 1973; Harlin, 1979; Page *et al.*, 1983 and Shuval *et al.*, 1986). The earliest documented sewage farms being in Bunzlan, Germany and Edinburgh, Scotland which were in operation from 1531 and 1650, respectively. Utilisation of wastewater may also reduce the need for few fresh water development projects and the high cost of advanced treatment and disposal facilities.

Sewage water varies widely in its composition. Irrigation with sewage water provides the crop a cheap source of water and nutrients. Indiscriminate use of sewage causes the development of “sewage sickness” as a result of clogging of soil pores resulting in decreased permeability. Lack of aeration in sewage sick soils cause anaerobic decomposition of sewage which produce toxic gases such as methane, hydrogen sulphide *etc.* and these gases are found to create unhygienic conditions. High salt concentration, heavy metal content, pathogenic microorganisms, pesticides and some organic compound present in sewage effluent are major concern to utilise sewage in crop production.

Prolonged sewage irrigation can result in excess accumulation of heavy metals in soils. These heavy metals may enter human beings and animals through food chain and cause diseases such as cancer.

Quality of water is important in irrigated agriculture and is decided by factors such as water composition, soil types, crops grown, climate and cultural practices. The quality of water resources which are in near vicinity of sewage nala might also get influenced. Keeping this in view, the present investigation was carried out with the following objectives.

1. To characterise and classify of Hubli - Dharwad urban sewage.
2. To classify underground waters around sewage irrigated areas.
3. To study the effect of sewage water irrigation on soil properties and
4. To study the depth wise distribution of heavy metals in these soils.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Sewage water varies widely in its composition. Application of sewage water to agricultural land results in beneficial and harmful effects, which is determined by the nature of sewage, soil and other factors. The information pertaining to characterization of sewage water, influence of sewage water irrigation on physico-chemical properties of soil, ground water contamination and distribution of heavy metals are briefly reviewed, here under.

2.1 NATURE AND COMPOSITION OF SEWAGE WATER

Sewage, a domestic water is defined as wastewater of a community (Mara, 1976). It may be purely domestic in origin or may contain some industrial and agricultural wastes as well. Shende (1974) defined the domestic wastewater or sewage water as the used water discharged by a residential community. It contains human faeces and urine, sullage which is wastewater from kitchen, bathroom and household washings.

Sewage water contains 99.9 per cent water and 0.1 per cent organic and inorganic solids in settleable, suspended and soluble forms. Fresh sewage is dark grey in appearance and the particles of suspended matter are visible to the naked eye. In hot climates sewage can soon lose its content of dissolved oxygen and become stale or septic. The septic sewage has most offensive odour, usually of hydrogen sulphide and mercaptans.

Chemical characteristics of sewage water vary with the source of the potable water supply, the sewage system, the season and the nature of the industrial discharge into the system. A major concern in using sewage effluent for irrigation is the presence of high concentrations of hazardous constituents, such as heavy elements, stable organics and complex synthetic micropollutants. Some of these such as Pb, Hg, As, Ni, Cd, Zn, Cu, Mn and Fe can be harmful to plants at excessive levels. However, the concentrations in most sewage water are below the toxicity level unless contaminated by industrial wastes for all crops and phyto-toxicity may occur only as a result of long term accumulation in the soil (Feigin *et al.*, 1991).

Analysis of sewage water from Tuscon, Arizona by Day *et al.* (1972) revealed the following composition: Total solids 819 ppm, total N 24 ppm, P_2O_5 20 ppm, K_2O 13 ppm, Ca 36 ppm, Mg 16 ppm, Na 152 ppm, CO_3 traces, HCO_3 378 ppm, Cl 92 ppm, SO_4 165 ppm, NO_2 2 ppm.

Dodolina (1971) analysed the composition of sewage from Western Meshchera (Russia) which had pH 6.8, total N 43 ppm, HCO_3 361 ppm, Cl 49 ppm, SO_4 81 ppm, Ca + Mg 64 ppm, Na 42 ppm, K 10 ppm, P_2O_5 9.0 ppm.

Analysis of sewage water from different source around Bangalore revealed the following composition: pH 7.1, turbidity 190 ppm, total solids 750 ppm, acidity 100 ppm, alkalinity 300 ppm, dissolved oxygen 0.1 ppm, BOD 300 ppm, ammonical N 50 ppm, water soluble P 5.2 ppm (Kasiviswanath, 1972).

Typical composition of raw municipal sewage are as follows (Pound and Crites 1973; Bond and Straub 1974; Thomas and Law 1977; Idelovitch 1978 and Asano *et al.*, 1985).

Consistuent	Concentration (mg L ⁻¹)		
	High	Medium	Low
Solids			
Total	1300	700	200
Dissolved	1000	500	200
Suspended	350	220	100
BOD ₍₅₎	350	200	100
COD	1000	500	250
TOC	290	160	80
Nitrogen			
Total	85	40	20
Ammonium	50	25	10
Organic	35	15	5
Nitrate	1.5	0.2	0
Phosphorus	36	10	4
Chlorides	650	150	10
Calcium + Magnesium	150	80	25
Sodium	460	120	10
Potassium	25	10	5
Alkalinity	400	200	50
Grease	150	100	35
pH	8.0	7.2	7.0

Beek *et al.* (1977a) have analysed the sewage water of Wageningen (Netherlands) and reported the following composition pH 7.1, BOD₅ 381 ppm, total N 20.5 ppm, total P 33 ppm, Na 145 ppm, K 32 ppm, Ca 70 ppm, Mg 8 ppm, Fe 0.2 ppm, Cl 160 ppm.

Analysis of sewage water of Nagpur city for a period of five months revealed considerable variations in various characteristics. The average general characteristics of sewage in Nagpur are as follows: Total solids 1200 ppm, total suspended solids 200 ppm, total dissolved solids 1000 ppm, pH 7.2, BOD₅ 350 mg L⁻¹, total nitrogen 60 mg L⁻¹, Cl 30 ppm, PO₄ 20 ppm, K 45 ppm (Thakur *et al.*, 1977).

Analysis of various physical and chemical characteristics of three sewage drains of Agra at 30 days interval for a period of two years by Sharma *et al* (1981) revealed the following composition, pH 7.0 to 8.25, turbidity 384.0 to 1102.0 mg L⁻¹, dissolved solids 409.15 to 827.60 mg L⁻¹, temperature 13 to 34.20°C, colour muddy to dirty muddy, suspended solids 436.75 to 812.35 mg L⁻¹, temporary hardness 65.25 - 163.70 mg L⁻¹ Cl⁻ 81.0 to 270.30 mg L⁻¹, organic -N 4.05 to 26.90, ammonical - N 3.83 to 14.33 mg L⁻¹, chlorine nil to 14.50 mg L⁻¹, COD 3.20 to 42.47 g L⁻¹, BOD 63 to 162.25 mg L⁻¹, Na 61 to 185.06 mg L⁻¹, Ca 5.50 to 27.0 mg L⁻¹, Mg 7.0 to 26.17 mg L⁻¹, Fe 0.0105 to 0.9406 mg L⁻¹, Cu 0.0034 to 0.7512 mg L⁻¹.

Sewage water of Apple Valley (Minnesota) had the following composition: pH 8.11, EC 1.96 dS m⁻¹, suspended solids 18 ppm, COD 415 ppm, Cl 49 ppm, total N 21.2 ppm, PO₄ 6.9 ppm, Na 279 ppm, Ca 72 ppm, Mg 24 ppm and K 12 ppm (Latterell *et al.*, 1982).

Jayaramani and Perumal (1984) reported the composition of Coimbatore sewage as total solids 2110 mg L⁻¹, pH 7.5, EC 1.2 dS m⁻¹, total N 91.8 mg L⁻¹, total P 37.5 ppm, total K 17.0 mg L⁻¹, Ca 183.0 mg L⁻¹, Na 149.0 mg L⁻¹.

Arora *et al.* (1985) analysed of the samples of wastewater collected periodically at fifteen days interval from 13 outlets during 1980 in Ludhiana city and reported a wide variation in physico-chemical parameters, (pH, EC, CO_3 , HCO_3 , Cl), concentration of plant nutrients (P, K, Ca, Mg, Zn, Cu, Fe, Mn) and potential hazardous heavy metals (Pb, Cd, Ni, Co).

Singh and Kansal (1985) reported that the chemical composition of wastewater collected from different sewage disposals in Punjab varied considerably from town to town. Concentration of nutrients and pollutants were high in the water of industrial town of Amritsar and Julandhar and concentration were high in winter than in summer.

Raw sewage water and the sewage water from primary and secondary treatment plant of Delhi had the following composition pH 7.0 to 7.5, EC 1.02-1.50 dS m^{-1} , COD 247.5 - 305 mg L^{-1} , BOD 108.4 - 140.5 mg L^{-1} , N 25.2 - 28.6 mg L^{-1} , Ca 234 to 240 mg L^{-1} , Mg 18.9 to 19.5 mg L^{-1} . Concentration of these constituents were more in raw sewage followed by primary treated and secondary treated sewage (Menon and Bhattacharya, 1988).

Analysis of sewage water of Patna city at 15 days interval over a period of two years (1985-87) revealed that sewage water varies widely in their composition during different seasons of the year. Generally the concentration was more during summer than during monsoon not much variation in the composition was observed between the sewage water at the upstream and the down stream (Trivedi and Singh, 1991).

Samples from major wastewater streams and sewage effluent at the main sewage treatment plant at Amberpet, Hyderabad, Secunderabad were evaluated for environmentally compatible irrigation use. The results indicated that the values of dissolved salts were higher than those in the well waters. The concentration of BOD, COD, oil and grease content were high in the industrial town. The range of different constituents are as follows: pH 6.9 to 8.10, EC 1.3 to 3.8 dS m⁻¹, BOD 50 to 1000 mg L⁻¹, COD 50 to 2400 mg L⁻¹, total N 25 to 260 mg L⁻¹, total P 1 to 15 mg L⁻¹, Ca 3.9 to 13.8 me L⁻¹, Mg 3.4 to 7.2 me L⁻¹, Na 6.3 to 35 me L⁻¹, K 15.2 to 53.0 me L⁻¹, Cl 3.6 to 12.3 me L⁻¹ and SO₄ 1.9 to 3.6 me L⁻¹ (Kale *et al.*, 1992).

Assessment of sewage effluents from eight discharge points of Calcutta at different seasons revealed that the composition of the sewage varied widely among the different discharge points and the constituents were present in larger proportion at the discharge point which received industrial effluent. The concentration was more during winter than monsoon season (Adhikari *et al.*, 1994). The quality of sewage effluent discharged from Howrah sewage treatment plant of Calcutta was assessed in order to utilize it for irrigation for two seasons (monsoon and summer). Although raw sewage in both the season was toxic in respect of salinity, sodicity, BOD, COD and heavy metals, its biological treatment decreased the toxicity hazard considerably making it worth using for irrigation (Som *et al.*, 1994).

Analysis of sewage of Aligarh city by Bansal (1998) revealed the following composition pH 7.3, EC 10.2 dS m⁻¹, BOD 298.3 mg L⁻¹, COD 550.2 mg L⁻¹, Cl 236.2 mg L⁻¹, total CO₃ 8.0 mg L⁻¹, total HCO₃ 176.0 mg L⁻¹, Na 17.0

mg L⁻¹, K 11.0 mg L⁻¹, Fe 2.1 ppm, Mn 2.80 ppm, Zn 0.82 ppm, Cu 0.32 ppm, Pb 0.29 ppm, Ni 0.17 ppm, Co 0.13 ppm, Cr 0.49 ppm, Cd 0.11 ppm.

Analysis of sewage water of Dharwad for a period of three months by Salakinkop (1998) had the following composition pH 7.49 to 7.65, EC 0.75 to 0.79 dS m⁻¹, total solids 698 to 721 mg L⁻¹, total soluble solids 558 to 593 mg L⁻¹, total suspended solids 105 - 163 mg L⁻¹, BOD₍₅₎ 136 to 148 mg L⁻¹, COD 275 to 295 mg L⁻¹, chloride 142 to 145 mg L⁻¹, total N - 12.5 to 26.30 mg L⁻¹, total P 11.95 to 17.30 mg L⁻¹, Ca 53.50 to 89.20 mg L⁻¹, Mg 24 to 29.50 mg L⁻¹, Na 21.20 to 26.0 mg L⁻¹, Zn 0.27 to 0.38 ppm, Fe 1.15 - 1.34 ppm, Mn 0.14 to 0.16 ppm, Cr 0.014 to 0.015 ppm.

2.2 INFLUENCE OF SEWAGE WATER IRRIGATION ON PHYSICAL PROPERTIES OF SOIL

Effect of sewage water irrigation on physical properties of soil is mainly due to the presence of suspended particles and high concentration of sodium.

Jones and Taylor (1965) observed the clogging of top 4 cm depth of soil after spreading the sewage effluent on sand. Clogging was faster under continuous irrigation than the intermittent irrigation. Decomposition of sewage in the sewage irrigated soil resulted in oxygen deficit which in turn caused reduction of Fe³⁺ to Fe²⁺. This displaced Fe accumulated in the lower horizons which forms an impermeable layer inhibiting water percolation into the drains (Backo, 1965).

Laboratory and field Lysimeter study conducted by Thomas *et al.* (1966) on Ottawa sand and revealed that the infiltration rate reduction

exhibited three phases like slow reduction under aerobic conditions, rapid reduction under anaerobic conditions and further gradual decline under anaerobic conditions. The possible cause for the reduction in infiltration was due to the presence of sulfide, iron phosphate, total organic matter, polysaccharide and polyuronide.

The results of five years of experiments on the use of sewage to irrigate sod-podzolic sandy loam soils of Western Meshchera lowland resulted in the improved soil structure due to the presence of calcium salts and organic matter in sewage water which promote the coagulation of soil micro aggregates (Dodolina, 1971).

Day *et al.* (1972) reported no change in the bulk density of soil due to continuous application of sewage for 14 years at Arizona (USA). Sewage water application results in decreased bulk density and increased maximum water holding capacity of soil (Nagaraja, 1981; Pradeep, 1993 and Salakinkop, 1998).

Effect of wastewater from cattle feed yard on infiltration of Randall clay and a highly permeable soil was studied by Lehman and Clark (1975) and their study revealed that infiltration rate reduced from initial of 0.1cm/hour to less than 0.006 cm/hour after two to three weeks of irrigation. They also reported that sealing of the soil occurs at the surface and the normal infiltration can be restored by removing the surface 2 cm of soil and applying clear water.

Application of sewage sludge at different rates to Woodstown silt loam resulted in increased soil moisture content upto 20 per cent and soil moisture retention by 18.5 per cent (Epstein *et al.*, 1976).

Studies on the effect of paper factory effluent on water holding capacity, pore space and aggregate stability of red and black soils of Tamil Nadu revealed increased water holding capacity, pore space and aggregate stability per cent of black soil and decreased water holding capacity of red soil. While pore space and aggregate stability per cent increased in red soil (Rajannan and Oblisami, 1979).

There was higher per cent of clay and silt in soils irrigated with sewage water than soils irrigated with good quality water (Azad *et al.*, 1987 and Narwal *et al.*, 1995).

The effect of wastewater irrigation on hydraulic properties of a highly volcanic ash soil was studied by Cook *et al.* (1994) by ponding wastewater for a period of 32 weeks to a soil monolith. They observed decreased infiltration rate by 50 per cent from 8.3×10^{-5} to $4.1 \times 10^{-5} \text{ m s}^{-1}$ after 32 months of wastewater irrigation due to clogging of soil pores.

Clanton and Slack (1987) have studied the hydraulic properties of three soils of Minnesota Agricultural Experimental Station (USA). The results indicated that application of wastewater for a period of 40 weeks to Lester clay loam, Walegan silt loam and loamy sand resulted in decreased hydraulic conductivity of the above three soils, while in case of loamy sand immediate seal was formed due to application of wastewater.

A method of labelling of suspended solids in sewage effluent to trace the distribution of deposit of solids in three soils (a sand, a sandy loam and a loessial silt loam) of Israel was studied by Vinten *et al.* (1983). The

results indicated that in silt loam, accumulation of solids was more at the soil surface and thus caused greatest reduction in the relative hydraulic conductivity, while in sand and sandy loam, little deposition of solids occurred.

The effect of salt - surfactants of domestic wastewater on the saturated hydraulic conductivity of a loam and a sandy loam soil under high sodium low - salt condition in the presence of non-ionic and ionic surfactants was studied by Abu-Zreig *et al.* (1996). An anionic surfactant under high sodium low-salt conditions resulted in slightly higher value of saturated hydraulic conductivity of loam soil than that in the absence of surfactants. For sandy soil there was significant increase in the saturated hydraulic conductivity.

Mageson *et al.* (1999) reported that blocking of soil pores by microbial growth and extracellular carbohydrate production was the possible cause for the reduction in the hydraulic conductivity of a sandy soil of Hamilton (New Zealand).

2.3 INFLUENCE OF SEWAGE WATER IRRIGATION ON SOIL CHEMICAL PROPERTIES

Effect of sewage water irrigation on soil chemical properties depends on the nature and composition of sewage, application rate, soil type and the vegetation cover.

2.3.1 Effect on soil pH

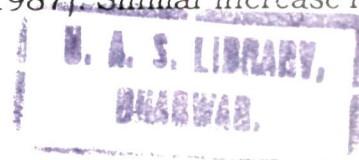
The pH of the soil and the pH of wastewater is modified by the chemical reactions in the soil. Wastewater containing organic acids may show an increase in pH as it moves through the soil because of biodegradation

of the acids. Ramati and Mor (1966) have reported a decrease in pH of soil while Marenkin *et al.* (1969) reported increased pH of sandy soils due to prolonged irrigation. Increase in pH of the soil was noticed in the soils having pH lesser than the wastewater while decrease in soil pH is due to the addition of organic acids by sewage application. Dodolina (1971) noticed increase in the pH of the soil from 4.4 to 5.0 of sod-podzolic soil of Russia after irrigating with sewage water for a period of five years. Effect of paper factory effluent which was alkaline in reactions on pH of red and black soil of Tamil Nadu was studied by Rajannan and Oblisami (1979). They reported increased pH of both the soil with application of undiluted paper factory effluent, but dilution of paper factory effluent to 25 per cent did not produce any marked difference in the soil pH.

Elliott and Singer (1988) have reported on increase in soil pH from 5.3 to 8.0 with the addition of sewage to soil at rates 2 - 10 per cent. King and Morris (1972) reported decrease in the pH of Cecil sandy clay loam of Athens from 5.2 to 4.2 in the 0 - 15 cm soil layer with the application of liquid sewage sludge. This decrease in soil pH was attributed to the nitrification of some of the applied $\text{NH}_4^+\text{-N}$ and organic N and probably from oxidation of sulphides. Similar decrease in pH with sewage application was noticed by Epstein *et al.* (1976) ; Day *et al.* (1979) and Baddesha *et al.* (1997).

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Depthwise analysis of soil samples being irrigated with sewage water around Budha Nullah (Ludhiana) indicated that pH of the soil increases with increase in soil depth (Azad *et al.*, 1987). Similar increase in



pH of soil with depth was noticed in the soils irrigated with sewage water at Calcutta by Adhikari *et al.* (1994).

Analysis of the soil samples at 0.5 km interval from the Hakmwala sewage drain (Amritsar) for soil pH indicated that the soil pH decreases as the distance from the sewage drain increases (Hundal and Sandhu, 1990).

2.3.2 Effect on electrical conductivity (EC) of soil

Dodolina (1971) analysed the soil samples to a depth of one metre at 20 cm intervals of sod-podzolic soil of Russia to study the possible accumulation of water soluble salts in the soil. The results indicated that the sewage irrigated block had a slightly higher content of water soluble salts. The accumulation of salts was confined to the top horizons (0-10 cm and 20 to 40 cm). The seasonal dynamics of the salts revealed that the amount of salts increased in the fall from 0.062 per cent in case of control to 0.063 per cent with domestic wastes, but decreased during the spring season.

Increased electrical conductivity of soil due to sewage application was reported by Wallingford *et al.* (1975); Epstein *et al.* (1976) and Mancino and Pepper, (1992). Effect of sewage water irrigation on EC depends on the rate of application and leaching percentage. High rate of application with high leaching percentage (>34%) reduced the original salinity (EC) of 3.99 to less than 1.39 dS m⁻¹ during the two year of crop season at Alberta, Canada. Reduction of application rate with the same leaching percentage increased the salinity, but salt levels were below those that would significantly reduce crop yield (Bole *et al.*, 1981).

An eight year study on effect of wastewater irrigation on orthic regosol series, calcareous series, orthic brown series and cumulic orthic brown series of Saskatchewan (Canada) by Jame *et al.* (1984) revealed that irrigation by 10-15 per cent more than the normal recommended application rate will ensure sufficient leaching to maintain salt content in the root zone at a level not deleterious to plant growth. A new steady state salinity profiles were developed in the orthic regosol, calcareous brown and orthic brown series after eight years of effluent irrigation. An increase in the EC_e value from initial of 0.6 dS m^{-1} to 2.5 dS m^{-1} and an increase in the salinity with depth was observed.

Azad *et al.* (1987) reported that electrical conductivity decreased with depth with the sewage irrigation. Similar observation was made by Adhikari *et al.* (1994). Hundal and Sandhu (1990) reported that electrical conductivity decreases as the distance from the sewage drain increases.

2.3.3 Effect on exchangeable cations and cation exchange capacity (CEC)

A two year study on the use of liquid sewage sludge to Cecil clay loam of Athens revealed that sewage application resulted in the increased sodium concentration but reduces the dilute acid-extractable K, Ca and Mg. The content of sodium increased with an increase in depth and rates of application (King and Morris, 1973).

Wallingford *et al.* (1975) reported that application of different rates of beef-feed lot waste to silty clay loam of Pratt (Minnesota) resulted in the leaching of sodium to lower depths. While potassium accumulated in the upper 30cm, magnitude were greatest in the higher application treatments.

Sawhney and Hill (1975) noticed increased CEC of the acid soil of Connecticut due to increased pH of the soil due to wastewater irrigation.

Application of different rates of sewage sludge application to Woodstown silt loam of Beltsville (USA) resulted in increased level of exchangeable cations, per cent carbon and cation exchange capacity (CEC). CEC increased to nearly three fold (Epstein *et al.* 1976).

In an attempt to know the movement of major ions when sewage effluent was treated, DeJong (1978) conducted a column study at Saskatchewan (Canada). Leaching the sewage effluent through the columns of the A, B and C horizons of a loamy sand and the A horizon of a clay revealed that neither temperature (7, 13 or 18°C) nor method of application (flood or trickle irrigation) affected the passage of Na, Ca, Mg, Cl and SO₄. Anions occurred much earlier in the leachates, also there was increased level of water soluble and exchangeable cations of the different horizons studied.

Jayaramani and Perumal (1984) reported that irrigating the soils of Coimbatore with municipal sewage effluent over a period of 25 years and 15 years found to accumulate higher amount of organic matter and higher concentration cations like calcium, magnesium, sodium and potassium. The concentration of exchangeable cations decreased with an increase in depth in both sewage irrigated and sewage unirrigated fields. Twenty five years and 15 years sewage irrigation recorded higher values of cation exchange capacity by 35.3 and 22.9 per cent respectively over farmers' field without sewage irrigation due to increased organic matter content.

The effect of wastewater having different SAR on soils of loamy sand, sandy loam, sandy clay loam and loam texture was studied by Juwarkar *et al.* (1987) at Akola. The result indicated that equilibrating soils with wastewater having different SAR of 6.6 and 5.3 did not attain the ESP limit of alkali soil, however all the soil samples equilibrated with SAR 18.8 and 11.1 of wastewater resulted in crossing of ESP limit of alkali soil. They also observed highly significant positive correlation with the SAR of the wastewater and resultant ESP of soil.

Azad *et al.* (1987) reported increased organic matter content in the soil profiles irrigated with sewage water than normal soil profile. The organic matter content decreased with depth. Similar observation was made by Adhikari *et al.* (1994).

A column study conducted by Menon and Bhattacharya (1988) to know the movement and accumulation of exchangeable Ca and Mg on soil of Delhi revealed that the calcium and mangesium concentration increased appreciably on sewage application. Elevated levels of magnesium was found in the surface layers while calcium was concentrated at the bottom 45-60 cm layer. Organic matter content of the soil decreased with an increase in the distance from the sewage drain (Hundal and Sandhu, 1990).

2.4 NUTRIENT AVAILABILITY

2.4.1 Nitrogen

Nitrogen is an essential nutrient element for living organisms, it is usually added in large quantities to agricultural lands to obtain high crop yields. Irrigation with sewage effluent results in the addition of

considerable amounts of N to the soil, depending on the content of N in the effluent and the volume of water applied.

The nitrogen content of liquid waste may be as low as essentially zero for some cannery wastes and as high as 700 mg L⁻¹ for slurries of fresh swine waste and the average being 20-40 mg L⁻¹ in the sewage effluent (Bouwer and Chaney, 1974).

When sewage effluent is applied in small amount, the soil is predominantly aerobic and the nitrogen in effluent which is mostly in the ammonical form will be converted to nitrate. The fate of this nitrogen is about 50 per cent will be used by the plants, 25 per cent will be lost by denitrification, such as ammonia volatilization (Woldendorp, 1963). The quantities of N added to soils through effluent irrigation can be similar to or even exceed those applied by standard fertilization during similar periods of time (Feigin *et al.*, 1978 and 1979).

Higher amounts of nitrogen can be added to soil by sewage sludge application (King and Morris, 1972b ; Kelling *et al.*, 1977 ; Epstein *et al.*, 1978 ; Stark and Clapp, 1980 and Maiti *et al.*, 1992). Most of the nitrogen will be ammoniacal form, it will be usually converted to nitrate. Temperature, application rate and time are the factors influencing conversion of ammonium to nitrate (Cassman and Munns, 1980 ; Magdoff and Amadon, 1980 ; Terry *et al.*, 1981 ; Lindeman and Cardenas, 1984 ; Chae and Tabatabai, 1986 ; Soni and Singh, 1994 and Soni *et al.*, 1994).

The major problem on the use of sewage effluent and sewage sludge is the ground water pollution with nitrate increase in the nitrate

concentration with depth and rates of application was noticed by King and Morris (1972b) ; Ryan *et al.* (1973) ; King *et al.* (1977) ; Kelling *et al.* (1977) and Schalscha *et al.* (1979).

Volatilization of ammoniacal nitrogen from newly applied anaerobically digested sewage sludge was about 60 per cent for five day experimental period and about 56 per cent for seven day period (Beauchamp *et al.*, 1978). Losses due to denitrification was upto 98 per cent when sewage effluent was intermittently flooded to the soil (Whisler *et al.*, 1974).

Analysis of soil samples from the fields around the sewage canal indicated that the available nitrogen status was more as compared to normal soil and it decreased with depth (Azad *et al.*, 1987).

Adhikari *et al.* (1994) have analysed the soil samples along the dry weather flow channel of Calcutta sewage and they found the available nitrogen status of the five sites tested remained high and it decreased with depth.

Irrigation with sewage water for 18 months to eucalyptus field significantly increased, available nitrogen content of a silt loam soil of Central Soil Salinity Research Institute (CSSRI), Karnal. The increase in available N varied according to the frequency of sewage water applied (Baddesha *et al.*, 1997).

2.4.2 Phosphorus

Phosphorus is an essential nutrient element for all crops and is applied in large quantities to obtain enhanced crop yield. Sewage water

contains appreciable amount of phosphorus, making it an important source of P for irrigated soils. The amount of P added to soil through sewage effluent irrigation is usually not high. However, higher loads of P are sometimes added, when the soil has been used for disposal purposes. Excess levels of available P may result in nutrient imbalances, such as Cu, Fe and Zn deficiencies (Ryden and Pratt, 1980).

The phosphate content of effluent values vary (0.5 to 40 mg of P per litre) (Feigin *et al.*, 1991).

Two year study on the use of liquid sewage sludge to Cecil clay loam of Georgia resulted in the significant increase in the dilute acid - extractable P in 0-15 cm layer (King and Morris 1973).

Sawhney and Hill (1975) reported that the phosphate sorption capacities of several Connecticut soils having different physical and chemical characteristics varied over a four fold range with wastewater irrigation.

Irrigating the soils varying in texture for a period of nine to 11 years with sewage significantly increased P content of the soil. The corn field site on Hublersburg clay loam had an average P concentration of 0.32, 0.070 and 0.046 mg/litre in soil water at 15, 60 and 120 cm depths, respectively under an adjacent fertilized, but unirrigated control (Kardos and Hook, 1976).

A sewage farm near Tilburg in Netherlands which has been irrigated with sewage water for a period of 50 years significantly increased the phosphate content of top 50 cm layer of soil. No significant difference

was observed for soil layers below 70 - 80cm. Most of the accumulated phosphate was mainly in inorganic phosphate form (80 to 85%), particularly of aluminium bound phosphates (Beek *et al.*, 1977a and 1977b).

Kelling *et al.* (1977) reported that application of different rates of sewage sludge to Plano silt loam resulted in the immediate marked increase in Bray-P. However, the extractable P levels decreased with time after sludge application, probably as a result of P fixation. Significant amounts of P remained available for at least 2 years at higher rate of treatments.

Irrigation of Hublersburg silty clay loam and Morrison sandy loam with secondary effluent for 11 to 12 years indicated that the majority of the phosphorus added to soils during wastewater irrigation remained in the upper 30cm of the Hublersburg clay loam soil. In contrast, appreciable amounts of P leached to 30 to 60cm depth in the Morrison sandy loam. The equilibrium phosphate concentration increased markedly at the 0-15cm depth as a result of wastewater irrigation, due to sorption of P added through the wastewater (Sommers *et al.*, 1979).

Increased concentration of phosphates with sewage water application in the surface layers was reported by Day *et al.* (1972); Enfield and Bledsoe (1975); Iskander and Syers (1980); Latterell *et al.* (1982); King (1982); Nagpal (1986); Azad *et al.* (1987); Maiti *et al.* (1992); Adhikari *et al.* (1994); Baddesha *et al.* (1997) and Salakinkop (1998).

2.4.3 Potassium

Potassium is an essential nutrient element for plants and it is taken up by crop in large quantities, similar to or even greater than those

for N. Content of potassium in effluent varies widely, typical concentration being 7-20 mg L⁻¹ (Feigin *et al.*, 1991).

King and Morris (1973) reported that application of different rates of liquid sewage sludge to Cecil clay loam resulted in the decreased exchangeable potassium in the surface with sludge application rate. However, at 30-45cm depth there was no significant difference between the treatments.

Lysimeter study conducted at Hanover (USA) on the use of domestic sewage water for a period of five years on two types soil revealed that the concentration of K in the soil solution remained low and it decreased with time. This was due to the low K/N ratio in the wastewater applied (Palazzo and Jenkins, 1979).

Experiments on the use of untreated wastewater and treated wastewater application on Cecil clay for a period of four years resulted in increased concentration of available potassium in the soil. It was more in untreated water fields than treated water fields (King, 1982).

Arora *et al.* (1985) reported elevated levels of total potassium in sewage irrigated fields than normal fields. The total potassium increased with depth in both the soils.

Maiti *et al.* (1992) studied the nutrient status of sewage irrigated upland and lowlands soils of Calcutta. The result indicated that the available potassium content of these soils was medium to high levels. Potassium content of lowland was more than upland in the surface layer.

Analysis of soils from five sites along the sewage drain of Calcutta by Adhikari *et al.* (1994) revealed that the available potassium content of these sites were high and it decreased with depth.

Arora and Brar (1995) reported higher content of available potassium in sewage irrigated fields than sewage unirigated fields of Ludhiana, Malerkotla and Samrala.

Irrigation with sewage water for 18 months to eucalyptus field significantly increased the available potassium content of silt loam of CSSRI, Karnal (Baddesha, *et al.*, 1997).

2.4.4 Micronutrients

Micronutrients are essential for plant growth and development since they participate in many of the biochemical processes. They are usually present in low concentration in wastewaters unless contaminated by industrial wastes. Application of these micronutrients by sewage water can help in overcoming deficiencies of these nutrients.

King and Morris (1972a) reported application of different rates of liquid sewage sludge to Cecil sandy clay loam increased exchangeable and water soluble Mn and exchangeable Zn in the soil.

Soil sample analysis for $\text{HNO}_3 + \text{HClO}_4$ extractable Cu, Fe, Mn and Zn in soils along the sewage drain was found to have higher concentration of Cu, Fe, Mn and Zn in soils irrigated with sewage water than fields irrigated with borewell water (Hundal and Sandhu, 1990).

Azad *et al.* (1987) reported increased levels of total and DTPA extractable Mn in soils irrigated with sewage water than soil irrigated with bore well water both total and DTPA extractable Mn content decreased with depth. The accumulation of total Mn was associated with soil organic matter, clay and silt content of soils Arora and Chhibba (1992) observed lesser incidence of micronutrient and sulphur deficiencies in sewage irrigated soils.

Profile study conducted by Bansal *et. al.* (1992) on the accumulation and bio-availability of micronutrients revealed that these nutrients largely accumulated in the top 15cm layer and decreased with depth. The amount accumulated depends on the period of use. The bioavailability depends on the levels of interacting metal ions. It was found that Mn was deficient in fields where large amounts of Zn and Fe accumulated.

Arora and Brar (1995) reported increased content of micronutrient on soils irrigated with sewage water than soils without sewage irrigation.

Baddesha *et al.* (1997) noticed significant increase in the available micronutrient content of the eucalyptus field irrigated for 18 months. Bansal (1998) reported increased levels of micronutrients in soils irrigated with Aligarh city sewage water.

2.5 HEAVY METAL DISTRIBUTION IN SOIL

The sources for heavy metals in soil are many which include industrial, Urban or agricultural wastes sludge, sewage effluent industrial effluent and gases emitted by vehicles and industries.

Heavy metals occur naturally in soil from geologic origin, but mainly in forms that are not available to living organisms. Higher quantities like industrial activity, disposed of domestic and waste materials.

Ross (1994) listed five major anthropogenic sources of toxic metals in the environment, such as metalliferous mining and smelting, industrial products and wastes atmospheric deposition, agriculture and waste disposed on land.

Typical concentration of heavy metals in soils amended by sewage sludge are given by Alloway (1990) and Fergusson (1990): Cr 8–40,000, Mn 60–3900, Ni 6–53000, Cu 50–8000, Zn 91–49,000, Cd less than 1–3410 and Pb 2–7000 mg kg⁻¹ dry soil.

Irrigation of agricultural lands with sewage effluents is identified as a major source of heavy metals in suburban soils of India (Azad *et al.*, 1986; Sakal *et al.*, 1992; Som *et al.*, 1994; Singh and Singh, 1994; Jeyabaskaran and Sreeramulu, 1996 and Jayalakshmi and Hegde, 1997). Soil contamination with heavy metals from sewage sludge application can be controlled to a larger extent by the quality of sludge, that is whether the sludge is rich in metals or not (Jing and Logan, 1992).

Though the concentration of trace elements in sewage water is low, elevated levels in soil may be due to long term application (Adhikari *et al.*, 1994 and Arora and Brar 1995).

Maximum tolerable levels of trace elements in agricultural soils proposed for various countries are : Cd 1.6 to 3, Cr 100 to 120, Cu 80 to 140,

Ni 48 to 75, Pb 90 to 300 and Zn 150 to 300 mg kg⁻¹ soil (Kolke, 1982 and Page *et al.*, 1988).

A vertisol irrigated for over five decades with an untreated municipal wastewater had elevated levels of DTPA extractable Cd, Co, Cu, Mn, Ni and Zn in the cultivated layer of the soil as compared to lower layers. Total Co, Ni and Zn were uniformly distributed in the 150 cm depth of the soil profile, total Cu increased with depth (Schirado *et al.*, 1986).

Aboulroos *et al.* (1989) reported that soils near Cairo, Egypt, which received sewage effluent for periods upto 60 years increased content of total Fe, Mn, Zn, Cu, Pb, Cd, Ni and Co in the soils. The content of these metals increased with time and Fe and Co applied to soil from sewage effluent were mostly immobilised mainly to unavailable forms. Lead, Cd and Ni were present in moderately available form and Mn, Zn and Cu in a highly available form.

Irrigation with polluted water leads to increase in heavy metal concentration in soil (Giordano and Mortvedt, 1976). Soils at an inlet of polluted water used for irrigation showed upto 5.8 ppm Cd in top soil, but Cd content gradually decreased to about one ppm with increase in distance from inlet point (Hsieh, 1990).

A green house study on the use of nickel enriched sewage water on corn for a period of eight years revealed that the concentrations of Ni, Mn and Fe increased and of Zn decreased with increasing levels of Ni in soils (Narwal *et al.*, 1991).

The fate of heavy metals in soils with slow rate of application was studied by Yediler *et al.* (1994) by analysing soil sample from form different depths (0-100 cm). The results indicated that these metals decreased with depth. Copper, Pb and Zn were considerably more mobile (50-80%) than either Cd or Hg in the soil profiles.

Jeyabaskaran and Sreeramulu (1996) have studied the vertical and horizontal distribution of DTPA extractable metals due to continuous application of sewage in soils of sewage farms at Avaniyapurnam, Sakkimangalam and Ukkadam. The study indicated that the DTPA extractable Fe, Cu, Mn, Zn, Co, Cd, Cr, Pb and Ni accumulated more in the surface soil and decreased with increasing soil depth and distance from the sewage entry point. Vertical movement was more in light textured soils of Avaniyapuram and Sakkamangalam than in heavy textured soils of Ukkadam.

Singh and Saha (1997) and Singh (1998) reported the results of All India Co-ordinated Research project on Pollutant Elements in Soils and Plants as high to excessive content of DTPA extractable heavy metals in soil the metal concentration range being Zn 0.8 to 119.6, Cu 1.18 to 70.2, Fe 28.8 to 470.8, Mn 56.6 to 59.3, Pb 4.2 to 60.0, Cr 2.1 to 9.16, Ni 0.88 to 6.78 and Cd 0.04 to 0.96 mg Kg⁻¹ soil. Ibrahim *et al.* (1992) and Bansal (1998) reported increased levels of DTPA extractable heavy metals in soils irrigated with sewage water.

2.6 GROUND WATER CONTAMINATION

Ground water pollution is a major concern under modern intensive agriculture. Water flowing below the root zone of crops carries various contaminants to the Vadose zone and eventually further to aquifers. An understanding of the transport of nutrients in the soil is important for a good irrigation and fertilizer management, particularly when using sewage effluents. Ground water depth is an important parameter in assessing the agronomic suitability of sewage irrigation. The upper layer of the water table will be more polluted than the deeper layers.

In a recent report by Council for Agricultural Science and Technology (1985) it was suggested that NO_3 and bacterial contamination can be avoided by drilling wells deeper.

Bole *et al.* (1981) reported that ground water pollution with sewage water depends on the leaching percentage. Low leaching percentage (<10%) resulted in higher EC and SAR of ground water and high leaching percentage (>15%) in lower EC and SAR.

Water samples from 14 open wells and nine bore wells, located in the vicinity of sewage courses of Hubli were analysed for different parameters. High concentration of Cl, Na, Ca and total dissolved solids was noticed in the ground water (Hegde *et al.*, 1992).

Ground water samples analysis along the stream of zinc smelter's effluent at different distance both longitudinally and laterally indicated that zinc content was 7.2 ppm above the permissible limits for irrigation water (Totawat *et al.*, 1994).

Analysis of ground water in sewage irrigated areas of Calcutta by Adhikari *et al.* (1994) revealed that the EC of all the five points was of excellent quality for irrigation, except for chlorides (14.9-33.6 me L⁻¹).

MATERIAL AND METHODS

III. MATERIAL AND METHODS

An investigation on the characterisation of Hubli-Dharwad urban sewage and its impact on soil properties was conducted during October 1998 to September 1999 in Hubli and Dharwad cities. The details of the materials used and the methods employed are discussed in this chapter.

3.1 EXPERIMENTAL SITE

This investigation was carried out in and around Hubli-Dharwad cities which is the second largest urban area in Karnataka. They are situated at 15°N latitude and 75°E longitude at an altitude of 678 m above mean sea level.

3.2 CLIMATIC CONDITIONS

The climate of Hubli - Dharwad is semi-arid with an average annual rainfall of 800 mm. The rainfall pattern is biennial in nature with two peaks. Meteorological data for 1998-1999 and the average of 48 years recorded at meteorological observatory ARS, Dharwad farm are presented in Table 1 and depicted in Fig. 1.

3.3 EXPERIMENTAL DETAILS

The present investigation consisted of collection of water samples at monthly intervals at every one kilometer interval in the sewage drains of Hubli and Dharwad. Out of the four drainage divisions in Dharwad, Madihal drainage was selected for the study. Three profiles representing farmers' fields with sewage irrigation such as near the sewage outlet, 5 km and 10 km away from the sewage outlet and two profiles representing farmers'

Table 1 : Mean monthly meteorological data for the period of 1950-97 (48 years) and for the year 1998-99 as recorded in the meteorological observatory, Main Research Station, Dharwad

Months	Rainfall (mm)			Mean temperature °C						Mean RH (%)		
	Rainfall (mm)			Maximum			Minimum			Mean RH (%)		
	1998	1999	1950-97	1998	1999	1950-97	1998	1999	1950-97	1998	1999	1950-97
Jan.	-	0.00	0.11	-	29.4	29.13	-	12.4	14.11	-	75	62.88
Feb.	-	0.00	0.0	-	32.8	34.76	-	16.9	15.94	-	63	50.82
March	-	0.00	7.77	-	36.2	35.76	-	20.2	18.76	-	63	56.48
April	-	14.7	49.51	-	36.6	37.09	-	21.2	21.37	-	65	79.10
May	-	32.8	87.62	-	32.2	36.75	-	21.3	21.45	-	75	67.10
June	-	71.8	112.96	-	28.0	29.47	-	21.0	21.20	-	85	81.77
July	-	113.9	156.03	-	26.4	27.05	-	20.80	20.96	-	89	88.31
Aug.	-	19.7	102.37	-	27.1	27.10	-	20.40	20.64	-	85	86.83
Sept.	-	8.8	104.13	-	28.3	28.75	-	20.0	20.16	-	83	83.24
Oct.	98.1	-	136.62	28.6	-	30.17	20.1	-	19.22	93	-	76.26
Nov.	40.2	-	35.04	29.3	-	29.37	17.1	-	15.33	75	-	68.44
Dec.	0.00	-	6.08	28.6	-	19.17	14.0	-	13.41	72	-	64.69

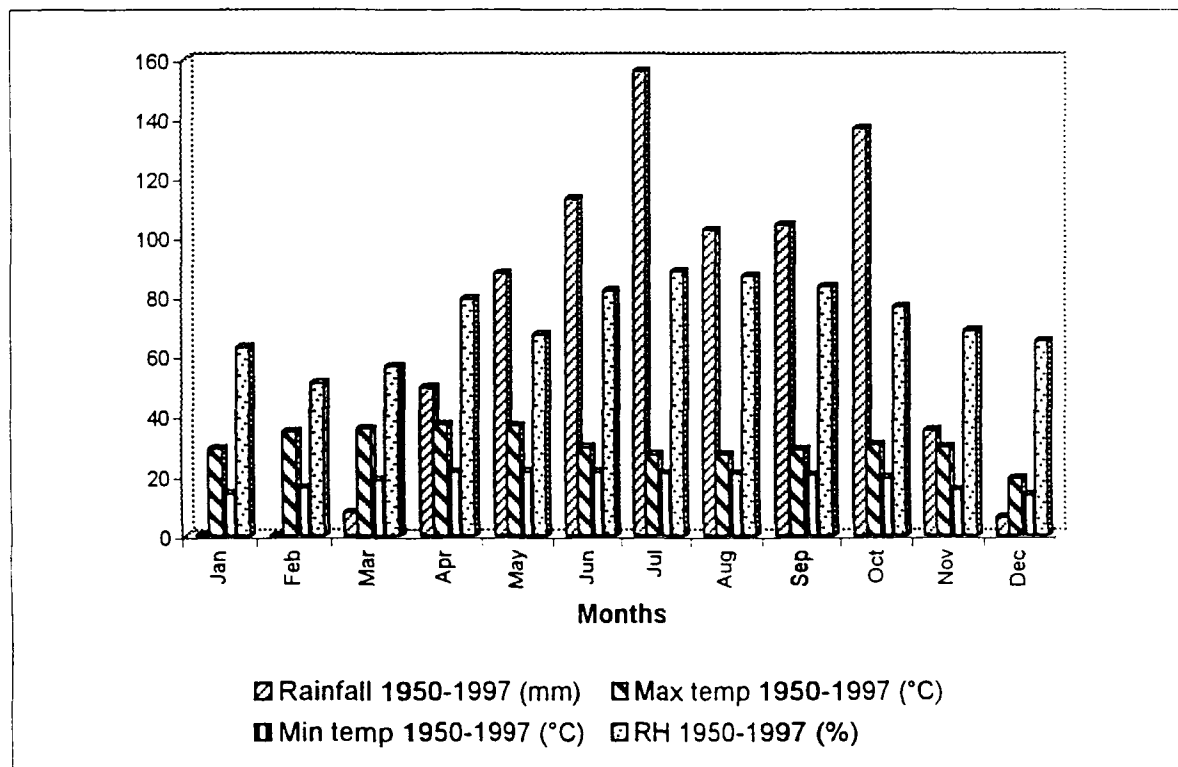
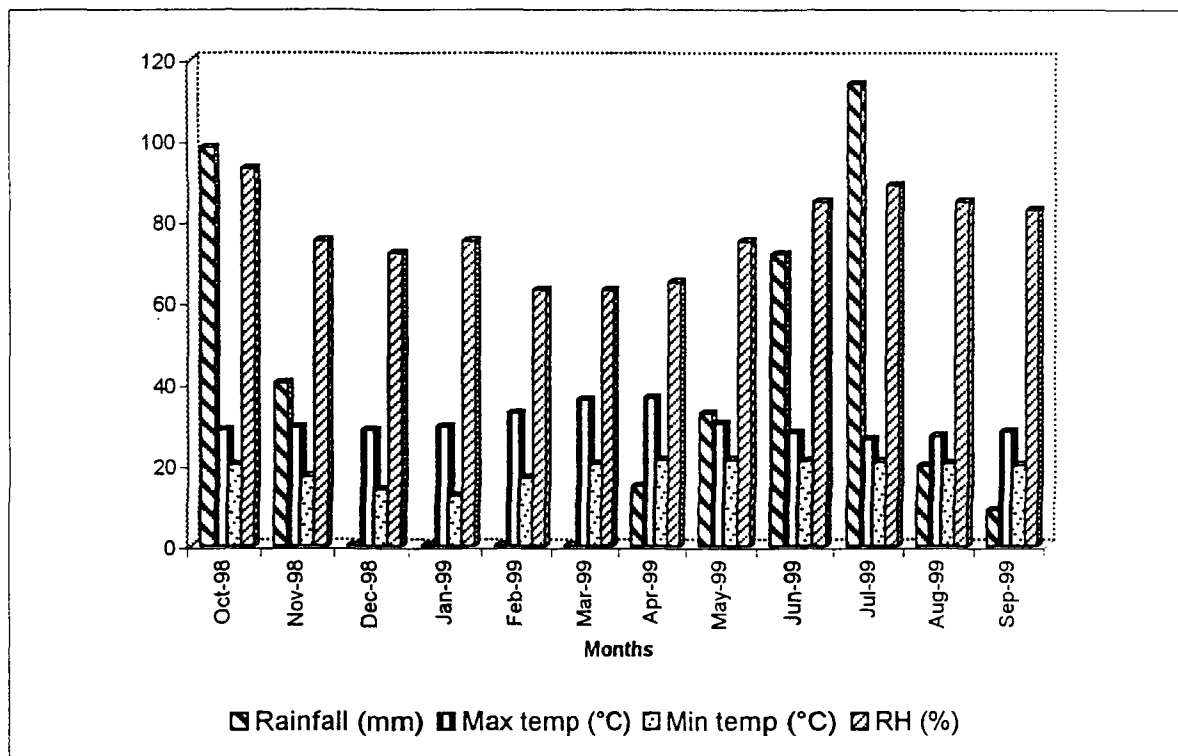


Fig. 1 : Monthly mean meteorological data for the period of 1950-1997 (48 years) and for the year 1998-1999 as recorded in the meteorological observatory, MRS, Dharwad

fields without sewage irrigation were taken for the study representing Hubli and Dharwad sewage irrigated areas. The location of this study have been presented in the Fig. 2 and 3. The samples thus collected were analysed for different parameters.

3.4 COLLECTION OF WATER SAMPLES

The water samples were collected in the polythene cans by employing the grab sampling method (American Public Health Association, 1975). The samples thus collected were taken to laboratory for further analysis. After bringing the samples they were refrigerated at 4°C immediately and analysed subsequently.

3.5 ANALYSIS OF WATER SAMPLES FOR VARIOUS PARAMETER

3.5.1 pH and electrical conductivity (EC)

The pH and EC of the waters were analysed immediately after bringing the samples using pH meter(model : systronics-331) and conductivity bridge (model: systronics-304) respectively as described by American Public Health Association, (1975).

3.5.2 Suspended solids

The suspended solids in the effluents were determined by filtration method. A known volume of sewage water was filtered through a previously weighed filter paper. The residue along with filter paper was oven dried at 108°C for three hours and the weight of oven dried residue with filter paper was recorded and the suspended solids was calculated and expressed as mg L⁻¹ (American Public Health Association, 1975).

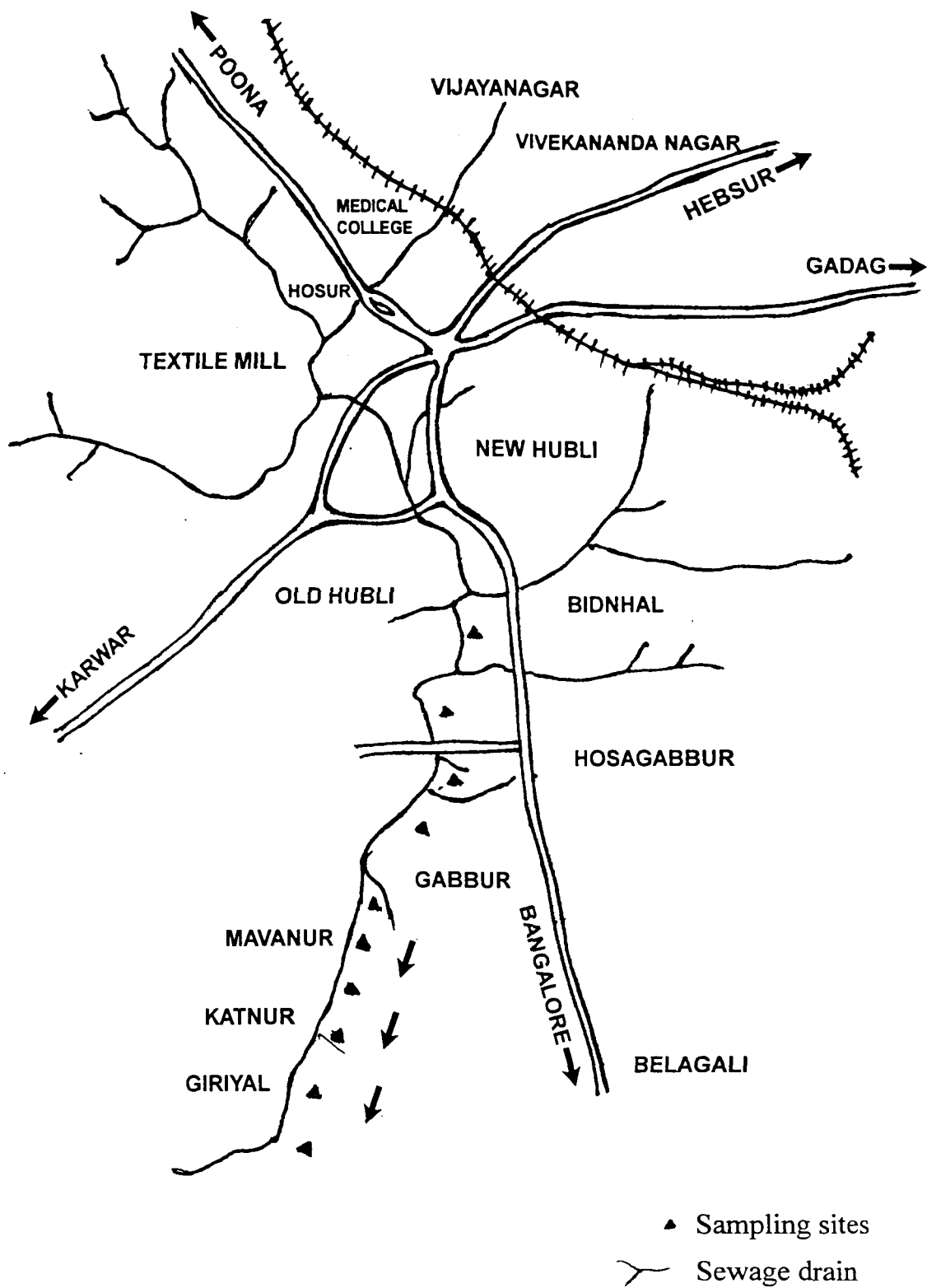


Fig. 2: Sampling sites at Hubli

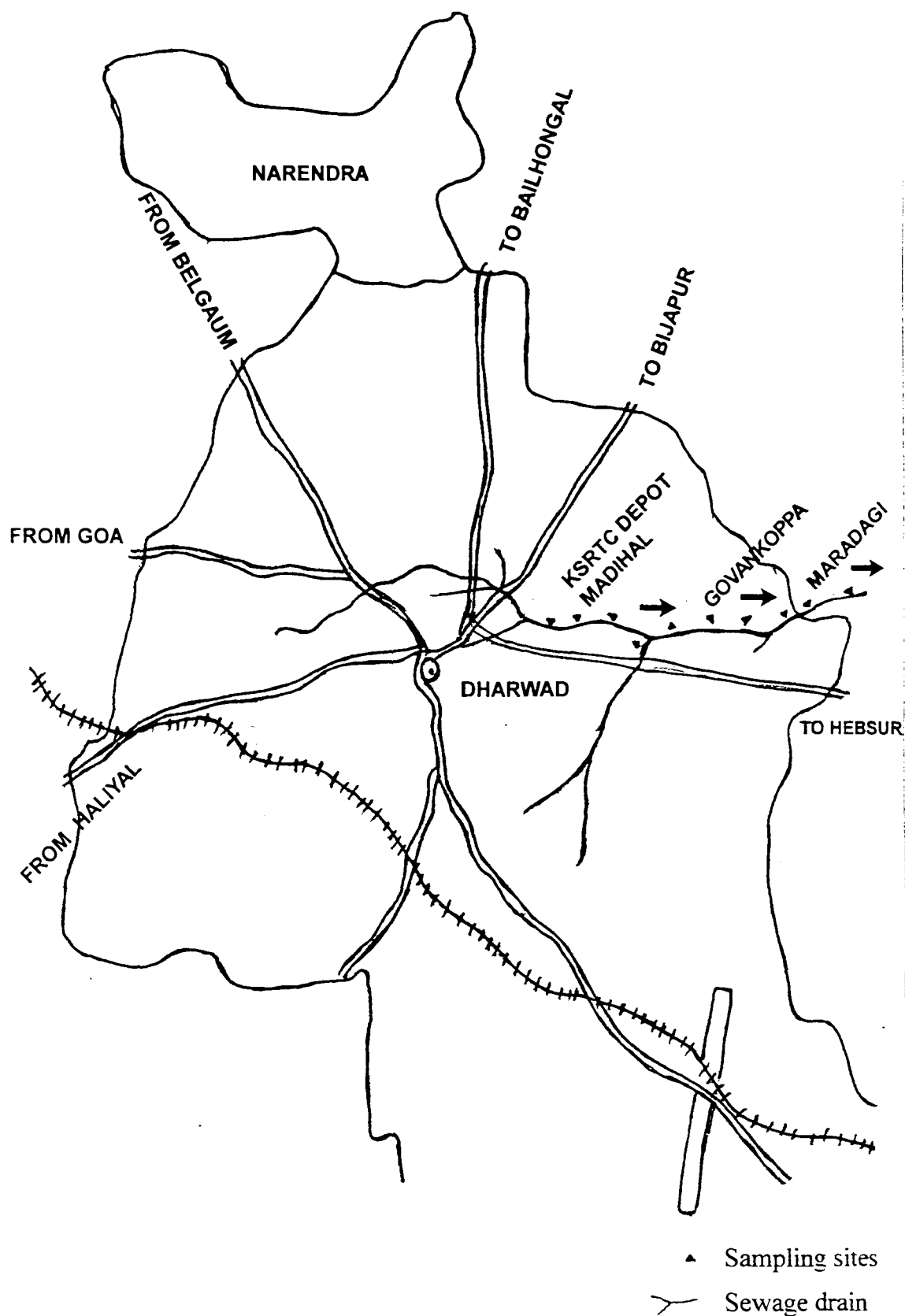


Fig. 3: Sampling sites at Dharwad

3.5.3 Biological oxygen demand (BOD)

The Biological Oxygen Demand (BOD) of effluents were determined by making suitable dilution of sewage water with standard dilution water which was prepared by aerating the distilled water. The dissolved oxygen of the samples before and after incubation at 20°C for five days were determined by titrating it against $\text{Na}_2\text{S}_2\text{O}_3$ using starch as indicator and the BOD of sewage water was calculated as described by American Public Health Association, (1975).

3.5.4 Carbonates and bicarbonates

Carbonates and bicarbonates were determined by titrating an aliquot of effluents against standard sulphuric acid using phenolphthalein and methyl orange as indicators (American Public Health Association, 1975).

3.5.5 Chlorides

Chlorides were estimated by titrating an aliquot of effluent against standard silver nitrate using potassium chromate as an indicator (American Public Health Association, 1975).

3.5.6 Sulphates

The sulphates in the effluents were determined by turbidometric method (American Public Health Association, 1975).

3.5.7 Phosphates

The phosphate in the effluents were determined by chloro stannous reduced blue colour method (American Public Health Association, 1975).

3.5.8 Sodium and potassium

Sodium and potassium in the effluents were determined by using the flame photometer (model : systronics FPM - 125) with suitable dilutions (American Public Health Association, 1975).

3.5.9 Calcium and magnesium

Calcium and magnesium were estimated by titrating an aliquot of effluent against standard Versanate using Eriochrome Black-T as an indicator. Calcium in the effluents were determined by taking a known aliquot and titrating against standard Versanate using murexide as an indicator and magnesium was calculated by deducting calcium from calcium plus magnesium (American Public Health Association, 1975).

3.5.10 Heavy metals and micronutrients

The heavy metals and micronutrient in the effluents were determined using atomic absorption spectrophotometer (model : GBC 932 AA) (American Public Health Association, 1975).

3.6 COLLECTION OF SOIL SAMPLES

The soil samples were collected in the farmers fields which have been irrigated by sewage water and also fields without sewage irrigation. The samples were collected depthwise such as 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm and 90-120 cm. The soil samples thus collected were air dried under shade and ground with wooden pestle and mortar and passed through 2 mm sieve. Soil samples were preserved in polyethylene bags for further analysis.

3.7 PHYSICAL PROPERTIES

The physical properties of soils were analysed by adopting standard procedures.

3.7.1 Infiltration rate

Infiltration rate was measured using double ring infiltrometer having a height of 30 cm for both the rings and diameter of 40 cm and 20 cm for the outer and inner rings respectively as described by Marshall and Strik (1950).

3.7.2 Bulk density

Bulk density was determined by core method as described by Black (1965).

3.7.3 Particle density

Particle density was determined by using pycnometer as described by (Gupta and Ghildyal, 1998).

3.7.4 Volume of expansion and maximum water holding capacity (MWHC)

Volume of expansion of soils were determined by using Keen Raczkowaski brass cup as described by Sankaram (1966).

3.8 CHEMICAL PROPERTIES

3.8.1 Soil reaction

Soil pH was determined in 1:2.5 soil-water suspension as described by Jackson (1967) using pH meter (model : Systronics - 331).

3.8.2 Electrical conductivity

Electrical conductivity of the soil was determined in the supernatant solutions of 1:2.5 soil to water suspension (Jackson, 1967) by using conductivity meter (model : Systronics - 304).

3.8.3 Organic carbon

The organic carbon content was determined by taking finely ground sample by Walkley and Black's wet oxidation method as described by Jackson (1967).

3.8.4 Cation exchange capacity (CEC)

The cation exchange capacity (CEC) of the soils were determining by sodium saturation method as described by Jackson (1967).

3.8.5 Exchangeable cations

Exchangeable cations were determined in neutral normal ammonium acetate leachate as described by Black (1965).

- a) Exchangeable sodium and potassium were determined in neutral normal ammonium acetate using flame photometer (model : Systronics FPM - 125).
- b) Exchangeable calcium + magnesium was determined by titrating a known aliquot of the extract against standard Versanate using Erichrome Black - T as an indicator, exchangeable calcium was determined by titrating a known aliquot of the extract against standard Versanate using murexide as an indicator and exchangeable Mg was calculated by deducting Ca from Ca+Mg.

3.8.6 Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR)

The ESP and SAR of the soils was calculated by using the following formulae

$$\text{ESP} = \frac{\text{Exchangeable Na}}{\text{CEC}} \times 100$$

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\text{Ca} + \text{Mg} / 2}}$$

3.8.7 Available nitrogen

Available nitrogen was estimated by alkaline potassium permanganate method (Subbaiah and Asija, 1956).

3.8.8 Available phosphorus

Available phosphorus was determined by extracting phosphorus with 0.5 M NaHCO_3 pH 8.5 (Olsen's method). The content of phosphorus extracted was determined by chlorostannous reduced molybdophosphoric blue colour method in HCl system using spectrophotometer at 660nm (Jackson, 1967).

3.8.9 Available potassium

Available potassium was extracted with neutral normal ammonium acetate and the contents of potassium in the solution was estimated by flame photometer (model : Systronics FPM - 125) (Jackson, 1967).

3.8.10 DTPA extractable micronutrients and Heavy metals

Micronutrients and heavy metals in the soil samples were extracted by using DTPA extractant and the content of Fe, Zn, Mn, Cu, Pb, Ni and Cd were measured by atomic absorption spectrophotometer (model : GBC 932 AA) (Lindsay and Norvell, 1978).

3.9 CORRELATION STUDIES

Correlation studies were made between organic carbon and other properties of the soil. The value of correlation co-efficient (r) were calculated and tested for their significance as per procedure outlined by Gomez and Gomez (1984).

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The results of the investigation “Characterisation of Hubli-Dharwad urban sewage and its impact on soil properties” conducted in and around Hubli-Dharwad during October 1998 to September 1999 are presented in this chapter.

4.1 CHARACTERISATION OF HUBLI-DHARWAD URBAN SEWAGE

4.1.1 pH

Irrespective of the seasons an increase in the pH of the sewage was noticed with an increase in the distance from the sewage outlet both in Hubli and Dharwad. The pH of the Hubli sewage was between 6.5 and 7.4, while that of Dharwad was between 6.6 and 7.7 (Table 2). Lowest monthly mean pH of 6.83 (Dharwad) and 6.68 (Hubli) was recorded during April, while highest monthly average of 7.40 was recorded during August '99 in Dharwad whereas Hubli sewage recorded highest monthly average of 7.13 during October '98. The lowest annual average pH of 6.78 and 6.82 was registered at one km from the sewage outlet of Hubli and Dharwad, respectively, while the highest was recorded at 10 km away from sewage outlet (7.16 and 7.42 for Hubli and Dharwad, respectively).

4.1.2 Electrical conductivity (EC)

Both Hubli and Dharwad sewage recorded higher electrical conductivity during summer months (March to May). The highest EC recorded was 2.20 and 1.90 dS m⁻¹ in Hubli and Dharwad, respectively, while the lowest EC registered was 1.20 and 0.81 dS m⁻¹ in Dharwad and Hubli, respectively. Further irrespective of the months the EC of the Hubli

Table 2 : pH of sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy				Mean	
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99		Oct-98
Hubli	1	6.70	6.80	6.75	6.70	6.55	6.50	6.60	6.90	7.05	7.00	6.90	6.90	6.78
	2	6.75	6.85	6.80	6.65	6.60	6.55	6.65	6.95	7.05	7.00	6.95	7.00	6.82
	3	6.80	6.85	6.80	6.70	6.65	6.55	6.70	6.95	7.10	7.05	6.95	6.95	6.84
	4	6.90	6.90	6.85	6.80	6.65	6.60	6.75	7.00	7.15	7.05	7.00	7.10	6.90
	5	6.95	6.95	6.90	6.85	6.70	6.70	6.75	7.05	7.20	7.10	7.10	7.10	6.94
	6	7.05	7.00	6.90	6.85	6.75	6.75	6.80	7.10	7.20	7.10	7.15	7.20	6.97
	7	7.10	7.05	7.00	6.96	6.80	6.75	6.85	7.10	7.25	7.15	7.15	7.25	7.03
	8	7.10	7.10	7.05	6.95	6.85	6.80	6.90	7.15	7.30	7.20	7.20	7.20	7.07
	9	7.15	7.20	7.10	7.00	6.90	6.80	6.70	7.20	7.30	7.20	7.25	7.30	7.12
	10	7.26	7.25	7.05	7.10	6.90	6.85	7.10	7.20	7.40	7.30	7.30	7.30	7.16
	Mean	6.97	7.00	6.92	6.86	6.74	6.68	6.81	7.06	7.20	7.12	7.10	7.13	
Dharwad	1	6.80	6.90	6.80	6.75	6.65	6.60	6.65	6.75	7.00	7.10	6.95	6.95	6.82
	2	6.95	6.95	6.85	6.80	6.80	6.70	6.75	6.80	7.05	7.15	7.05	7.05	6.91
	3	7.05	7.10	6.95	6.70	6.75	6.70	6.70	6.80	7.10	7.20	7.10	7.10	6.94
	4	7.60	7.50	7.30	7.10	6.85	6.80	6.80	7.30	7.40	7.50	7.40	7.50	7.25
	5	7.35	7.30	7.20	6.90	6.80	6.75	6.80	6.90	7.20	7.40	7.30	7.30	7.10
	6	7.50	7.35	7.20	6.90	6.90	6.80	6.85	7.10	7.25	7.45	7.35	7.35	7.17
	7	7.50	7.40	7.30	7.00	6.90	6.85	6.90	7.10	7.30	7.50	7.35	7.40	7.21
	8	7.60	7.50	7.35	7.05	6.90	6.90	7.05	7.30	7.40	7.50	7.40	7.50	7.29
	9	7.70	7.55	7.40	7.10	7.05	7.10	7.10	7.40	7.50	7.55	7.45	7.50	7.37
	10	7.60	7.50	7.45	7.20	7.10	7.10	7.20	7.50	7.60	7.65	7.50	7.60	7.42
	Mean	7.36	7.31	7.18	6.95	6.87	6.83	6.88	7.10	7.28	7.40	7.28	7.32	

Table 3 : Electrical conductivity (dS m^{-1}) of sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy				Mean	
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99		Oct-98
Hubli	1	1.65	1.76	1.80	1.90	2.00	2.10	2.20	1.41	1.25	1.31	1.36	1.52	1.69
	2	1.64	1.76	1.82	1.91	2.10	2.10	2.00	1.38	1.24	1.30	1.34	1.54	1.68
	3	1.66	1.74	1.86	1.89	1.90	2.00	1.96	1.42	1.31	1.32	1.40	1.56	1.67
	4	1.62	1.71	1.82	1.86	1.86	1.90	1.94	1.40	1.32	1.28	1.38	1.52	1.63
	5	1.58	1.68	1.78	1.85	1.88	1.89	1.93	1.38	1.28	1.26	1.36	1.50	1.61
	6	1.56	1.69	1.78	1.84	1.86	1.86	1.95	1.35	1.26	1.27	1.34	1.51	1.60
	7	1.58	1.68	1.76	1.82	1.85	1.85	1.91	1.37	1.29	1.25	1.32	1.48	1.60
	8	1.54	1.65	1.74	1.81	1.85	1.86	1.89	1.37	1.26	1.24	1.33	1.46	1.58
	9	1.52	1.66	1.72	1.79	1.86	1.86	1.90	1.35	1.24	1.22	1.30	1.42	1.57
	10	1.51	1.64	1.74	1.76	1.87	1.87	1.88	1.36	1.24	1.20	1.31	1.38	1.56
Dharwad	Mean	1.59	1.70	1.78	1.84	1.90	1.93	1.96	1.38	1.27	1.26	1.34	1.49	
	1	1.28	1.40	1.56	1.72	1.81	1.9	1.83	1.12	0.96	1.10	1.21	1.38	1.44
	2	1.26	1.41	1.52	1.68	1.79	1.87	1.81	1.14	0.97	1.09	1.17	1.32	1.42
	3	1.28	1.38	1.48	1.62	1.76	1.84	1.79	1.08	0.94	1.10	1.19	1.31	1.40
	4	0.96	1.06	1.12	1.23	1.72	1.81	1.79	0.96	0.81	0.96	1.01	1.01	1.20
	5	1.09	1.28	1.38	1.56	1.68	1.79	1.80	1.01	0.89	1.07	1.17	1.28	1.33
	6	1.10	1.26	1.36	1.58	1.65	1.76	1.77	1.05	0.92	1.06	1.16	1.27	1.33
	7	1.12	1.24	1.40	1.55	1.64	1.78	1.76	1.07	0.91	1.06	1.12	1.25	1.32
	8	1.14	1.25	1.38	1.55	1.66	1.74	1.76	1.10	0.94	1.05	1.14	1.26	1.31
	9	1.13	1.21	1.36	1.54	1.63	1.73	1.73	1.10	0.92	1.01	1.10	1.19	1.30
10	1.10	1.25	1.32	1.53	1.62	1.72	1.71	1.09	0.91	1.09	1.09	1.20	1.30	
	Mean	1.15	1.27	1.39	1.56	1.70	1.79	1.78	1.07	0.92	1.05	1.14	1.25	

sewage was higher than Dharwad sewage and EC decreased with an increase in the distance from the sewage outlet. August '99 and July '99 recorded the lowest monthly mean EC of 1.26 and 0.92 dS m⁻¹ in Hubli and Dharwad, respectively (Table 3). May and April '99 registered the highest monthly mean EC of 1.96 and 1.79 dS m⁻¹ in Hubli and Dharwad, respectively. Ten km from the sewage outlet point recorded the lowest annual average EC of 1.56 dS m⁻¹ in Hubli, while four km from the sewage outlet point recorded lowest annual average EC of 1.20 dS m⁻¹ in Dharwad. The highest annual average EC of 1.69 and 1.44 dS m⁻¹ was recorded at one km from the sewage outlet in both Hubli and Dharwad, respectively.

4.1.3 Biological oxygen demand (BOD)

The data pertaining to the BOD of the sewage of Hubli and Dharwad are presented in the Table 4. The BOD of the sewage decreased with an increase in the distance from the sewage outlet irrespective of the season. Higher BOD was recorded during summer months (March to May) both in Hubli and Dharwad. It ranged from 90 to 305 mg L⁻¹ (Hubli) and 81 to 235 mg L⁻¹ (Dharwad). The lowest monthly mean BOD of 130 and 111 mg L⁻¹ was recorded during July '99 in Hubli and Dharwad, respectively, while the highest was recorded during May '99 and April '99 in Hubli and Dharwad (229 mg L⁻¹ and 189 mg L⁻¹, respectively). With regard to annual average, the lowest was registered at ten km from the sewage outlet both in Hubli and Dharwad and highest of 245 and 200 mg L⁻¹ was observed at one km from the sewage outlet in Hubli and Dharwad, respectively.

Table 4 : Biological oxygen demand (mg L^{-1}) of sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy				Mean	
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99		Oct-98
Hubli	1	242	236	252	271	260	287	305	250	190	200	215	230	245
	2	231	216	238	258	242	272	281	242	171	188	208	213	230
	3	224	201	226	242	231	251	268	231	152	174	197	186	215
	4	210	198	210	236	224	230	247	225	143	154	186	178	203
	5	196	185	200	205	218	221	226	205	131	141	178	160	189
	6	182	165	188	186	186	210	217	196	120	136	165	151	175
	7	176	160	172	172	171	192	206	182	112	124	159	148	164
	8	161	152	161	165	160	178	192	178	97	116	147	137	154
	9	150	130	148	148	148	168	182	164	95	102	132	121	128
	10	136	120	132	139	138	152	169	151	90	95	128	110	130
Dharwad	Mean	191	176	193	202	198	216	229	202	130	143	172	163	
	1	205	216	200	218	226	235	221	190	156	168	175	196	200
	2	196	203	192	205	212	221	216	178	143	151	162	182	188
	3	182	193	185	197	201	216	207	164	131	143	151	168	178
	4	102	116	121	135	194	205	195	121	85	95	98	95	130
	5	171	172	171	181	186	193	183	142	121	135	132	148	161
	6	152	161	156	169	175	184	176	133	113	121	124	131	150
	7	143	149	148	158	161	176	163	121	101	113	116	125	140
	8	131	131	131	151	153	168	157	116	193	105	109	108	129
	9	123	125	128	140	141	151	146	103	87	98	95	95	119
10	106	113	119	131	138	143	134	96	81	91	89	91	111	
	Mean	151	158	155	168	179	189	180	136	111	122	125	134	

4.1.4 Total suspended solids

The total suspended solids of Hubli and Dharwad sewage decreased with an increase in the distance from the sewage outlet irrespective of the months. Higher total suspended solids were recorded during summer months (March to May). It ranged between 40 and 280 mg L⁻¹ in Hubli, while that of Dharwad it ranged between 30 and 250 mg L⁻¹ (Table 5). During October '98 the lowest monthly mean total suspended solids of 92 and 141 mg L⁻¹ was recorded both in Hubli and Dharwad, respectively, while the highest of 186 and 148 mg L⁻¹ was registered during February '99 in Hubli and Dharwad, respectively. The highest annual average suspended solids was reported at one km from the sewage outlet of Hubli and Dharwad (228 and 189 mg L⁻¹, respectively), while the lowest total suspended solids of 94 and 53 mg L⁻¹ was noticed at ten km from the sewage outlet of Hubli and Dharwad, respectively.

4.1.5 Cations

Irrespective of the months, the concentration of different cations like calcium, magnesium, sodium and potassium of Hubli and Dharwad sewage decreased with an increase in the distance from the sewage outlet. The concentration of these cations were more during summer season (March to May).

Lowest calcium concentration registered was 4.1 and 3.8 me L⁻¹ in Hubli and Dharwad sewage, respectively, while the highest calcium concentration reported in Hubli and Dharwad sewage 6.2 and 6.6 me L⁻¹, respectively (Table 6). The concentration of calcium was more in Dharwad

Table 5 : Total suspended solids (mg L^{-1}) of sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy					Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	220	210	230	250	250	280	280	240	200	180	190	210	228
	2	200	190	200	230	220	240	220	210	190	180	180	200	205
	3	190	170	190	210	210	210	200	200	190	170	180	180	192
	4	180	170	120	210	180	200	160	200	180	170	190	160	181
	5	170	150	170	190	180	160	140	190	170	160	170	150	167
	6	150	150	160	190	140	120	140	170	150	150	150	130	150
	7	140	130	160	170	100	80	110	170	130	130	140	110	131
	8	130	120	150	170	80	60	80	150	130	120	130	100	117
	9	110	110	130	150	80	60	60	140	120	110	110	90	100
	10	100	110	120	120	60	40	60	120	120	110	90	80	94
Dharwad	Mean	159	151	159	186	150	145	145	179	158	148	151	141	189
	1	160	180	190	210	230	240	250	190	140	150	160	170	174
	2	150	160	180	200	220	210	230	180	140	130	150	140	157
	3	122	140	150	190	200	200	200	170	120	130	130	130	102
	4	60	60	80	100	190	180	170	90	80	90	80	50	122
	5	90	110	120	170	150	140	130	140	100	110	100	110	105
	6	70	90	100	150	120	100	100	130	100	110	100	90	88
	7	70	80	90	140	80	60	80	110	90	90	80	90	77
	8	50	80	80	120	80	40	40	110	90	90	80	60	70
	9	50	60	60	110	60	30	40	80	80	70	70	50	53
10	40	40	50	90	40	30	40	80	80	70	50	30		
	Mean	86	100	110	148	137	123	128	128	100	104	100	92	

Table 6: Calcium content (me L^{-1}) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer				Rainy				Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	5.40	5.30	5.40	5.50	5.60	5.80	6.20	5.40	4.80	4.90	5.00	5.10	5.37
	2	5.30	5.30	5.40	5.30	5.50	5.60	6.20	5.20	4.80	4.70	4.80	5.10	5.22
	3	5.30	5.20	5.10	5.10	5.30	5.50	6.00	5.30	4.70	4.80	4.60	5.00	5.16
	4	5.20	5.10	5.10	5.20	5.10	5.50	5.95	5.00	4.60	4.60	4.70	5.05	5.09
	5	5.25	5.10	5.00	5.00	5.20	5.40	5.90	4.90	4.70	4.75	4.50	4.90	5.05
	6	5.10	5.00	5.00	5.00	5.10	5.30	5.80	4.90	4.60	4.50	4.50	4.95	4.95
	7	5.10	4.90	4.90	4.90	5.00	5.30	5.80	4.80	4.50	4.50	4.40	4.80	4.91
	8	5.00	4.90	4.90	4.90	4.90	5.10	5.70	4.90	4.50	4.30	4.30	4.70	4.84
	9	5.10	4.80	5.00	4.80	4.90	5.10	5.60	4.85	4.45	4.30	4.30	4.75	4.83
	10	4.90	4.25	4.80	4.80	4.80	5.05	5.40	4.70	4.40	4.20	4.10	4.60	4.72
Dharwad	Mean	5.16	5.04	5.04	5.05	5.06	5.16	5.86	5.00	4.99	4.56	4.52	4.90	
	1	5.00	5.20	5.30	5.40	5.80	6.20	6.60	5.20	4.70	4.40	4.90	5.30	5.33
	2	5.00	5.20	5.10	5.30	5.60	5.90	6.50	5.20	4.60	4.00	4.80	5.30	5.23
	3	4.90	5.10	5.10	5.30	5.70	5.90	6.40	5.10	4.50	4.20	4.70	5.25	5.18
	4	4.20	4.40	4.50	4.60	5.65	6.00	6.40	3.80	3.60	3.80	3.90	4.30	4.60
	5	4.70	5.00	4.09	5.10	5.50	5.80	6.30	4.90	4.30	4.00	4.50	5.15	5.01
	6	4.70	4.90	4.95	5.15	5.55	5.70	6.20	4.90	4.20	4.10	4.40	5.10	4.99
	7	4.65	4.90	4.80	5.00	5.40	5.85	6.10	4.80	4.30	4.00	4.30	5.10	4.93
	8	4.60	4.80	4.80	5.10	5.30	5.60	6.20	4.80	4.20	3.95	4.40	5.00	4.90
	9	4.60	4.85	4.70	4.90	5.35	5.65	6.10	4.70	4.10	3.90	4.20	4.90	4.83
	10	4.50	4.70	4.75	4.85	5.20	5.50	6.00	4.75	4.10	3.90	4.20	4.90	4.78
	Mean	4.68	4.91	4.89	5.07	5.51	5.81	6.28	4.72	4.26	4.05	4.43	5.03	

Table 7 : Magnesium content (me L^{-1}) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy				Mean	
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99		Oct-98
Hubli	1	4.4	4.2	4.4	4.6	4.9	4.7	4.9	4.1	3.8	3.9	4.3	4.3	4.38
	2	4.3	4.2	4.3	4.5	4.7	4.6	4.8	4.0	3.8	4.0	4.2	4.3	4.31
	3	4.4	4.1	4.3	4.4	4.8	4.6	4.7	4.0	3.6	3.8	4.1	4.2	4.25
	4	4.3	4.0	4.2	4.3	4.6	4.5	4.6	3.9	3.7	3.6	4.1	4.1	4.16
	5	4.2	3.9	4.1	4.2	4.5	4.5	4.6	4.0	3.6	3.4	4.0	4.0	4.08
	6	4.2	3.9	4.1	4.3	4.4	4.4	4.5	3.8	3.5	3.5	4.0	4.1	4.08
	7	4.0	3.8	3.9	4.1	4.4	4.5	4.3	3.7	3.4	3.2	3.8	3.9	3.92
	8	3.9	3.7	3.8	4.0	4.2	4.4	4.2	3.8	3.4	3.1	3.6	3.9	3.83
	9	3.8	3.8	3.8	3.9	4.1	4.3	4.1	3.7	3.2	3.1	3.5	3.8	3.76
	10	3.7	3.7	3.7	3.9	4.1	4.1	4.0	3.8	3.2	3.2	3.5	3.7	3.73
Dharwad	Mean	4.12	3.93	4.06	4.22	4.47	4.48	4.44	3.88	3.52	3.48	3.91	4.03	4.08
	1	3.6	4.2	4.4	4.5	4.6	4.7	4.6	3.9	3.4	3.5	3.7	3.8	3.98
	2	3.5	4.1	4.3	4.4	4.5	4.6	4.5	3.8	3.2	3.4	3.6	3.8	3.98
	3	3.5	3.9	4.1	4.4	4.5	4.6	4.5	3.8	3.3	3.4	3.5	3.7	3.93
	4	3.1	3.3	3.5	3.4	4.3	4.4	4.4	3.1	3.0	3.0	3.2	3.2	3.94
	5	3.4	3.7	4.0	4.2	4.2	4.3	4.3	3.6	3.1	3.3	3.4	3.5	3.75
	6	3.3	3.6	3.9	4.1	4.3	4.3	4.2	3.5	3.0	3.2	3.3	3.5	3.68
	7	3.2	3.6	3.8	4.0	4.1	4.2	4.1	3.6	3.1	3.0	3.2	3.4	3.61
	8	3.2	3.5	3.9	3.7	4.2	4.1	4.0	3.4	3.0	3.1	3.1	3.4	3.55
	9	3.1	3.3	3.7	3.8	4.1	4.0	4.1	3.2	3.1	3.2	3.2	3.2	3.50
	10	3.0	3.2	3.5	3.6	4.0	4.1	4.0	3.1	3.0	3.2	3.1	3.2	3.42
	Mean	3.29	3.25	3.66	4.00	4.28	4.33	4.27	3.5	3.12	3.23	3.33	3.47	

sewage than at Hubli. The lowest monthly mean calcium concentration of 4.52 and 4.05 me L⁻¹ was recorded during September '99 and August '99 in Hubli and Dharwad, respectively, while the highest of 6.28 and 5.86 me L⁻¹ was registered during May '99 in Dharwad and Hubli, respectively. With regard to annual average one km from the sewage outlet registered highest calcium concentration, while the lowest annual concentration was reported at ten km away from the sewage outlet in Hubli and four km away from sewage outlet in Dharwad.

The magnesium concentration of Hubli sewage ranged between 3.1 and 4.9 me L⁻¹, while that of Dharwad ranged between 3.0 and 4.7 me L⁻¹. Hubli sewage had higher magnesium concentration as compared to Dharwad (Table 7). July '99 registered the lowest monthly mean Mg concentration of 3.12 me L⁻¹ in Dharwad, while August '99 registered the lowest monthly mean Mg concentration in Hubli (3.48 me L⁻¹). The highest annual average Mg concentration of 4.38 and 4.08 me L⁻¹ was recorded at one km from the sewage outlet of Hubli and Dharwad, respectively, while the lowest was noticed at 10 km from the sewage outlet of both Hubli and Dharwad (3.73 and 3.42 me L⁻¹, respectively).

The lowest monthly mean concentration of sodium was registered during July '99 both in Hubli and Dharwad (5.81 and 3.88 me L⁻¹, respectively) and the highest monthly mean Na concentration was registered during May '99 in both Hubli and Dharwad (9.61 and 8.35 me L⁻¹, respectively). The lowest annual average concentration of 6.92 me L⁻¹ and 5.23 me L⁻¹ was recorded at ten km from the sewage outlet of Hubli and four km from the

Table 8 : Sodium content (me L⁻¹) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer				Rainy				Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	6.96	6.87	7.22	7.83	8.52	9.13	9.89	7.13	5.91	6.26	6.37	6.17	7.36
	2	6.87	6.78	7.13	7.83	8.52	9.02	9.67	7.13	5.91	6.17	6.26	6.08	7.28
	3	6.87	6.69	7.13	7.74	8.43	9.02	9.78	7.04	5.82	6.26	6.17	6.08	7.24
	4	6.78	6.60	7.04	7.65	8.35	8.91	9.67	7.13	5.82	6.17	6.17	5.91	7.18
	5	6.78	6.52	6.96	7.65	8.26	9.02	9.56	7.04	5.74	6.08	6.08	5.91	7.13
	6	6.69	6.60	6.96	7.56	8.26	8.91	9.56	6.96	5.82	6.08	6.08	5.82	7.09
	7	6.60	6.52	6.86	7.47	8.17	8.91	9.46	6.96	5.82	6.00	5.91	5.82	7.04
	8	6.52	6.52	6.78	7.56	8.17	8.80	9.56	7.04	5.82	5.91	5.82	5.91	7.03
	9	6.52	6.43	6.78	7.47	8.09	8.80	9.46	7.04	5.74	5.91	5.91	5.91	7.00
	10	6.43	6.35	6.69	7.30	8.09	8.69	9.46	6.96	5.74	5.82	5.82	5.74	6.92
Dharwad	Mean	6.70	6.59	6.96	7.61	8.29	8.92	9.61	7.04	5.81	6.07	6.06	5.94	
	1	6.08	6.17	6.96	7.83	8.35	8.43	8.52	6.26	4.43	5.13	5.47	5.82	6.62
	2	5.91	6.08	6.87	7.74	8.26	8.35	8.52	6.17	4.35	5.04	5.39	5.82	6.54
	3	5.82	5.91	6.87	7.65	8.26	8.26	8.43	6.08	4.17	5.04	5.39	5.74	6.47
	4	4.35	4.61	4.8	5.13	8.00	8.26	8.35	3.22	3.30	4.00	4.52	4.20	5.23
	5	5.74	5.65	6.34	7.47	8.17	8.17	8.43	5.91	3.91	4.86	5.30	5.65	6.31
	6	5.74	5.65	6.35	7.30	8.00	8.17	8.35	5.74	3.74	4.86	5.22	5.56	6.22
	7	5.65	5.56	6.35	7.47	7.83	8.09	8.26	5.65	3.82	4.69	5.24	5.56	6.18
	8	5.56	5.65	6.17	7.3	7.83	8.09	8.26	5.47	3.74	4.69	5.13	5.47	6.11
	9	5.56	5.47	6.08	7.22	7.74	8.17	8.17	5.47	3.65	4.52	5.13	5.47	6.05
	10	5.47	5.56	6.17	7.13	7.65	8.09	8.17	5.39	3.65	4.43	5.04	5.39	6.01
	Mean	5.59	5.63	6.31	7.22	8.01	8.21	8.35	5.54	3.88	4.73	5.18	5.47	

Table 9 : Potassium content (me L^{-1}) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer				Rainy				Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	1.15	1.10	1.23	1.36	1.44	1.59	1.64	1.23	0.97	1.08	1.10	1.08	1.25
	2	1.15	1.02	1.15	1.33	1.41	1.54	1.59	1.23	0.92	1.02	1.10	0.97	1.20
	3	1.10	1.08	1.15	1.30	1.36	1.554	1.54	1.15	0.89	0.97	1.08	1.02	1.18
	4	1.02	0.97	1.08	1.26	1.36	1.51	1.51	1.08	0.82	0.92	1.02	0.97	1.13
	5	0.97	0.97	1.02	1.30	1.33	1.49	1.51	1.02	0.82	0.89	0.92	0.95	1.10
	6	0.95	0.92	0.97	1.15	1.26	1.46	1.46	0.97	0.89	0.82	0.92	0.95	1.06
	7	0.95	0.89	0.97	1.08	1.15	1.44	1.49	0.89	0.79	0.89	0.89	0.92	1.03
	8	0.89	0.82	0.89	1.02	1.26	1.36	1.36	0.92	0.82	0.82	0.89	0.89	1.00
	9	0.92	0.99	0.92	0.97	1.08	1.33	1.33	0.89	0.77	0.77	0.82	0.89	0.96
	10	0.87	0.79	0.89	0.97	1.02	1.33	1.26	0.89	0.74	0.77	0.77	0.92	0.94
	Mean	1.00	0.94	1.03	1.17	1.27	1.46	1.47	1.03	0.84	0.9	0.95	0.96	
Dharwad	1	0.92	0.97	1.10	1.15	1.23	1.30	1.36	0.92	0.82	0.92	1.05	1.02	1.06
	2	0.92	0.92	1.08	1.15	1.15	1.26	1.26	0.92	0.79	0.92	1.02	0.97	1.03
	3	0.87	0.92	1.08	1.10	1.08	1.15	1.15	0.89	0.74	0.89	1.02	0.92	0.98
	4	0.61	0.67	0.72	0.77	1.08	1.08	1.02	0.59	0.51	0.61	0.72	0.64	0.75
	5	0.82	0.87	0.97	1.02	1.02	1.02	1.08	0.77	0.72	0.77	0.97	0.87	0.91
	6	0.77	0.87	0.97	0.97	0.97	1.08	1.02	0.74	0.64	0.72	0.92	0.87	0.88
	7	0.82	0.82	0.92	0.97	0.97	0.97	0.97	0.77	0.61	0.64	0.97	0.82	0.93
	8	0.77	0.77	0.87	0.92	0.92	0.97	0.92	0.74	0.64	0.61	0.89	0.77	0.82
	9	0.72	0.77	0.82	0.87	0.95	0.95	0.97	0.72	0.61	0.61	0.89	0.74	0.80
	10	0.69	0.72	0.82	0.85	0.92	0.92	0.89	0.72	0.56	0.63	0.82	0.72	0.77
	Mean	0.79	0.83	0.94	0.98	1.03	1.07	1.06	0.78	0.66	0.73	0.93	0.83	

sewage outlet of Dharwad, respectively (Table 8). The highest annual average concentration of Na was recorded at one km from the sewage outlet in both the places.

Potassium concentration of Hubli sewage ranged from 0.74 to 1.64 me L⁻¹, while that of Dharwad ranged between 0.5 and 1.36 me L⁻¹ (Table 9). Potassium concentration of Hubli sewage was more than the Dharwad sewage. The lowest monthly mean potassium concentration of 0.84 and 0.66 me L⁻¹ was reported during July '99 both in Hubli and Dharwad, while the highest monthly mean of 1.47 and 1.07 me L⁻¹ was registered during May '99 in Hubli and April '99 in Dharwad, respectively. Ten km from the sewage outlet at Hubli and four km from the sewage outlet registered the lowest annual average potassium concentration of 0.94 and 0.75 me L⁻¹, respectively.

4.1.6 Anions

The various anions such as carbonates, bicarbonates, chlorides, sulphates and phosphates analysed decreased with an increase in the distance from the sewage outlet. The concentration of these anions was high during summer season (March to May).

Carbonates were present in traces during the course of investigation at all the sewage collecting sites of Hubli and Dharwad. The bicarbonate concentration of Hubli sewage was lower than that of Dharwad sewage samples and it ranged between 8.08 and 17.15 me L⁻¹ in Hubli and 8.82 and 18.62 me L⁻¹ in Dharwad. July '99 registered the lowest monthly mean bicarbonate content of 8.70 and 9.60 me L⁻¹ in sewage samples of both

Table 10 : Bicarbonate content (me/L) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer				Rainy				Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	10.78	11.76	12.01	12.74	15.44	16.42	17.15	12.00	9.56	11.27	11.51	10.53	12.60
	2	10.53	11.51	12.01	12.50	15.19	16.17	16.90	11.76	9.56	11.27	11.51	10.53	12.45
	3	10.53	11.02	11.76	12.50	15.19	15.93	16.67	11.76	9.06	10.78	11.02	10.29	12.20
	4	10.29	10.78	11.51	12.01	14.94	15.68	16.42	11.51	8.82	10.53	10.78	10.04	11.94
	5	10.29	10.78	11.51	12.01	14.45	15.43	16.17	11.02	8.58	10.53	10.78	10.29	11.82
	6	10.04	10.53	11.02	12.01	14.21	15.43	15.92	11.02	8.58	10.29	10.53	9.80	11.59
	7	9.80	10.29	10.78	11.76	13.98	15.19	15.19	10.78	8.33	10.29	10.29	9.80	11.35
	8	9.80	10.04	10.78	11.51	13.23	14.94	14.94	10.53	8.33	9.80	10.29	9.55	11.14
	9	9.50	10.04	10.53	11.02	13.23	14.70	14.21	10.29	8.08	9.55	10.04	9.50	10.89
	10	9.50	9.80	10.29	10.78	12.98	14.45	14.21	10.29	8.08	9.08	10.04	9.08	10.71
	Mean	10.11	10.65	11.22	10.76	12.98	13.99	14.36	11.09	8.70	10.34	10.68	9.94	
Dharwad	1	11.76	12.74	13.72	14.71	17.15	17.89	18.62	12.74	10.29	10.78	10.53	11.27	13.52
	2	11.51	12.50	13.23	14.70	16.90	17.64	18.38	12.74	10.04	10.29	10.53	11.27	13.31
	3	11.51	12.50	13.23	13.96	16.42	17.64	18.13	12.50	10.04	10.29	10.29	11.06	13.13
	4	11.02	11.76	12.98	13.96	16.42	17.39	17.89	12.00	9.80	10.04	10.04	10.78	12.84
	5	11.02	11.76	12.98	13.23	16.17	17.15	17.89	11.78	9.80	10.04	10.04	10.78	12.72
	6	10.78	11.51	12.74	13.23	16.17	17.15	17.64	11.78	9.55	9.80	9.80	10.53	12.56
	7	10.53	11.51	12.50	12.98	15.92	16.90	17.64	11.51	9.55	9.55	9.55	10.29	12.37
	8	10.53	11.02	12.01	12.74	15.92	16.42	17.39	11.51	9.08	9.55	9.08	10.29	12.12
	9	10.29	10.78	12.01	12.50	15.19	16.17	17.15	11.02	9.08	9.08	8.82	10.04	11.84
	10	10.29	10.78	11.78	12.50	14.94	16.17	16.90	11.02	8.82	9.08	8.82	10.04	11.76
	Mean	10.92	11.69	12.72	13.41	16.12	17.05	17.76	11.02	9.60	9.85	9.75	10.64	

Carbonates were present in traces.

Table 11 : Chlorides content (me L^{-1}) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy				Mean	
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99		Oct-98
Hubli	1	8.75	9.55	9.85	9.95	10.25	10.50	11.15	7.50	5.30	7.45	8.60	8.85	8.98
	2	8.60	9.50	9.70	9.80	10.10	10.35	11.05	7.45	5.25	7.30	8.50	8.70	8.86
	3	8.55	9.35	9.55	9.75	10.05	10.20	10.85	7.30	5.25	7.35	8.45	8.75	8.78
	4	8.60	9.35	9.50	9.60	9.95	10.15	10.80	7.35	5.15	7.20	8.50	8.65	8.73
	5	8.45	9.20	9.40	9.55	9.80	10.00	10.65	7.20	5.05	7.05	8.25	8.50	8.59
	6	8.30	9.15	9.25	9.40	9.85	9.85	10.70	7.25	4.95	6.95	8.05	8.45	8.51
	7	8.35	9.05	9.30	9.35	9.75	9.90	10.55	7.15	5.00	6.90	7.90	8.25	8.45
	8	8.20	8.90	9.15	9.25	9.60	9.75	10.45	7.05	4.90	6.95	7.85	8.10	8.34
	9	8.15	8.75	9.05	9.10	9.55	9.60	10.30	7.00	4.90	6.80	7.75	8.15	8.23
	10	8.00	8.70	9.10	9.15	9.45	9.65	10.15	7.05	4.85	6.75	7.70	8.05	8.22
Dharwad	Mean	8.40	9.15	9.39	9.49	9.84	10.00	10.67	7.23	5.06	7.07	8.16	8.45	
	1	6.50	7.05	7.00	8.55	8.70	9.15	9.35	6.15	5.25	5.55	5.85	6.55	7.14
	2	6.35	6.90	6.85	8.40	8.65	9.05	9.15	6.10	5.15	5.50	5.70	6.45	7.02
	3	6.20	6.95	6.80	8.45	8.55	8.95	9.20	6.05	5.05	5.35	5.65	6.30	6.96
	4	5.85	5.80	5.90	6.25	8.35	8.70	9.05	5.05	4.55	4.60	4.75	5.95	6.23
	5	6.05	6.75	6.60	8.15	8.40	8.85	8.95	5.95	4.95	5.05	5.35	6.15	6.77
	6	5.95	6.60	6.50	8.05	8.20	8.65	8.95	5.80	4.80	5.10	5.20	6.05	6.65
	7	5.95	6.45	6.35	8.10	8.15	8.65	8.70	5.85	4.75	4.95	5.25	6.10	6.60
	8	5.85	6.50	6.40	7.95	8.20	8.50	8.65	5.70	4.60	4.85	5.10	5.95	6.52
	9	5.90	6.35	6.25	7.75	8.05	8.45	8.55	5.65	4.55	4.85	5.05	5.90	6.44
10	5.75	6.20	6.10	7.80	8.05	8.20	8.40	5.60	4.50	4.70	4.80	5.85	6.33	
	Mean	6.04	6.56	6.48	7.95	8.33	8.72	8.90	5.79	4.82	5.05	5.27	6.13	

Table 12 : Sulphate content (ppm) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer				Rainy				Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	19.29	18.63	19.86	19.71	23.79	23.52	21.75	16.05	10.85	13.36	12.48	17.58	18.07
	2	19.12	18.56	19.68	19.58	23.56	23.34	21.64	15.87	10.68	13.18	12.27	17.42	17.91
	3	19.04	18.42	19.50	19.43	23.42	23.14	21.48	15.68	10.72	13.03	12.18	17.34	17.78
	4	18.86	18.33	19.37	19.32	23.32	22.86	21.32	15.47	10.56	12.92	12.03	17.12	17.62
	5	18.72	18.26	19.22	19.18	23.17	21.74	21.06	15.42	10.43	12.86	11.86	16.98	17.41
	6	18.64	18.17	19.06	18.97	23.00	21.56	20.86	15.28	10.38	12.73	11.72	16.86	17.27
	7	18.72	18.03	18.92	18.86	22.81	21.42	20.68	15.17	10.21	12.58	11.58	16.74	17.14
	8	18.56	17.90	18.78	18.68	22.70	21.21	20.48	15.03	10.16	12.42	11.42	16.56	17.00
	9	18.47	17.76	18.63	18.57	22.51	20.96	20.36	14.98	10.02	12.38	11.38	16.46	16.87
	10	18.31	17.65	18.48	18.40	22.31	20.78	20.16	14.75	9.86	12.13	11.16	16.56	16.71
Dharwad	Mean	18.77	18.17	19.15	19.07	23.06	22.05	20.98	15.37	10.39	12.76	11.81	16.96	
	1	8.41	10.25	10.80	10.26	12.62	13.87	15.36	11.41	8.76	9.05	9.88	9.62	10.86
	2	8.38	10.08	10.68	10.09	12.48	13.68	15.23	11.30	8.58	8.86	9.69	9.42	10.70
	3	8.17	9.86	10.43	9.88	12.36	13.56	15.08	11.17	8.63	8.72	9.53	9.36	10.56
	4	8.06	9.74	10.29	9.72	12.17	13.41	14.91	11.09	8.42	8.57	9.42	9.21	10.42
	5	7.95	9.68	10.11	9.68	12.08	13.30	14.78	10.93	8.28	8.43	9.53	9.07	10.32
	6	7.86	9.74	10.03	9.54	11.92	13.18	14.54	10.86	8.17	8.38	9.38	8.82	10.20
	7	7.86	9.52	9.86	9.43	11.87	13.08	14.38	10.72	8.09	8.43	9.24	8.76	10.10
	8	7.64	9.38	9.72	9.28	11.78	12.96	14.23	10.68	7.95	8.27	9.17	8.72	9.98
	9	7.56	9.21	9.68	9.17	11.64	12.81	14.11	10.53	7.86	8.17	9.24	8.76	9.89
	10	7.47	9.08	9.52	9.10	11.51	12.70	14.03	10.36	7.66	8.08	9.02	8.53	9.76
	Mean	7.94	9.65	10.11	9.62	12.04	13.26	14.67	10.91	8.24	8.50	9.41	9.03	

Hubli and Dharwad, respectively. While the highest bicarbonate concentration of 14.36 and 17.76 me L⁻¹ (Table 10) was registered during May '99 in Hubli and Dharwad, respectively. One km from the sewage outlet recorded a highest annual bicarbonate concentration while lowest was noticed at ten km from the sewage outlet in both the places.

Chloride concentration of Hubli sewage ranged from 4.85 me L⁻¹ to 11.15 me L⁻¹, while that of Dharwad was 4.50 to 9.35 me L⁻¹. The lowest monthly mean chloride concentration of 5.06 and 4.82 me L⁻¹ was reported during July '99 in Hubli and Dharwad, respectively. While the highest monthly mean chloride concentration of 10.67 and 8.90 me L⁻¹ was recorded during May '99 in Hubli and Dharwad, respectively. The lowest annual average chloride concentration of 8.22 me L⁻¹ and 6.23 me L⁻¹ was recorded at ten km from the sewage outlet in Hubli and four km from the sewage outlet in Dharwad, respectively (Table 11).

Hubli sewage had higher sulphate concentration compared to Dharwad and it ranged between 9.86 ppm and 23.79 ppm in Hubli and 7.47 and 15.36 ppm in Dharwad sewage (Table 12). March '99 recorded the highest monthly mean sulphate concentration in Hubli samples. May '99 (14.67 ppm) recorded the highest monthly mean sulphate concentration in Dharwad. The annual average sulphate concentration decreased with an increase in the distance from the sewage outlet. It was the lowest at ten km from the sewage outlet in Hubli and Dharwad (16.71 and 9.76 ppm, respectively).

The phosphate concentration in Hubli sewage was more than that

Table 13 : Phosphate content (ppm) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer				Rainy				Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	2.82	2.69	2.94	3.42	4.16	4.83	5.26	4.34	2.02	2.20	2.14	2.63	3.28
	2	2.75	2.58	2.86	3.36	4.12	4.77	5.21	4.31	1.96	2.12	2.06	2.58	3.22
	3	2.71	2.52	2.74	3.32	4.06	4.71	5.17	4.25	1.96	2.05	2.06	2.52	3.17
	4	2.65	2.46	2.65	3.27	3.94	4.65	5.12	4.17	1.92	2.05	2.00	2.47	3.11
	5	2.61	2.41	2.54	3.21	3.92	4.59	5.08	4.11	1.86	1.97	1.91	2.43	3.05
	6	2.58	2.36	2.48	3.16	3.86	4.51	5.02	3.05	1.81	1.97	1.85	2.37	2.92
	7	2.51	2.32	2.38	3.12	3.83	4.42	4.96	2.96	1.78	1.89	1.78	2.31	2.85
	8	2.46	2.26	2.31	3.08	3.75	4.37	4.91	2.96	1.72	1.82	1.78	2.27	2.81
	9	2.36	2.17	2.26	3.02	3.71	4.26	4.85	2.89	1.68	1.79	1.65	2.21	2.74
	10	2.24	2.13	2.16	2.96	3.65	4.17	4.78	2.92	1.59	1.79	1.56	2.17	2.68
Dharwad	Mean	2.57	2.39	2.53	3.19	3.90	4.53	5.04	3.60	1.83	1.96	1.88	2.40	
	1	2.08	2.30	2.54	2.69	2.92	3.00	3.86	2.48	1.80	1.90	1.99	2.17	2.43
	2	2.02	2.22	2.46	2.62	2.84	2.92	3.82	2.42	1.78	1.86	1.96	2.12	2.42
	3	1.96	2.16	2.42	2.58	2.78	2.86	3.76	2.36	1.72	1.82	1.92	2.08	2.37
	4	1.96	2.16	2.36	2.52	2.78	2.82	3.68	2.36	1.72	1.78	1.92	2.02	2.34
	5	1.92	2.08	2.36	2.52	2.72	2.78	3.54	2.28	1.68	1.78	1.86	1.96	2.29
	6	1.86	1.96	2.28	2.46	2.64	2.78	3.48	2.12	1.52	1.72	1.82	1.92	2.21
	7	1.82	1.92	2.16	2.32	2.60	2.72	3.32	2.08	1.52	1.68	1.78	1.96	2.16
	8	1.78	1.92	2.12	2.26	2.54	2.64	3.28	2.02	1.46	1.52	1.72	1.86	2.09
	9	1.72	1.82	2.16	2.16	2.50	2.60	3.16	1.96	1.42	1.52	1.68	1.81	2.04
	10	1.68	1.78	2.08	2.16	2.46	2.54	3.08	1.92	1.38	1.42	1.62	1.78	1.99
	Mean	1.88	2.03	2.29	2.43	2.68	2.77	3.50	2.20	1.60	1.70	1.83	1.97	

of Dharwad sewage. It ranged from 1.38 to 3.86 ppm in Dharwad sewage and 1.56 to 5.26 ppm in case of Hubli sewage (Table 13). The highest monthly mean phosphate concentration of 5.04 and 3.50 ppm was recorded during May month '99 in both Hubli and Dharwad. While the lowest of 1.83 and 1.60 ppm was registered during July '99 in both Hubli and Dharwad, respectively.

4.1.7 Residual sodium carbonate (RSC) and sodium adsorption ratio (SAR)

The data pertaining to RSC and SAR of sewage water have been presented in the Table 14 and 15. The average annual RSC ranged from 0.57 to 5.62 me L⁻¹ at Hubli and 1.99 to 7.24 me L⁻¹ in Dharwad. Average RSC of Dharwad was more than the Hubli sewage irrespective of the seasons.

Monthly mean SAR of Hubli sewage was more than the SAR of Dharwad sewage and it ranged from 2.81 to 4.24 in case of Hubli sewage and 2.02 to 3.64 in Dharwad. However, no definite trend was noticed with respect to increase in the distance from the sewage outlet.

4.1.8 Heavy metals

The concentration of cadmium and nickel was present in below detectable limits during the course of investigation and also at all the collecting points. The heavy metals like Zn, Cu, Mn, Fe and Pb decreased with an increase in the distance from the sewage outlet. Hubli sewage recorded higher concentration of monthly mean irrespective of the seasons.

The concentration of Zn in Hubli sewage ranged from 0.121 ppm to 1.035 ppm, while that of Dharwad was below detectable limits to 0.879

Table 14 : Sodium adsorption ratio of sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer		Rainy				Mean		
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99		Sep-99	Oct-98
Hubli	1	3.15	3.15	3.27	3.48	3.72	3.95	4.19	3.27	2.86	2.98	2.95	2.86	3.32
	2	3.14	3.11	3.27	3.54	3.77	3.99	4.13	3.33	2.81	2.97	2.95	2.81	3.32
	3	3.12	3.10	3.30	3.55	3.75	4.00	4.23	3.26	2.85	3.02	2.97	2.84	3.33
	4	3.11	3.10	3.26	3.23	3.79	3.98	4.20	3.33	2.85	3.05	2.94	2.76	3.30
	5	3.12	3.24	3.27	3.57	3.75	4.06	4.17	3.34	2.82	3.00	2.95	2.80	3.34
	6	3.08	3.13	3.27	3.50	3.79	4.01	4.21	3.35	2.89	3.04	2.95	2.73	3.33
	7	3.10	3.13	3.27	3.52	3.78	4.03	4.20	3.38	2.92	3.06	2.95	2.79	3.34
	8	3.10	3.15	3.26	3.58	3.83	4.03	4.48	3.38	2.92	3.08	2.92	2.86	3.38
	9	3.09	3.10	3.23	3.59	3.81	4.04	4.30	3.40	2.94	3.08	3.00	2.86	3.37
	10	3.10	3.07	3.23	3.51	3.83	4.06	4.32	3.38	2.94	3.03	2.97	2.81	3.35
Dharwad	Mean	3.11	3.13	3.26	3.61	3.78	4.02	4.24	3.34	2.88	3.03	2.96	2.81	3.04
	1	2.94	2.86	3.16	3.53	3.66	3.61	3.59	2.94	2.20	2.58	2.64	2.73	3.03
	2	2.87	2.81	3.18	3.52	3.67	3.65	3.64	2.91	2.21	2.57	2.63	2.73	3.03
	3	2.84	2.79	3.21	3.48	3.65	3.61	3.62	2.88	2.12	2.57	2.67	2.72	3.01
	4	2.28	2.35	2.40	2.58	3.58	3.62	3.60	1.73	1.81	2.03	2.40	2.18	2.54
	5	2.92	2.72	3.05	3.40	3.73	3.83	3.88	2.87	2.04	2.54	2.70	2.72	3.00
	6	2.88	2.74	3.02	3.40	3.62	3.65	3.66	2.80	1.95	2.54	2.66	2.68	2.97
	7	2.85	2.70	3.05	3.52	3.59	3.57	3.65	2.76	1.99	2.46	2.69	2.70	2.96
	8	2.82	2.77	2.97	3.48	3.59	3.64	3.65	2.71	1.97	2.46	2.64	2.67	2.95
	9	2.83	2.71	2.96	3.47	3.57	3.71	3.62	2.71	1.92	2.40	2.61	2.72	2.94
10	2.82	2.79	3.04	3.48	3.57	3.69	3.65	2.87	1.94	2.36	2.64	2.68	2.96	
	Mean	2.81	2.72	3.00	3.39	3.62	3.84	3.63	2.72	2.02	2.45	2.63	2.65	

Table 15 : Residual sodium carbonate content (me L^{-1}) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy				Mean	
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99		Oct-98
Hubli	1	0.98	2.26	2.21	2.64	4.94	5.72	6.05	2.50	0.96	2.47	2.21	1.13	2.84
	2	0.93	2.01	2.51	2.70	4.99	5.97	5.90	2.56	0.96	2.57	2.51	1.13	2.90
	3	0.83	1.72	2.36	3.00	5.09	5.83	5.97	2.56	0.76	2.18	2.32	1.09	2.81
	4	0.79	1.68	2.21	2.51	5.24	5.68	5.87	2.31	0.52	2.33	1.98	0.89	2.67
	5	0.84	2.68	2.41	2.81	4.75	5.53	5.67	2.12	0.28	2.38	2.28	1.39	2.76
	6	0.74	1.63	1.92	2.46	4.71	5.53	5.63	2.32	0.48	2.20	2.03	0.75	2.53
	7	0.70	1.59	1.98	2.51	4.56	5.39	5.09	2.28	0.43	2.59	2.09	1.10	2.53
	8	0.90	1.44	2.08	2.51	4.13	5.44	5.84	1.83	0.43	2.40	2.39	0.95	2.53
	9	0.60	1.44	1.73	2.32	4.23	5.54	4.51	1.65	0.43	2.15	2.24	0.95	2.52
	10	0.90	1.25	1.79	2.08	3.90	5.30	4.61	1.79	0.48	1.66	2.44	0.76	2.25
Dharwad	Mean	0.82	1.77	2.12	2.55	4.65	5.59	5.51	2.19	0.57	2.29	2.25	1.01	
	1	3.16	3.34	4.02	4.80	6.75	6.99	7.42	3.64	2.19	2.88	1.93	2.17	4.11
	2	3.01	3.20	3.83	4.60	6.80	7.14	7.38	3.74	2.24	2.59	2.13	2.17	4.07
	3	3.11	3.50	4.03	3.76	6.22	7.14	7.23	3.60	2.24	2.69	2.09	2.11	3.98
	4	3.72	4.06	4.98	4.01	6.47	6.99	7.09	5.10	3.20	2.24	2.94	3.28	4.51
	5	3.22	3.06	4.08	3.53	6.47	7.05	7.29	3.28	2.40	2.74	2.14	2.13	3.95
	6	2.78	3.01	3.89	3.83	6.32	7.15	7.24	3.38	2.35	2.50	2.10	1.93	3.87
	7	2.68	3.01	3.90	3.48	6.42	6.85	7.44	3.11	2.15	2.55	2.05	1.79	3.78
	8	2.73	2.72	3.31	3.24	6.42	6.72	7.19	3.31	1.86	2.50	1.56	1.89	3.62
	9	2.59	2.63	3.61	3.05	5.74	6.52	7.19	2.82	1.86	1.96	1.42	1.94	3.44
10	2.79	2.88	3.53	3.30	5.74	6.57	6.90	3.17	1.72	1.96	1.52	1.94	3.51	
	Mean	2.98	3.14	3.92	3.76	6.34	6.91	7.24	3.52	2.22	2.46	1.99	2.14	

Table 16 : Zinc content (ppm) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer				Rainy				Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	0.426	0.521	0.591	0.725	0.879	0.962	1.035	0.744	0.320	0.416	0.444	0.383	0.620
	2	0.409	0.506	0.578	0.704	0.852	0.956	1.012	0.726	0.300	0.392	0.416	0.352	0.600
	3	0.382	0.488	0.554	0.689	0.836	0.938	0.986	0.702	0.281	0.368	0.392	0.341	0.580
	4	0.374	0.463	0.538	0.675	0.821	0.917	0.952	0.682	0.252	0.343	0.374	0.327	0.560
	5	0.359	0.439	0.519	0.654	0.806	0.887	0.943	0.654	0.216	0.321	0.356	0.309	0.538
	6	0.342	0.418	0.501	0.638	0.782	0.863	0.927	0.623	0.195	0.316	0.341	0.295	0.520
	7	0.325	0.392	0.483	0.617	0.775	0.849	0.906	0.606	0.174	0.304	0.320	0.287	0.503
	8	0.310	0.376	0.047	0.596	0.750	0.821	0.891	0.600	0.156	0.287	0.306	0.271	0.486
	9	0.302	0.357	0.456	0.584	0.742	0.810	0.872	0.581	0.142	0.268	0.291	0.259	0.472
	10	0.287	0.340	0.438	0.572	0.729	0.798	0.858	0.562	0.121	0.245	0.278	0.236	0.455
Dharwad	Mean	0.352	0.430	0.563	0.645	0.797	0.880	0.938	0.648	0.216	0.326	0.352	0.300	
	1	0.315	0.441	0.553	0.644	0.679	0.725	0.879	0.045	0.161	0.232	0.280	0.274	0.469
	2	0.298	0.416	0.536	0.617	0.648	0.696	0.858	0.398	0.143	0.196	0.261	0.243	0.442
	3	0.276	0.393	0.510	0.601	0.627	0.674	0.836	0.362	0.128	0.174	0.243	0.216	0.420
	4	0.082	0.086	0.096	0.108	0.608	0.643	0.821	0.032	BDL	0.056	0.068	0.074	0.223
	5	0.247	0.372	0.472	0.576	0.678	0.626	0.796	0.316	0.098	0.152	0.198	0.182	0.393
	6	0.218	0.346	0.417	0.556	0.652	0.607	0.778	0.282	0.074	0.143	0.174	0.156	0.367
	7	0.196	0.326	0.392	0.543	0.624	0.582	0.752	0.271	0.053	0.121	0.154	0.143	0.346
	8	0.173	0.307	0.376	0.526	0.617	0.554	0.746	0.250	0.041	0.098	0.127	0.121	0.328
	9	0.161	0.281	0.353	0.517	0.601	0.536	0.732	0.230	0.027	0.074	0.116	0.102	0.308
	10	0.142	0.263	0.338	0.508	0.583	0.512	0.710	0.214	0.011	0.051	0.089	0.098	0.293
	Mean	0.211	0.323	0.404	0.520	0.632	0.616	0.791	0.280	0.074	0.130	0.171	0.161	

BDL - Below detectable levels.

Table 17 : Copper content (ppm) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter					Summer			Rainy					Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98		
Hubli	1	0.095	0.078	0.096	0.103	0.134	0.123	0.148	0.076	0.062	0.085	0.098	0.085	0.110	
	2	0.092	0.076	0.094	0.098	0.128	0.118	0.142	0.072	0.058	0.082	0.082	0.078	0.094	
	3	0.091	0.076	0.092	0.097	0.122	0.114	0.136	0.072	0.052	0.079	0.088	0.076	0.091	
	4	0.090	0.072	0.089	0.095	0.120	0.112	0.132	0.070	0.048	0.073	0.082	0.072	0.088	
	5	0.086	0.070	0.085	0.089	0.118	0.110	0.128	0.066	0.038	0.068	0.079	0.072	0.084	
	6	0.086	0.066	0.082	0.087	0.110	0.108	0.126	0.065	0.032	0.066	0.077	0.068	0.081	
	7	0.082	0.065	0.079	0.084	0.106	0.105	0.124	0.062	0.030	0.064	0.072	0.066	0.078	
	8	0.081	0.062	0.078	0.082	0.102	0.103	0.122	0.060	0.028	0.062	0.070	0.065	0.076	
	9	0.078	0.058	0.074	0.078	0.098	0.100	0.120	0.058	0.022	0.060	0.068	0.062	0.073	
	10	0.074	0.053	0.069	0.072	0.091	0.100	0.118	0.052	0.018	0.052	0.065	0.061	0.069	
Dharwad	Mean	0.086	0.068	0.084	0.089	0.101	0.109	0.130	0.065	0.039	0.069	0.079	0.071	0.054	
	1	0.04	0.049	0.058	0.062	0.076	0.081	0.095	0.034	0.022	0.036	0.047	0.045	0.049	
	2	0.039	0.045	0.052	0.056	0.071	0.078	0.092	0.031	0.018	0.022	0.040	0.042	0.049	
	3	0.035	0.041	0.050	0.054	0.065	0.076	0.091	0.027	0.011	0.018	0.036	0.038	0.045	
	4	0.010	0.018	0.024	0.031	0.058	0.074	0.089	0.010	BDL	BDL	0.010	0.011	0.028	
	5	0.030	0.037	0.046	0.050	0.059	0.070	0.086	0.020	0.007	0.011	0.031	0.030	0.040	
	6	0.027	0.035	0.041	0.046	0.052	0.066	0.082	0.017	0.005	0.009	0.028	0.028	0.036	
	7	0.026	0.032	0.037	0.041	0.050	0.062	0.077	0.012	0.003	0.005	0.027	0.024	0.033	
	8	0.021	0.029	0.035	0.039	0.046	0.057	0.072	0.009	0.001	0.003	0.021	0.022	0.030	
	9	0.019	0.026	0.031	0.032	0.042	0.052	0.070	0.007	BDL	BDL	0.018	0.021	0.026	
	10	0.015	0.022	0.027	0.028	0.040	0.051	0.068	0.003	BDL	BDL	0.015	0.017	0.024	
	Mean	0.026	0.033	0.04	0.044	0.056	0.062	0.082	0.017	0.007	0.01	0.027	0.028	0.024	

ppm (Table 16). July '99 recorded the lowest monthly mean concentration of 0.074 ppm in Dharwad sewage, while it was 0.216 ppm was registered during July '99 in Hubli sewage. One km from the sewage outlet registered the highest annual average concentration of 0.620 and 0.469 ppm Zn in Hubli and Dharwad, respectively, while ten km from sewage outlet registered lowest annual average of 0.455 and 0.293 ppm Zn in Hubli and Dharwad, respectively.

The concentration of copper in Hubli sewage was more than the Dharwad sewage. It ranged between 0.018 and 0.148 ppm in Hubli and below detectable level to 0.095 ppm in Dharwad sewage. July '99 registered the lowest monthly mean concentration of Cu in both Hubli and Dharwad (Table 17), while May '99 recorded the highest monthly mean Cu concentration. The highest annual average concentration of Cu was recorded at one km from the sewage outlet both in Hubli and Dharwad, while the lowest was recorded at ten km from the sewage outlet.

The iron concentration in Hubli sewage ranged from 1.805 ppm to 6.0153 ppm. The highest Fe concentration recorded in Dharwad sewage, was 4.023 ppm and the lowest was 0.521 ppm. Lowest monthly mean Fe concentration was recorded during July '99 in both Hubli and Dharwad, while the highest being during the month of May '99 (Table 18). Ten km from the sewage outlet registered the lowest annual average Fe concentration in Hubli, while four km from the sewage outlet registered the lowest Fe concentration in Dharwad (3.644 and 1.665 ppm, respectively). One km from the sewage outlet registered the highest Fe content both in Hubli and Dharwad.

Table 18 : Iron content (ppm) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy				Mean	
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99		Oct-98
Hubli	1	3.150	3.150	3.575	3.876	4.526	5.423	6.153	4.056	2.106	3.525	4.161	3.627	3.941
	2	3.098	3.086	3.516	3.798	4.474	5.373	5.989	3.954	1.981	3.491	3.989	3.589	3.861
	3	2.996	3.004	3.482	3.764	4.456	5.356	5.972	3.903	1.956	3.456	3.954	3.548	3.820
	4	2.954	2.967	3.456	3.728	4.527	5.329	5.943	3.876	1.927	3.423	3.917	3.542	3.800
	5	2.926	2.943	3.442	3.697	4.506	5.306	5.916	3.854	1.908	3.406	3.896	3.527	3.777
	6	2.907	2.927	3.427	3.674	4.482	5.281	5.889	3.821	1.897	3.381	3.874	3.506	3.756
	7	2.887	2.906	3.409	3.658	4.472	5.269	5.862	3.806	1.872	3.363	3.856	3.483	3.737
	8	2.872	2.888	2.992	3.643	4.459	5.247	5.843	3.784	1.854	3.350	3.837	3.456	3.686
	9	2.856	2.872	2.976	3.627	4.423	5.228	5.828	3.760	1.828	3.330	3.821	3.428	3.665
	10	2.826	2.853	2.956	3.610	4.400	5.210	5.798	3.749	1.805	3.313	3.804	3.405	3.664
Dharwad	Mean	2.947	2.960	3.323	3.710	4.472	5.302	5.919	3.856	1.913	3.404	3.911	3.511	
	1	3.273	2.969	2.814	2.970	3.404	3.867	4.023	2.680	1.905	2.226	2.814	2.459	2.952
	2	3.140	2.752	2.786	2.901	3.316	3.782	3.967	2.596	1.852	2.186	2.706	2.219	2.850
	3	3.014	2.710	2.701	2.876	3.298	3.717	3.952	2.542	1.805	2.153	2.652	2.176	2.80
	4	1.056	0.997	1.116	1.297	3.253	3.684	3.927	0.968	0.521	1.076	1.169	0.921	1.665
	5	2.866	2.568	2.656	2.786	3.227	3.659	3.903	2.468	1.776	1.896	2.407	1.986	2.683
	6	2.817	2.547	2.643	2.743	3.206	3.628	3.868	2.453	1.756	1.853	2.386	1.967	2.656
	7	2.778	2.521	2.617	2.706	3.185	3.597	3.851	2.427	1.727	1.828	2.352	1.941	2.628
	8	2.756	2.486	2.586	2.686	3.171	3.572	3.827	2.401	1.700	1.816	2.323	1.927	2.604
	9	2.724	2.472	2.574	2.670	3.152	3.558	3.797	2.386	1.685	1.783	2.291	1.900	2.583
	10	2.684	2.451	2.558	2.623	3.127	3.543	3.772	2.356	1.669	1.754	2.263	1.886	2.540
	Mean	2.711	2.447	2.506	2.626	3.234	3.663	3.889	2.328	1.64	1.857	2.336	1.938	

Table 19 : Manganese content (ppm) of sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer			Rainy					Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	1.073	1.355	1.497	1.376	1.444	1.567	1.717	0.936	0.707	0.843	1.073	1.035	1.218
	2	1.056	1.327	1.472	1.352	1.426	1.543	1.697	0.927	0.683	0.828	0.997	1.003	1.192
	3	1.031	1.316	1.456	1.327	1.401	1.527	1.672	0.907	0.676	0.807	0.972	0.981	1.173
	4	1.004	1.301	1.432	1.306	1.382	1.506	1.685	0.889	0.643	0.782	0.952	0.971	1.154
	5	0.986	1.286	1.427	1.289	1.375	1.489	1.672	0.872	0.627	0.769	0.938	0.956	1.140
	6	0.963	1.273	1.406	1.252	1.356	1.474	1.656	0.856	0.605	0.748	0.927	0.937	1.121
	7	0.947	1.261	1.389	1.228	1.336	1.452	1.628	0.847	0.586	0.728	0.910	0.928	1.103
	8	0.932	1.247	1.372	1.206	1.317	1.427	1.606	0.816	0.572	0.717	0.896	0.918	1.085
	9	0.921	1.232	1.357	1.193	1.302	1.408	1.585	0.802	0.563	0.698	0.872	0.891	1.069
	10	0.905	1.216	1.342	1.176	1.288	1.492	1.574	0.785	0.548	0.675	0.860	0.872	1.061
Dharwad	Mean	0.982	1.281	1.415	1.271	1.363	1.490	1.650	0.864	0.621	0.760	0.940	0.950	
	1	0.749	0.843	0.755	0.936	1.206	1.355	1.497	0.642	0.512	0.641	0.697	0.744	0.881
	2	0.737	0.830	0.716	0.917	1.186	1.321	1.473	0.637	0.486	0.623	0.681	0.712	0.860
	3	0.719	0.817	0.701	0.893	1.156	1.286	1.448	0.618	0.456	0.586	0.663	0.682	0.835
	4	0.198	0.216	0.262	0.278	1.132	1.246	1.416	0.162	0.104	0.116	0.124	0.144	0.450
	5	0.698	0.786	0.682	0.868	1.106	1.217	1.383	0.586	0.421	0.556	0.632	0.610	0.795
	6	0.681	0.771	0.668	0.857	0.990	1.189	1.376	0.532	0.403	0.543	0.610	0.586	0.767
	7	0.673	0.759	0.647	0.828	0.980	1.172	1.352	0.517	0.381	0.526	0.589	0.572	0.750
	8	0.662	0.743	0.631	0.806	0.810	1.157	1.310	0.506	0.356	0.517	0.574	0.561	0.719
	9	0.647	0.732	0.620	0.796	0.794	1.142	1.298	0.490	0.328	0.503	0.562	0.550	0.705
10	0.621	0.715	0.603	0.781	0.785	1.127	1.263	0.471	0.301	0.487	0.546	0.528	0.685	
	Mean	0.638	0.721	0.628	0.716	1.014	1.221	1.361	0.516	0.375	0.51	0.568	0.569	

Table 20 : Lead content (ppm) in sewage of Hubli and Dharwad at different intervals of time and distance

Place	Distance (km)	Winter				Summer				Rainy				Mean
		Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	Oct-98	
Hubli	1	0.061	0.078	0.095	0.098	0.106	0.126	0.148	0.048	0.034	0.051	0.068	0.056	0.072
	2	0.005	0.071	0.086	0.091	0.097	0.123	0.132	0.040	0.009	0.038	0.052	0.045	0.070
	3	0.037	0.068	0.079	0.086	0.082	0.116	0.118	0.033	0.007	0.027	0.039	0.032	0.060
	4	0.032	0.062	0.072	0.081	0.078	0.109	0.103	0.027	BDL	0.013	0.032	0.028	0.054
	5	0.029	0.057	0.068	0.077	0.072	0.098	0.095	0.021	BDL	0.009	0.024	0.026	0.048
	6	0.022	0.053	0.061	0.073	0.069	0.091	0.09	0.018	BDL	0.004	0.009	0.021	0.043
	7	0.013	0.048	0.057	0.068	0.062	0.087	0.081	0.013	BDL	BDL	0.003	0.019	0.038
	8	0.012	0.045	0.055	0.065	0.058	0.081	0.073	0.009	BDL	BDL	BDL	0.011	0.034
	9	0.008	0.041	0.051	0.061	0.051	0.007	0.069	0.006	BDL	BDL	BDL	0.008	0.030
	10	0.006	0.032	0.048	0.057	0.043	0.058	0.061	0.003	BDL	BDL	BDL	0.002	0.029
Dharwad	Mean	0.027	0.056	0.067	0.076	0.072	0.090	0.097	0.022	0.007	0.014	0.024	0.025	
	1	0.098	0.105	0.126	0.154	0.168	0.192	0.282	0.156	0.064	0.084	0.092	0.088	0.134
	2	0.041	0.052	0.062	0.072	0.086	0.093	0.104	0.072	0.028	0.035	0.046	0.032	0.060
	3	0.037	0.046	0.051	0.065	0.072	0.086	0.095	0.065	0.017	0.012	0.025	0.028	0.050
	4	BDL	BDL	BDL	BDL	0.062	0.073	0.086	BDL	BDL	BDL	BDL	BDL	0.018
	5	0.026	0.035	0.043	0.052	0.063	0.071	0.069	0.043	0.009	0.006	0.012	0.016	0.037
	6	0.019	0.026	0.035	0.041	0.056	0.058	0.051	0.032	0.003	0.003	BDL	0.012	0.028
	7	0.011	0.017	0.021	0.033	0.042	0.042	0.040	0.021	BDL	BDL	BDL	0.005	0.019
	8	0.006	0.011	0.012	0.021	0.031	0.027	0.029	0.016	BDL	BDL	BDL	0.003	0.013
	9	0.003	0.008	0.008	0.012	0.017	0.018	0.016	0.012	BDL	BDL	BDL	BDL	0.007
	10	0.001	0.003	0.003	0.008	0.010	0.016	0.012	0.005	BDL	BDL	BDL	BDL	0.004
	Mean	0.042	0.030	0.033	0.046	0.061	0.068	0.078	0.039	0.012	0.014	0.018	0.018	

Cadmium and nickel were present in below detectable levels,

BDL - Below detectable level.

The concentration of Mn during different months and at different points from the sewage outlet has been presented in Table 19. The highest and lowest Mn concentration recorded in Hubli sewage was 0.548 and 1.717 ppm, while that of in Dharwad sewage was 0.104 and 1.497 ppm, respectively. July '99 recorded the lowest monthly mean Mn concentration, while the highest was registered during May '99 both in Hubli and Dharwad. Annual average concentration of Mn decreased with an increase in the distance from the sewage outlet.

The content of lead in sewage water of Hubli ranged between below detectable level and 0.148 ppm, while that of Dharwad was between below detectable level to 0.282 ppm. July '99 recorded the lowest monthly mean concentration of Pb in sewage of Hubli and Dharwad (0.007 and 0.012 ppm, respectively). While the highest of 0.097 and 0.078 ppm of Pb was registered during May '99 both in Hubli and Dharwad, respectively (Table 20).

4.2 EFFECT OF SEWAGE WATER IRRIGATION ON SOIL PROPERTIES

4.2.1 Physical properties

4.2.1.1 Bulk density (BD)

Sewage irrigated field had lower bulk density than fields not irrigated with the sewage water. Relatively lower BD of soil was recorded at fields near the sewage outlet. The bulk density increased with an increase in depth. It increased as the distance along the sewage outlet increased. The BD of Dharwad soils was lesser than that of Hubli soils (Table 21). Lowest BD of 1.22 Mg m^{-3} was recorded in the 0-15 cm layer of soil profile

Table 21 : Effect of sewage water irrigation on bulk density (Mg m^{-3}), Particle density (Mg m^{-3}) and per cent porosity of soils of Hubli and Dharwad

Depth(cm)	Sewage irrigated									Sewage unirrigated					
	0 km			5 km			10 km			0 km			10 km		
	BD	PD	Porosity	BD	PD	Porosity	BD	PD	Porosity	BD	PD	Porosity	BD	PD	Porosity
Hubli															
0-15	1.28	2.51	48.38	1.36	2.53	45.82	1.39	2.52	44.84	1.39	2.54	46.06	1.42	2.53	43.87
15-30	1.33	2.56	48.04	1.41	2.59	45.34	1.43	2.61	45.21	1.44	2.61	46.18	1.49	2.61	42.97
Dharwad															
0-15	1.22	2.52	51.58	1.32	2.51	47.82	1.37	2.54	53.93	1.39	2.50	45.27	1.40	2.53	44.66
15-30	1.31	2.58	48.06	1.36	2.58	47.49	1.43	2.60	45.00	1.41	2.60	46.18	1.48	2.61	43.29

irrigated with the sewage near to the outlet in Dharwad. Highest BD of 1.43 Mg m^{-3} was recorded in the 15-30 cm layer of the sewage irrigated field which was ten km away from the sewage outlet in Dharwad (Table 21).

The BD of sewage irrigated fields at Hubli ranged between 1.28 and 1.43 Mg m^{-3} . While with no sewage irrigation, the values ranged from 1.39 to 1.49 Mg m^{-3} .

4.2.1.2 Particle density (PD) and percent porosity

The data pertaining to particle density (PD) and percent porosity of sewage irrigated and unirrigated fields of Hubli and Dharwad are presented in the Table 21. The particle density of sewage irrigated fields ranged between 2.51 and 2.61 Mg m^{-3} in Hubli and 2.52 and 2.60 Mg m^{-3} in Dharwad while, that of sewage unirrigated fields it ranged between 2.53 and 2.61 Mg m^{-3} and 2.50 and 2.61 Mg m^{-3} in Dharwad. Highest per cent porosity of 48.38 was registered in surface layer (0-15 cm) of sewage irrigated soils near the outlet, while the lowest of 44.84 per cent was recorded in surface layer (0-15 cm) of sewage irrigated fields which was ten km a way from the sewage outlet. Per cent porosity of sewage unirrigated fields in Hubli ranged from 42.97 to 46.18 per cent. In sewage irrigated fields of Dharwad, per cent porosity ranged from 45.00 to 53.93 while in sewage unirrigated fields it ranged from 43.29 to 46.18 per cent.

4.2.1.3 Volume of expansion and maximum water holding capacity (MWHC)

The volume of expansion and maximum water holding capacity (MWHC) of both sewage irrigated and unirrigated profile increased with an

Table 22 : Effect of sewage water irrigation of volume of expansion and maximum water holding capacity of soils of Hubli and Dharwad

Depth (cm)	Sewage Irrigated						Sewage unirrigated			
	0 km		5 km		10 km		0 km		10 km	
	Volume of expansion (%)	MWHC (%)	Volume of expansion (%)	MWHC (%)	Volume of expansion (%)	MWHC (%)	Volume of expansion (%)	MWHC (%)	Volume of expansion (%)	MWHC (%)
Hubli										
0-15	51.12	63.12	52.26	62.16	49.52	61.36	50.16	60.18	51.12	61.12
15-30	52.24	65.16	65.16	63.26	51.12	63.28	51.12	61.12	52.84	63.18
30-60	53.36	66.28	53.36	64.18	52.18	64.26	52.28	64.24	54.18	64.08
60-90	54.28	68.14	54.28	62.16	54.06	65.12	54.18	64.46	56.12	65.56
90-120	55.16	68.82	55.16	66.14	55.28	65.76	55.12	66.28	55.92	66.42
Dharwad										
0-15	56.12	64.12	53.16	63.42	55.12	62.12	52.18	61.18	51.18	60.18
15-30	58.62	66.18	55.12	64.28	56.72	64.48	53.42	62.18	52.24	62.52
30-60	59.71	67.12	55.82	65.72	57.12	65.76	54.16	64.16	52.92	64.12
60-90	63.82	69.78	56.56	66.16	57.82	66.73	55.08	65.08	53.68	64.56
90-120	65.12	68.12	58.26	68.82	58.12	68.12	56.02	65.92	54.12	66.92

increase in the depth. Higher volume of expansion and MWHC was recorded at the profile near the sewage outlet in both Hubli and Dharwad and it decreased with an increase in the distance from the sewage outlet. The volume of the expansion of sewage irrigated profile samples of Hubli ranged from 49.52 to 55.28 per cent, while sewage unirrigated profile sample in Hubli, volume of expansion ranged from 50.16 to 56.12 per cent. The lowest volume of expansion of 55.12 per cent was recorded in the 0-15 cm layer of soil profile irrigated with sewage at ten km from the outlet, while the highest of 65.12 per cent was registered in the 90-120 cm profile layer irrigated with the sewage near the outlet in Dharwad. Sewage unirrigated profile samples in Dharwad had volume of expansion ranging from 51.18 and 56.02 per cent. MWHC of Hubli profile sample irrigated with sewage was between 61.36 and 68.82 per cent, while that of profile samples without sewage irrigation it ranged from 60.18 to 66.42 per cent. Soil profile samples irrigated with sewage water in Dharwad, had MWHC ranged from 62.12 to 69.78 per cent, while soil profile samples without sewage irrigation it ranged between 60.18 and 66.92 per cent (Table 22).

4.2.1.4 Infiltration rate (IR)

Infiltration rate of sewage irrigated and unirrigated field has been depicted in the Fig. 4. The IR of sewage irrigated fields were lower than the unirrigated fields both in Hubli and Dharwad. Greater reduction in IR was observed in the farmers' fields irrigated with sewage near the outlet in Hubli and Dharwad.

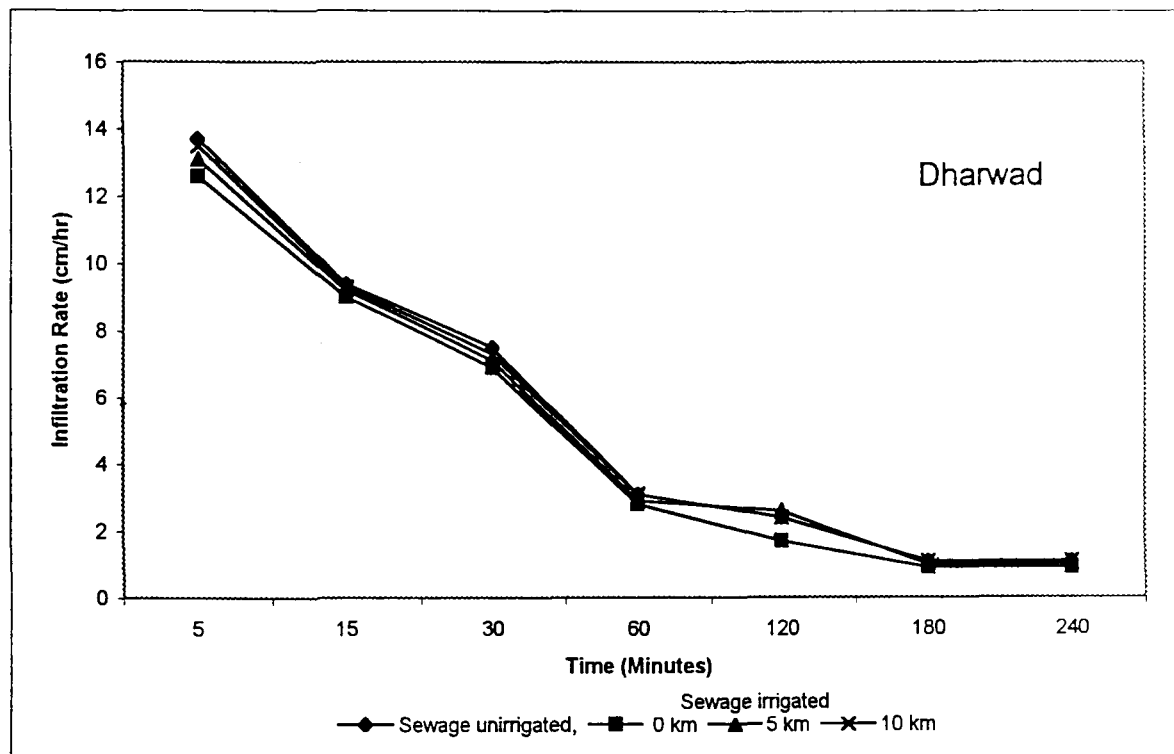
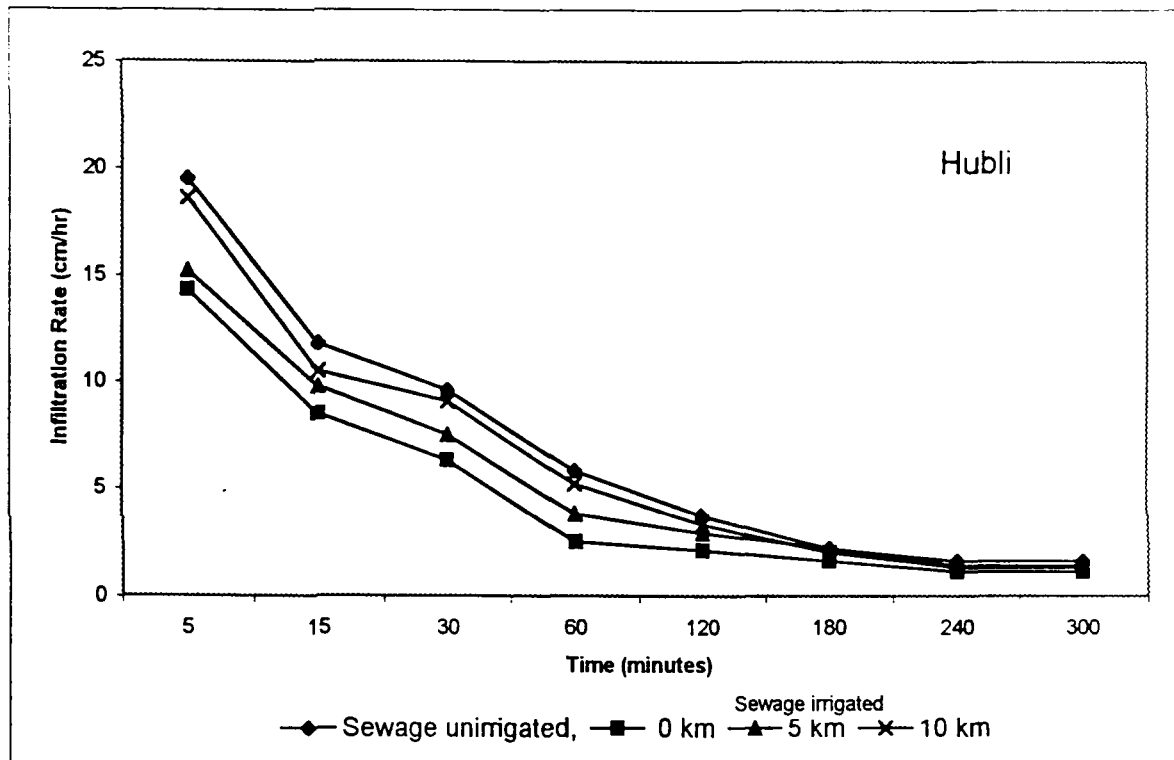


Fig. 4 : Effect of sewage water irrigation on infiltration rate of soils of Hubli and Dharwad

4.3 EFFECT OF SEWAGE WATER IRRIGATION ON CHEMICAL PROPERTIES OF SOIL

4.3.1 Soil reaction

In sewage irrigated profile samples, pH values were higher than that of sewage unirrigated profiles in both Hubli and Dharwad. The pH of the both sewage irrigated and sewage unirrigated profile samples increased with an increase in the depth. Higher pH was recorded in the soil profile samples near to the sewage outlet. The pH of the soil profile irrigated with sewage in Hubli ranged between 7.60 to 8.90, while that of unirrigated profiles it ranged between 7.60 and 7.85. Sewage irrigated profile samples in Dharwad had pH ranging from 7.85 to 8.75, while in sewage unirrigated profile samples it ranged 7.75 to 7.85 (Table 23).

The pH of the surface layer (0-15 cm) of the sewage irrigated fields near the sewage outlet, five km and 10 km away from the sewage outlet was 8.25, 8.05 and 7.60 in Hubli and 8.35, 8.40 and 7.85 in Dharwad, respectively. While in sewage unirrigated samples (0-15 cm layer) the pH ranged between 7.60 and 7.65 in Hubli and 7.75 and 7.65 in Dharwad.

4.3.2 Electrical conductivity (EC)

The EC of surface layer (0-15 cm) of the sewage irrigated fields near the sewage outlet, five km and 10 km away from the sewage outlet was 0.41, 0.32 and 0.24 dS m⁻¹, in Hubli and 0.49, 0.36 and 0.31 dS m⁻¹.

Relatively higher electrical conductivity of soil was noticed in the profiles irrigated with sewage than unirrigated profiles and it increased with an increase in the depth. EC of profile samples decreased as the distance

Table 23 : Effect of sewage water irrigation on pH, EC and organic carbon content of soils of Hubli and Dharwad

Depth (cm)	Sewage irrigated									Sewage unirrigated					
	0 km			5 km			10 km			0 km			10 km		
	pH	EC dSm ⁻¹	OC (%)	pH	EC dSm ⁻¹	OC (%)	pH	EC dSm ⁻¹	OC (%)	pH	EC dSm ⁻¹	OC (%)	pH	EC dSm ⁻¹	OC (%)
Hubli															
0-15	8.25	0.41	1.23	8.05	0.32	0.95	7.60	0.24	0.47	7.60	0.16	0.44	7.65	0.13	0.42
15-30	8.45	0.56	0.65	8.35	0.39	0.64	7.65	0.27	0.42	7.75	0.19	0.37	7.70	0.16	0.39
30-60	8.70	0.58	0.54	8.45	0.41	0.55	7.70	0.29	0.41	7.60	0.25	0.32	7.65	0.20	0.35
60-90	8.85	0.69	0.54	8.30	0.43	0.53	7.85	0.32	0.39	7.65	0.38	0.28	7.80	0.33	0.29
90-120	8.90	0.64	0.48	8.50	0.42	0.48	7.80	0.36	0.37	7.70	0.32	0.25	7.85	0.32	0.27
Dharwad															
0-15	8.35	0.49	0.92	8.40	0.36	0.88	7.85	0.31	0.46	7.75	0.26	0.42	7.65	0.24	0.39
15-30	8.40	0.51	0.66	8.50	0.38	0.51	7.90	0.33	0.41	7.80	0.28	0.35	7.70	0.27	0.31
30-60	8.50	0.54	0.66	8.55	0.41	0.50	7.95	0.36	0.36	7.80	0.31	0.32	7.80	0.30	0.28
60-90	8.65	0.59	0.54	8.60	0.51	0.47	8.10	0.40	0.32	7.85	0.35	0.32	7.75	0.32	0.28
90-120	8.70	0.50	0.51	8.75	0.47	0.37	8.05	0.45	0.32	7.85	0.33	0.28	7.85	0.34	0.27

from the sewage outlet increased. EC of sewage irrigated profiles in Hubli ranged from 0.24 to 0.69 dS m⁻¹. While that of profiles without sewage irrigation it was between 0.13 and 0.38 dS m⁻¹. The range of EC in profile of sewage irrigated sites in Dharwad was between 0.31 and 0.59 dS m⁻¹, while that of unirrigated profiles was between 0.24 and 0.35 dS m⁻¹ (Table 23).

4.3.3 Organic carbon content

The organic carbon content of surface layer of sewage irrigated fields near the outlet, five km and ten km away from the sewage outlet was 1.23, 0.95 and 0.47 per cent in Hubli and 0.92, 0.88 and 0.46 per cent in Dharwad, respectively. While sewage unirrigated fields had organic carbon content of 0.44 and 0.42 per cent in 0-15 cm layer in fields near the outlet and ten km away from the sewage outlet, respectively in Hubli, while in Dharwad it was between 0.42 and 0.39 per cent, respectively in 0-15 cm layer in fields near the outlet and ten km away from the sewage outlet.

Soil profile samples irrigated with sewage near the sewage outlet both at Hubli and Dharwad had relatively higher organic carbon content and it decreased with an increase in the distance from the sewage outlet and depth. The organic carbon content of soil profile samples irrigated with sewage in Hubli ranged from 0.37 to 1.23 per cent, while that of without sewage irrigation it ranged between 0.25 and 0.44 per cent (Table 23). Sewage irrigated profile in Dharwad had organic carbon content ranging from 0.32 to 0.92 per cent, while that of sewage unirrigated profile it ranged between 0.27 and 0.42 per cent.

4.3.4 Exchangeable cations, cation exchange capacity (CEC), exchangeable sodium percentage(ESP) and sodium adsorption ratio (SAR)

The data pertaining to exchangeable cations, CEC, ESP and SAR of soils of Hubli and Dharwad are presented in the Table 24. Sewage irrigated profile samples of both Hubli and Dharwad had higher concentration of exchangeable cations such as Ca, Mg, Na and K than profile samples without sewage irrigation. It decreased with an increase in the distance from the sewage outlet in both Hubli and Dharwad.

Sewage irrigated profiles had highest exchangeable Ca content of 28.8 cmol (p+) kg⁻¹ was recorded in 0-15 profile layer near the sewage outlet in Hubli and 38.4 cmol (p+) kg⁻¹ in 90-120 cm profile layer near the sewage outlet in Dharwad. The lowest exchangeable Ca content of 24.00 cmol (p+) kg⁻¹ was recorded in 0-15 cm profile layer which was ten km away from sewage outlet in Hubli and 30.3 cmol (p+) kg⁻¹ was recorded in the 90-120 cm profile layer ten km away from the sewage outlet in Dharwad. Sewage unirrigated profiles had exchangeable Ca content ranging from 26.70 to 32.30 cmol (p+) kg⁻¹ in Dharwad and 21.00 to 26.70 cmol (p+) kg⁻¹ in Hubli.

Sewage irrigated profiles had highest exchangeable Mg content of 15.00 cmol (p+) kg⁻¹ in 60-90 cm profile layer near the sewage outlet in Dharwad and 9.8 cmol (p+) kg⁻¹ in 90-120 cm profile layer near the sewage outlet in Hubli. The lowest exchangeable Mg content of 5.2 cmol (p+) kg⁻¹ and 6.8 cmol (p+) kg⁻¹ was recorded in 0-15 cm profile layer ten km away from sewage outlet at both Hubli and Dharwad, respectively. Sewage unirrigated profiles had exchangeable Mg content ranging from 6.1 to 7.4 cmol (p+) kg⁻¹ in Dharwad and 4.8 to 6.5 cmol (p+) kg⁻¹ in Hubli.

Table 24 : Effect of sewage water irrigation on exchangeable cations, CEC, ESP and SAR of soils of Hubli and Dharwad

Depth (cm)	Sewage Irrigated															
	0 km								5 km							
	Ca	Mg	Na	K	CEC	ESP	SAR		Ca	Mg	Na	K	CEC	ESP	SAR	
	cmol (P+) kg ⁻¹								cmol (P+) kg ⁻¹							
Hubli																
0-15	28.80	9.60	3.58	1.28	47.22	7.54	1.23		24.60	8.60	1.96	1.00	35.41	5.50	0.49	
15-30	27.60	9.40	6.44	0.90	46.34	13.90	1.50		25.80	8.80	2.30	0.68	36.36	6.32	0.56	
30-60	27.40	9.40	7.56	0.84	47.85	15.79	1.63		25.60	8.20	2.38	0.36	37.34	6.37	0.57	
60-90	28.40	8.40	8.04	0.70	48.74	16.75	1.74		25.60	8.60	2.68	0.36	40.24	6.66	0.65	
90-120	27.40	9.60	8.24	0.56	49.10	16.78	1.92		25.90	8.20	2.72	0.32	38.12	7.13	0.66	
	Sewage unirrigated															
Hubli																
0-15	21.20	4.80	1.08	0.62	28.10	3.84	0.29									
15-30	21.20	5.20	1.16	0.62	28.06	4.06	0.32									
30-60	23.10	5.50	1.22	0.52	32.34	3.77	0.32									
60-90	21.00	5.40	1.40	0.46	32.86	4.26	0.38									
90-120	24.80	6.20	1.92	0.46	34.38	5.58	0.49									

Contd...

Contd....

Depth(Cm)		Sewage Irrigated																							
		0 km						5 km						10 km											
		Ca	Mg	Na	K	CEC	ESP	SAR	Ca	Mg	Na	K	CEC	ESP	SAR	Ca	Mg	Na	K	CEC	ESP	SAR			
		cmol (P+) kg ⁻¹						cmol (P+) kg ⁻¹						cmol (P+) kg ⁻¹											
Dharwad		33.80	15.40	3.80	1.18	57.98	6.55	0.77	30.60	12.00	3.04	0.94	49.78	6.10	0.65	30.40	6.80	1.94	0.60	42.20	4.60	0.45			
0-15		27.60	14.80	5.34	0.96	52.80	10.11	1.16	30.60	14.00	3.68	0.82	52.70	6.98	0.78	30.90	7.10	2.12	0.61	43.30	4.90	0.49			
15-30		29.60	14.20	6.60	0.58	56.00	11.78	1.41	30.80	14.80	4.08	0.84	54.12	7.53	0.85	31.10	6.90	2.30	0.54	43.94	5.23	0.53			
30-60		31.80	15.00	7.44	0.48	59.90	12.72	1.54	33.80	14.20	4.38	0.72	55.50	7.89	0.89	32.20	7.80	3.56	0.51	47.27	7.53	0.81			
60-90		38.40	13.00	8.08	0.46	63.30	12.76	1.59	34.80	12.60	4.52	0.72	54.70	8.28	0.93	30.30	8.10	5.60	0.48	46.86	11.94	1.28			
90-120																									
		Sewage unirrigated																							
Dharwad		26.70	6.40	1.28	0.62	36.17	3.54	0.31								29.10	6.10	1.34	0.66	36.26	3.50	0.32			
0-15		27.90	6.70	1.46	0.54	37.42	3.90	0.35								30.80	6.40	1.52	0.50	39.26	3.87	0.35			
15-30		29.00	7.20	1.58	0.37	39.12	4.03	0.37								30.70	6.40	1.64	0.38	41.15	3.99	0.38			
30-60		30.30	7.10	1.74	0.35	41.48	4.18	0.40								32.30	6.90	2.00	0.36	43.28	4.62	0.45			
60-90		30.00	6.80	1.88	0.32	40.86	4.60	0.44								31.00	7.40	2.44	0.34	42.16	5.80	0.56			
90-120																									

The exchangeable sodium content increased with an increase in the depth of profiles in the both sewage irrigated and unirrigated sites. It ranged from 1.56 to 8.24 cmol (p+) kg⁻¹ in sewage irrigated profiles of Hubli and 1.94 to 8.08 cmol (p+) kg⁻¹ in sewage irrigated profiles in Dharwad. The exchangeable sodium content of sewage unirrigated profiles ranged from 1.08 to 1.92 cmol (p+) kg⁻¹ in Hubli and 1.28 to 2.24 cmol (p+) kg⁻¹ in Dharwad.

Exchangeable potassium content in soil profile samples with sewage irrigation decreased with an increase in depth of the profile. The content of exchangeable potassium in profile of sewage irrigated profiles ranged from 0.32 to 1.28 cmol (p+) kg⁻¹ in Hubli and 0.46 to 1.18 cmol (p+) kg⁻¹ in Dharwad (Table 24). Profiles unirrigated with sewage had exchangeable potassium content ranged between 0.46 and 0.65 cmol (p+) kg⁻¹ in Hubli and 0.32 and 0.66 cmol (p+) kg⁻¹ in Dharwad.

The CEC of soil profile samples irrigated with sewage was higher than unirrigated soil profiles. The CEC decreased with an increase in the distance along the sewage outlet. The CEC value of Dharwad soil profile samples was higher than the CEC values of Hubli soil profile samples with and without sewage irrigation. The CEC of soil profile samples with sewage irrigation ranged from 34.56 to 49.10 cmol (p+) kg⁻¹ in Hubli and 42.2 to 63.3 cmol (p+) kg⁻¹ in Dharwad. The sewage unirrigated profile had CEC ranging between 28.10 to 35.86 cmol (p+) kg⁻¹ in Hubli and 36.17 to 43.28 cmol (p+) kg⁻¹ in Dharwad.

Higher percentage of ESP and SAR was recorded in profile samples near by sewage outlets both in Hubli and Dharwad. The ESP of sewage

irrigated profiles ranged from 4.51 to 16.78 per cent in Hubli, while in Dharwad it ranged from 4.60 to 12.76 per cent. Sewage unirrigated profiles had ESP ranging from 3.51 to 5.58 per cent in Hubli and 3.50 to 5.80 per cent in Dharwad.

Sewage irrigated profiles had SAR ranging from 0.41 to 1.92 in Hubli and 0.45 to 1.59 in Dharwad. While sewage unirrigated profiles had SAR ranging from 0.29 to 0.49 in Hubli and 0.31 to 0.56 in Dharwad.

4.4 NUTRIENT STATUS IN SOIL

The available nitrogen, phosphorus and potassium content of the sewage irrigated profile samples were higher than profiles without sewage irrigation both in Hubli and Dharwad. The available nutrient content in these profile samples decreased as the distance along the sewage outlet increased in both the places. They also decreased with increase in the depth of the profiles.

High N status was recorded in the surface samples (0-15 cm layer) of sewage irrigated profiles near the sewage outlet and five km away from sewage outlet in Hubli, whereas it was so, only near the sewage outlet in Dharwad. While medium N status was recorded in 0-15 cm layer of sewage irrigated profile five km away from the outlet in Dharwad. While low N status was noticed in sewage unirrigated profiles and sewage irrigated profiles ten km away from the outlet both in Hubli and Dharwad.

Available nitrogen content of 117.0 to 796.0 kg ha⁻¹ was recorded in the soil profile samples irrigated with sewage in Hubli as that of sewage

Table 25 : Effect of sewage water irrigation on available N, P₂O₅ and K₂O of soils of Hubli and Dharwad

Depth (cm)	Sewage irrigated										Sewage unirrigated									
	0 km					10 km					0 km					10 km				
	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O		N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	
	Kg ha ⁻¹										Kg ha ⁻¹									
Hubli																				
0-15	796.0	68.30	984.00	590.0	41.61	768.60	206.0	27.98	576.00	185.0	17.48	552.00	193.0	16.16	548.00					
15-30	377.0	52.60	696.00	364.0	30.78	528.00	152.0	17.22	528.00	165.0	10.61	504.00	137.0	10.10	546.00					
30-60	336.0	24.32	648.00	322.0	19.18	288.00	137.0	10.12	312.00	151.0	7.21	336.00	124.0	7.46	288.00					
60-90	302.0	10.06	438.00	309.0	8.76	284.00	123.0	9.16	240.00	111.0	6.48	264.00	96.0	6.18	264.00					
90-120	247.0	8.26	528.00	268.0	8.58	284.00	117.0	8.64	240.00	96.0	5.31	240.00	89.0	5.43	296.00					
Dharwad																				
0-15	569.0	54.28	912.00	439.0	27.22	676.00	268.0	18.60	628.00	239.0	13.12	586.00	252.0	14.32	558.00					
15-30	398.0	39.26	816.00	370.0	20.16	596.00	233.0	10.12	594.00	219.0	9.16	492.00	225.0	9.62	514.00					
30-60	336.0	19.12	552.00	274.0	10.16	556.00	220.0	8.14	416.00	194.0	7.98	386.00	186.0	8.10	436.00					
60-90	374.0	12.16	456.00	158.0	9.59	436.00	165.0	6.84	398.00	148.0	6.12	312.00	151.0	6.46	313.00					
90-120	151.0	10.12	432.00	130.0	8.56	388.00	130.0	5.12	363.00	128.0	5.31	287.00	111.0	5.12	282.00					

unirrigated profiles it ranged from 89.0 to 193.0 kg ha⁻¹ (Table 25). Available nitrogen content in sewage irrigated profiles in Dharwad ranged from 130.0 to 569.0 kg ha⁻¹, whereas in sewage unirrigated profiles it ranged from 111.0 to 252.0 kg ha⁻¹.

Available phosphorus status was high in sewages irrigated profiles (0-15 cm) near the sewage outlet, while medium available P status was registered in the surface layer (0-15 cm) irrigated with sewage at five km away from sewage outlet and it was low in sewage irrigated profile ten km away from sewage outlet and sewage unirrigated profiles.

The available phosphorus content of soil profiles irrigated with sewage in Hubli ranged from 8.26 to 68.3 kg ha⁻¹ while in sewage unirrigated profile it ranged from 5.31 to 17.48 kg ha⁻¹ (Table 25). The available P content in sewage irrigated profiles in Dharwad ranged from 5.12 to 54.28 kg ha⁻¹, where as in sewage unirrigated profiles it ranged from 5.12 to 14.32 kg ha⁻¹.

The available potassium content of both sewage irrigated and unirrigated profiles was high in surface layer (0-15 cm). Sewage irrigated profiles had higher available potassium content than sewage unirrigated profiles.

Available potassium content ranged from 240.00 to 948.00 kg ha⁻¹ in sewage irrigated profiles of Hubli, while that of unirrigated profiles the value ranged from 240.00 to 552.00 kg ha⁻¹. The available potassium content of soil profile irrigated with sewage in Dharwad was between 363.00 and 912.00 kg ha⁻¹, while that of sewage unirrigated profile it was 282.00 to 586.00 kg ha⁻¹ (Table 25).

4.5 DTPA EXTRACTABLE MICRONUTRIENTS IN SOIL

The data pertaining to DTPA extractable micronutrients in soil profiles with and without sewage irrigation are presented in the Table 26. The content of these micronutrients such as Zn, Fe, Cu and Mn decreased with an increase in the depth of the profile and also with an increase in the distance from the sewage outlet in Hubli and Dharwad. Highest content of DTPA extractable micronutrients such as Fe, Mn, Cu and Zn were recorded in sewage irrigated profiles (0-15 cm) near the sewage outlet in both Hubli (12.55, 7.38, 8.32 and 3.54 ppm, respectively) and in Dharwad (9.45, 6.36, 6.82, 2.21 ppm, respectively).

4.6 DTPA EXTRACTABLE HEAVY METAL CONTENT IN SOIL

The DTPA extractable heavy metals such as Pb and Ni decreased with an increase in the depth of the soil profile in the sewage irrigated profiles of Hubli and Dharwad, While the content of DTPA extractable Cd was below detectable levels in sewage irrigated profile of Hubli and Dharwad (Table 27). Among the heavy metals Pb registered highest concentration. It varied between 0.39 and 0.97 ppm in sewage irrigated profiles near the outlet.

4.7 GROUND WATER QUALITY

The characteristics of ground water at Hubli and Dharwad are presented in the Table 28. The concentration of Fe, Mn, Cu, Zn, Pb, Ni and Cd were present at below detectable levels in both Hubli and Dharwad. The pH of the two bore well waters tested in Hubli was 6.9, while that of the open well water was 7.1. On the other hand bore well water in Dharwad

Table 26 : Effect of sewage water irrigation on DTPA extractable micronutrients (ppm) in soils of Hubli and Dharwad

Depth (cm)		Sewage Irrigated												Sewage unirrigated											
		0 km				5 km				10 km				0 km				10 km							
		Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn				
Hubli																									
	0-15	12.55	7.38	8.32	3.54	10.05	5.92	7.81	2.99	8.60	4.92	4.85	2.27	5.80	4.05	0.38	0.52	5.60	4.21	0.34	0.54				
	15-30	8.45	5.52	3.65	2.04	7.20	4.29	7.52	2.07	7.75	3.76	2.28	1.06	4.25	2.36	0.37	0.39	4.05	2.46	0.21	0.40				
	30-60	8.10	5.25	3.62	1.71	6.55	2.41	6.17	1.49	6.65	3.32	2.29	0.6	2.65	1.98	0.21	0.30	2.95	1.90	0.21	0.35				
	60-90	5.20	4.34	3.41	0.94	6.00	2.38	3.96	0.66	4.95	2.91	2.01	0.56	1.75	1.68	0.20	0.32	2.35	1.72	0.19	0.30				
90-120	4.15	2.47	3.37	0.87	5.60	2.01	3.38	0.49	3.70	2.36	1.58	0.52	1.80	1.46	0.17	0.26	1.85	1.56	0.17	0.29					
Dharwad																									
	0-15	9.45	6.36	6.82	2.21	8.95	5.65	5.00	1.82	7.75	4.29	3.21	1.08	4.55	3.40	0.28	0.61	4.87	3.42	0.24	0.65				
	15-30	8.40	4.30	5.88	2.03	8.05	4.88	3.42	0.95	4.95	3.92	2.68	0.96	2.36	2.90	0.19	0.43	3.46	2.61	0.18	0.48				
	30-60	7.80	3.23	4.85	1.16	5.80	3.45	2.84	0.56	3.70	2.61	1.70	0.61	1.98	2.23	0.18	0.39	3.10	2.38	0.17	0.37				
	60-90	4.25	2.35	3.72	0.58	4.10	2.95	2.57	0.47	2.80	2.38	1.28	0.36	1.68	1.59	0.15	0.36	1.96	2.41	0.15	0.34				
90-120	3.30	1.36	2.33	0.44	3.20	2.23	2.32	0.38	1.70	2.41	1.16	0.28	1.46	1.75	0.15	0.33	1.75	1.68	0.12	0.26					

Table 27 : Effect of sewage water irrigation on DTPA extractable heavy metal (ppm) in soil of Hubli and Dharwad

Depth (cm)	Sewage Irrigated												Sewage unirrigated					
	0 km			5 km			10 km			0 km			10 km					
	Pb	Cd	Ni	Pb	Cd	Ni	Pb	Cd	Ni	Pb	Cd	Ni	Pb	Cd	Ni			
Hubli																		
0-15	0.97	BDL	0.23	0.29	BDL	0.12	0.17	BDL	0.10	0.070	BDL	BDL	0.018	BDL	BDL			
15-30	0.23	BDL	0.18	0.25	BDL	0.06	0.15	BDL	0.06	0.040	BDL	NDL	0.009	BDL	BDL			
30-60	0.20	BDL	0.17	0.21	BDL	0.03	0.12	BDL	0.03	0.006	BDL	BDL	BDL	BDL	BDL			
60-90	0.19	BDL	BDL	0.14	BDL	BDL	0.12	BDL	0.017	BDL	BDL	BDL	BDL	BDL	BDL			
90-120	0.12	BDL	BDL	0.13	BDL	BDL	0.10	BDL	0.009	BDL	BDL	BDL	BDL	BDL	BDL			
Dharwad																		
0-15	0.39	BDL	0.06	0.27	BDL	0.05	0.14	BDL	0.03	0.045	BDL	BDL	0.003	BDL	BDL			
15-30	0.29	BDL	0.05	0.18	BDL	0.03	0.10	BDL	0.012	0.038	BDL	BDL	0.003	BDL	BDL			
30-60	0.24	BDL	BDL	0.15	BDL	BDL	0.08	BDL	0.008	BDL	BDL	BDL	BDL	BDL	BDL			
60-90	0.18	BDL	BDL	0.13	BDL	BDL	0.08	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL			
90-120	0.14	BDL	BDL	0.12	BDL	BDL	0.06	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL			

BDL - Below detectable level.

Table 28 : Ground water characteristics around sewage drains in Hubli and Dharwad

	pH	EC dS/m	Ca	Mg	Na	SAR	K	CO ₃	HCO ₃	RSC	Cl	SO ₄	Fe	Mn	Cu	Zn	Pb	Ni	Cd
Place				meL ⁻¹						meL ⁻¹			ppm						
Hubli																			
Open well	7.10	2.24	4.80	6.30	8.70	3.69	2.18	Traces	12.08	0.98	10.15	8.62	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Borewell	6.90	1.51	2.50	4.90	5.62	2.92	2.92	Traces	9.60	2.20	12.05	7.48	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Borewell	6.90	1.92	3.60	5.10	7.39	3.54	2.43	Traces	10.56	1.86	10.70	6.49	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Dharwad																			
Open well	6.80	2.35	6.10	7.80	9.12	3.46	1.28	Traces	15.56	1.66	9.55	7.02	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Borewell	6.90	2.12	6.90	8.50	7.82	2.91	0.98	Traces	16.52	1.12	7.80	4.05	BDL	BDL	BDL	BDL	BDL	BDL	BDL

BDL - Below detectable levels

had a pH of 6.9 and open well water had a pH of 6.8. The EC of bore well waters in Hubli was 1.51 and 1.92 dS m⁻¹, whereas that of open well water was 2.24 dS m⁻¹. Bore well water in Dharwad had EC of 2.12 dS m⁻¹ and open well water had EC of 2.35 dS m⁻¹.

The Ca, Mg, Na and K concentration of open well water in Hubli was 4.8, 6.3, 8.7 and 2.18 me L⁻¹, respectively, while the concentration in bore well waters was between 2.5 and 3.6, 4.9 and 5.1, 5.62 and 7.39 and 2.43 and 2.92 me L⁻¹, respectively.

The concentration of Ca, Mg, Na and K in open well water in Dharwad was 6.1, 7.8, 9.12 and 1.28 me L⁻¹, respectively, whereas that of in bore well water was 6.9, 8.5, 7.82 and 0.98 me L⁻¹, respectively.

The HCO₃ and Cl concentration of open well water in Hubli was 12.08 and 10.15 me L⁻¹, respectively, while that of bore well waters was between 9.6 and 10.56 me L⁻¹ and 10.7 and 12.05 me L⁻¹, respectively.

The RSC of open well water in Hubli was 0.98 me L⁻¹, whereas that of bore well waters was between 1.86 and 2.2 me L⁻¹. Open well water in Dharwad had RSC of 1.66 me L⁻¹, while bore well water had RSC of 1.12 me L⁻¹.

The SAR of open well water in Hubli was 3.69, while that of bore well waters was 2.92 and 3.54. The SAR of open well water in Dharwad was 3.46, while that of bore well water in Dharwad was 2.91.

4.8 CORRELATION STUDIES

Positive and highly significant correlation was reported between organic carbon and pH (0.472 **), exchangeable K (0.788**), CEC (0.401**), DTPA extractable Cu (0.882**), Fe (0.868**), Zn (0.892 **) and Pb (0.914**), N (0.945**), P_2O_5 (0.880**) and K_2O (0.780**). Significant correlation was reported between OC and EC (0.352*), Ca (0.344**), exchangeable Na(0.329*) (Table 29).

Table 29 : Correlation coefficient (r) between organic carbon and other soil properties

Parameter	r' value
pH	0.472**
EC	0.352*
Ca+Mg	0.344*
Na	0.329*
K	0.788**
CEC	0.401**
Cu	0.882**
Fe	0.868**
Mn	0.821**
Zn	0.892**
Pb	0.914**
N	0.945**
P ₂ O ₅	0.88**
K ₂ O	0.780**
Volume of expansion	-0.017
MWHC	-0.135

DISCUSSION

V. DISCUSSION

When available fresh water supplies are limited, the urban wastewater may be viewed as agricultural resource. The characteristics of the sewage varies with the municipal cities resulting in the varied effect on soil and crops upon its use. The results of the present investigation on characterization of Hubli-Dharwad urban sewage and its impact on soil properties are discussed under the following headings.

5.1 CHARACTERISATION OF SEWAGE

Seasonal variation in the characteristics of the sewage such as pH, EC, BOD, total suspended solids, anions, cations and heavy metals was noticed at Hubli and Dharwad. Lowest concentration of the said parameters were recorded during rainy season (June to August '99) due to dilution with rain water during rainy season and highest concentration during the summer season (March -May '99) due to non-addition of rain water which has low concentration of the said parameters. Similar seasonal variation in the characteristics of sewage was reported by Adhikari *et al.* (1994); Trivedi and Singh, (1991) and Som *et al.*(1994).

Summer season and also sampling points one km from the sewage outlet recorded lower pH in Hubli and Dharwad (Fig.7). This may be due to the higher BOD at these points which might have resulted in the increased microbial activity which inturn resulted in the increased organic acids content and also due to the non-addition of rain water, the pH of which is near neutral might have also caused decrease in pH during summer. The pH of sewage of Hubli and Dharwad ranged between 6.5 and 7.7 which is

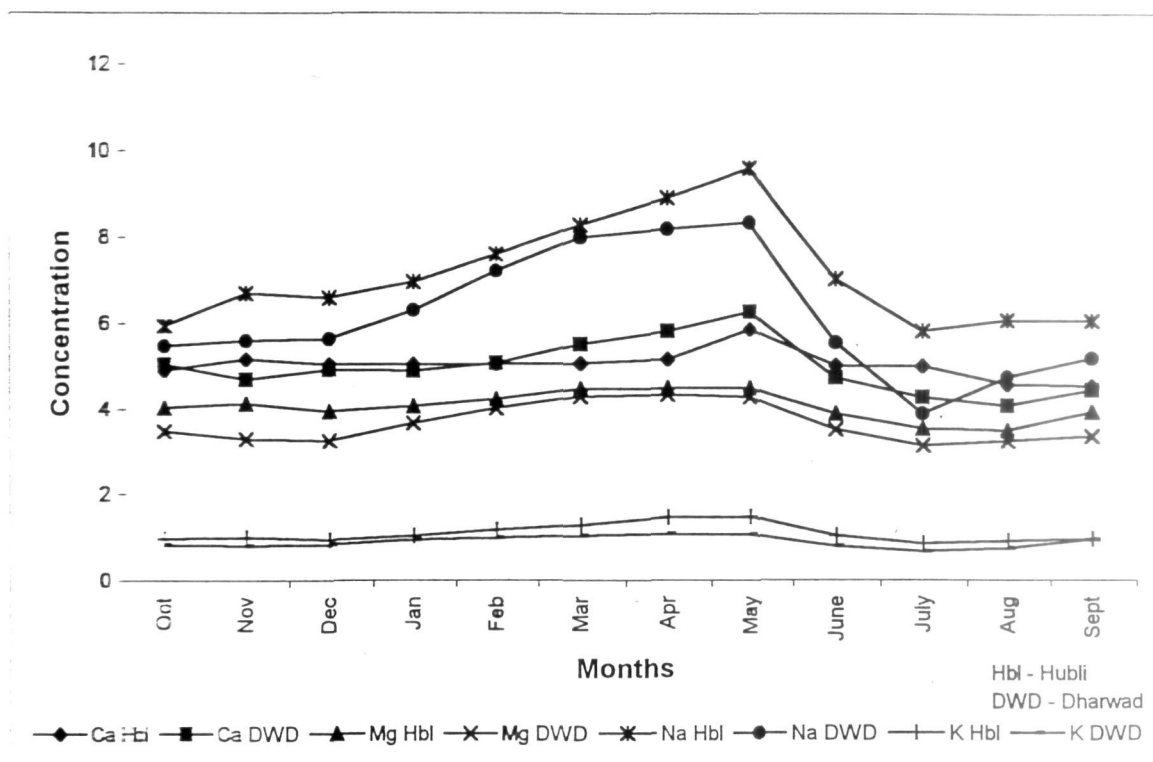
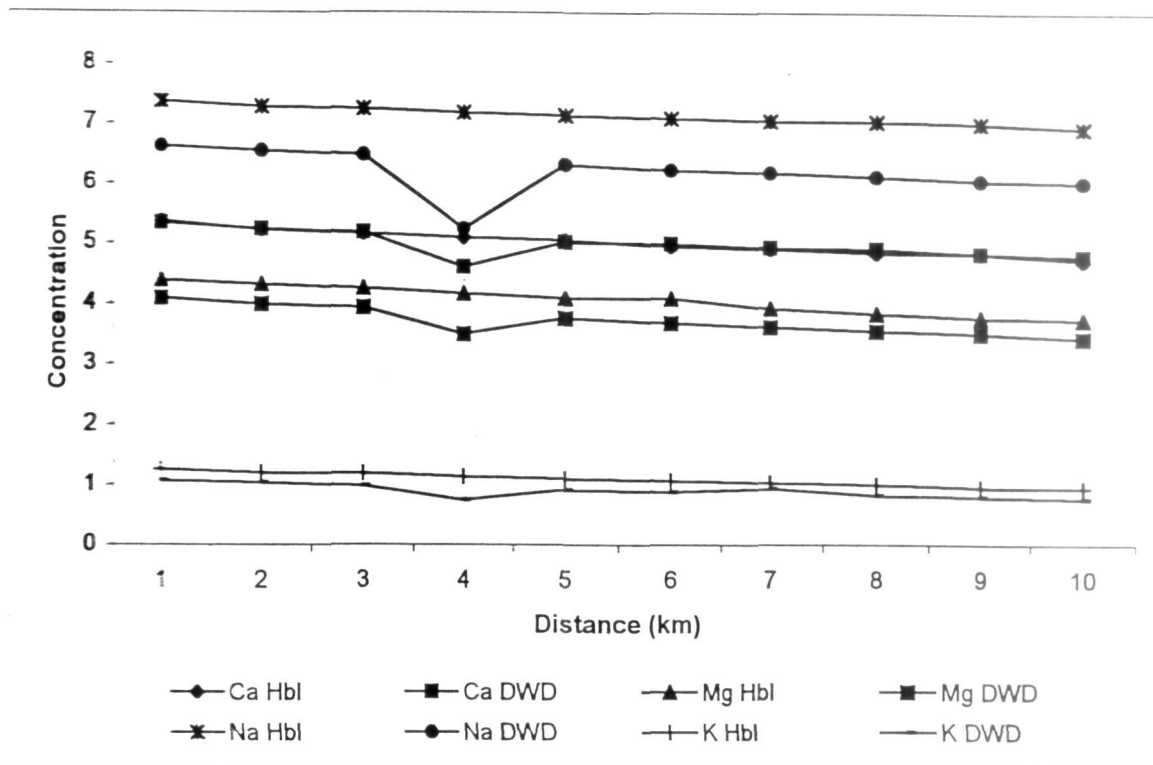


Fig. 5 : Average content of Ca, Mg, Na and K (me/L) in sewage of Hubli and Dharwad at different intervals of distance and time

within the safe limits of 6-8.5 (United States Salinity Laboratory Staff, 1954) for irrigation.

The EC of sewage of Dharwad remained less than 2.0 dSm^{-1} which falls under good quality of irrigation water category as per classification CSSRI, Karnal during the course of the investigation (Fig. 7). Hubli sewage also recorded EC of less than 2.0 dS m^{-1} except during (summer season) March, April and May '99 months at one and two km from the sewage outlet. Lower EC during rainy season may be due to the dilution effect of rainfall (205.4 mm rainfall during rainy season).

The content of BOD of Hubli and Dharwad sewage was between 81 to 305 mg L^{-1} (Table 4) and can be grouped under category which are fit for irrigation (Mara, 1976).

The total suspended solids decreased with an increase in the distance from the sewage outlet. This may be due to the sedimentation of these suspended particles. Lower monthly mean suspended solids concentration may be due to the restrictions made for the flow of sewage by farmer through construction of bunds. The total suspended solids were within the permissible limits prescribed (FAO, 1985).

The concentration of different cations (Ca, Mg, Na and K) and anions (HCO_3 , Cl, SO_4 and PO_4) were low during rainy season June to August '99. Lowest concentration of these ions were observed during July '99 (Fig. 5) in both Hubli and Dharwad due to higher rainfall during this month (113.9 mm) which caused more dilution of the sewage water. The lower average

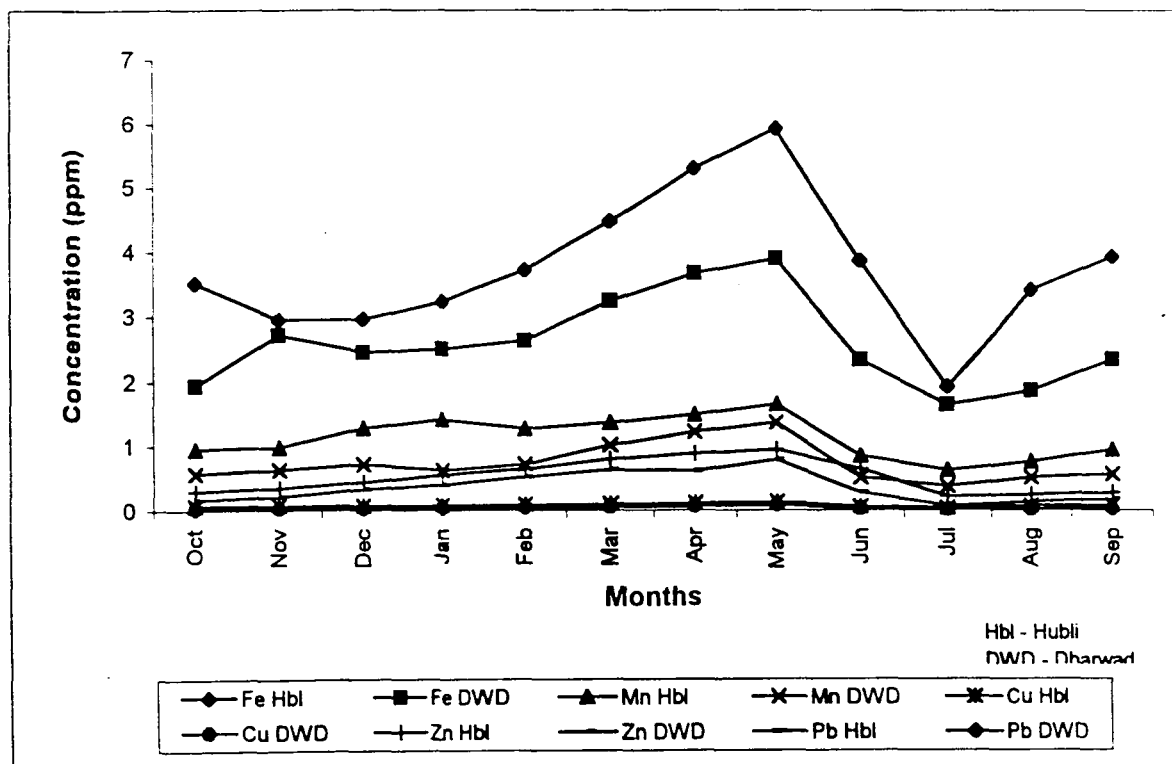
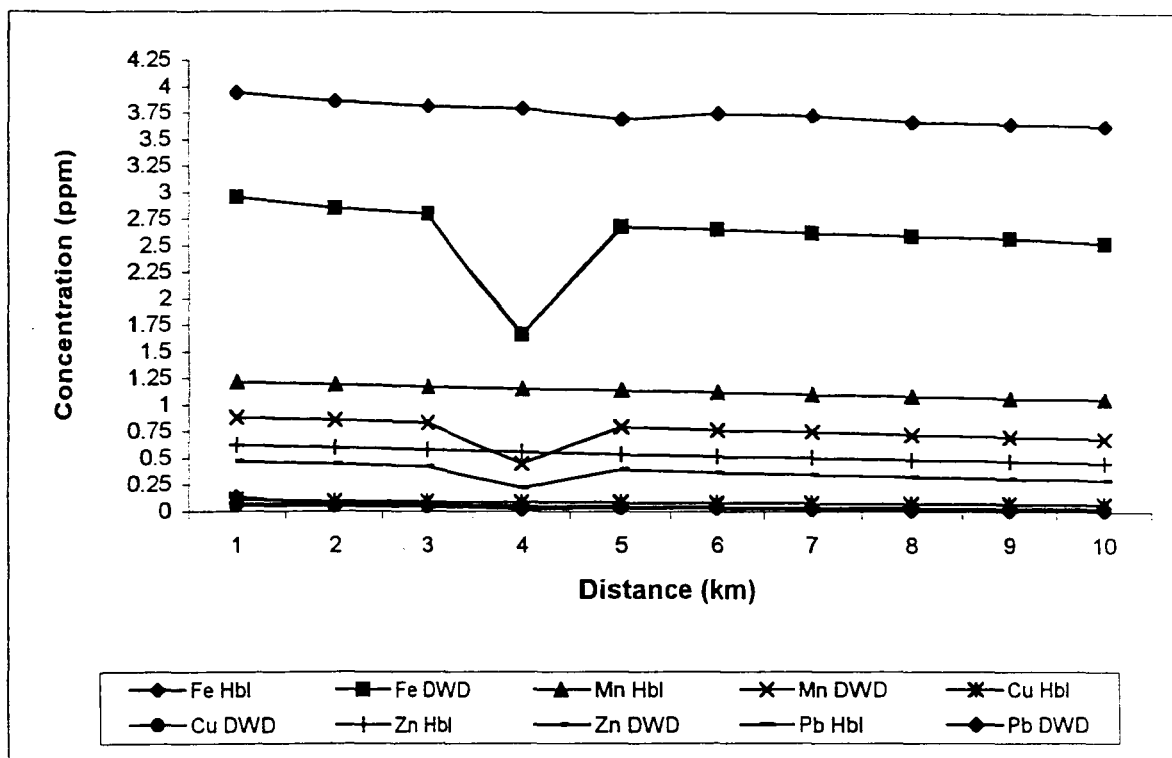


Fig. 6 : Average heavy metal content in sewage of Hubli and Dharwad at different intervals of distance and time

annual concentration of these ions was registered at ten km from sewage outlet in Hubli. Decrease in concentration of anions and cations with increase in the distance from the sewage outlet might be due to the precipitation of cation with anion with an increase in contact time, while it was at four km at Dharwad. This is because at four km the characteristics of sewage was less concentrated with regard to the said ions from that of the main stream. Higher concentration of these ions in summer season may be due to the lower use of water by the community. Mara (1976) reported that the composition of the sewage depends on the amount of the water used by community and non addition of rain water having low concentration of these ions during summer. However the concentration of chlorides in both Hubli and Dharwad sewage water was more than 4.0 meL^{-1} during the course of investigation which fall under the category of slight to moderate restriction on the use for irrigation as prescribed by (FAO, 1985). Chloride concentration during (summer season) March to May '99 in some location was greater than 10.0 meL^{-1} which falls under the category of severe restriction on the use for irrigation. The concentration of chloride was more than recommended for foliar application to some of the crops such as almond, plum by (Mass 1986), while it can be used through sprinkler irrigation for some of the crops like corn, alfalfa safflower, sesame, sorghum cauliflower, cotton *etc.*

The bicarbonate concentration of both Hubli and Dharwad sewage was more than the recommended for sprinkler irrigation. The use of such sewage waters for sprinkler irrigation may cause white patches on fruits, flowers and leaves and reduce their marketability.

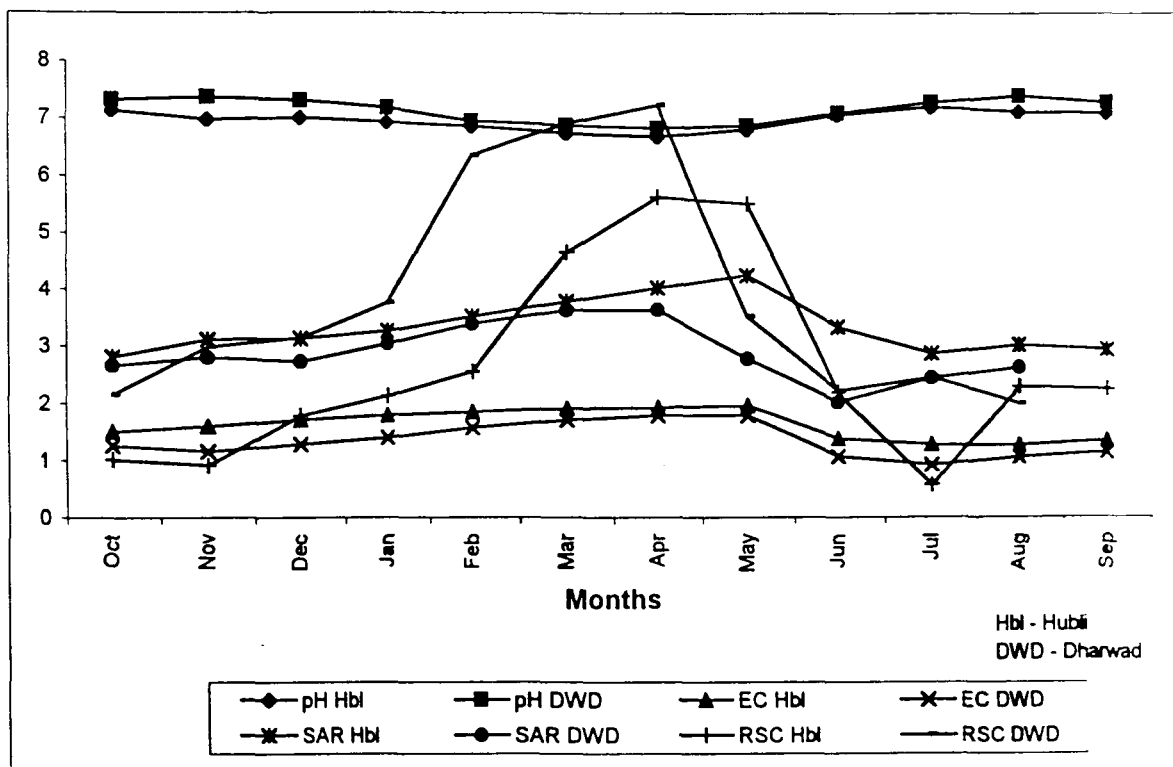
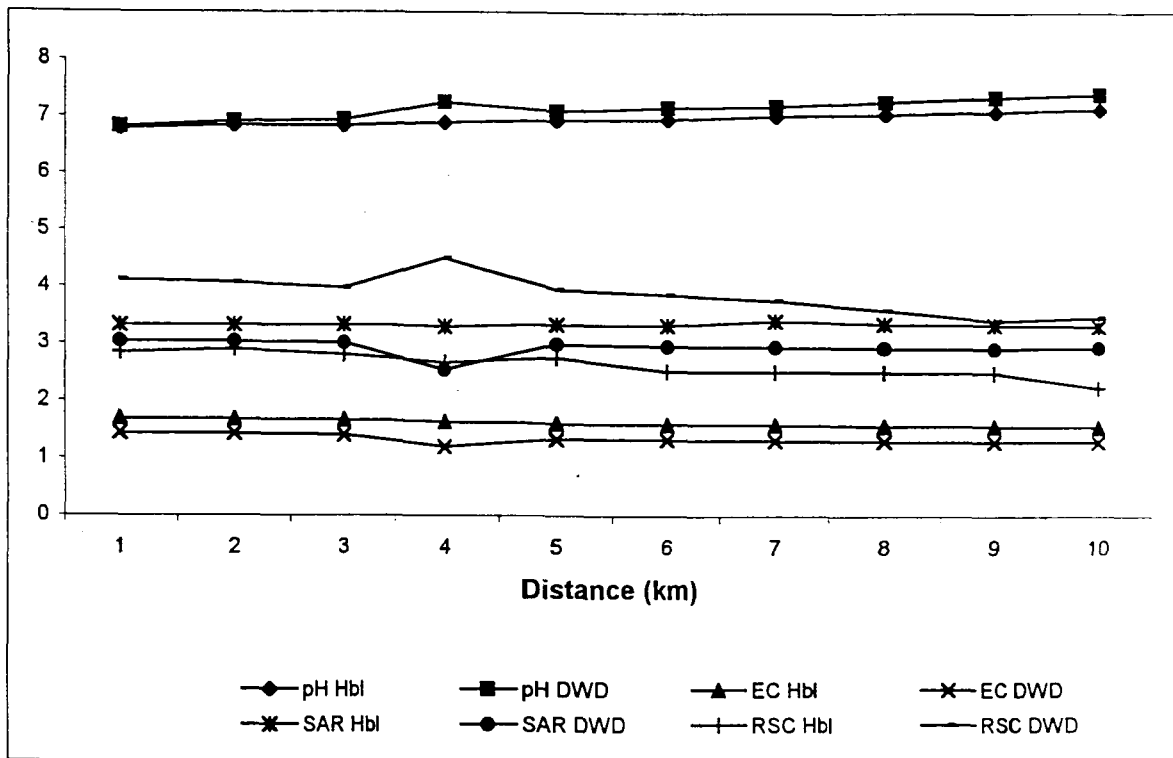


Fig. 7 : Average content of pH, EC (dS/m), SAR and RSC (me/L) in sewage of Hubli and Dharwad at different intervals of distance and time

The SAR (sodium adsorption ratio) of both Hubli and Dharwad sewage was below ten indicating that the sewage water was safe for surface irrigation (Fig. 7). The RSC of sewage water of Hubli and Dharwad was more than 2.5 me L^{-1} during summer season suggesting that it is unsafe for surface irrigation during those months. If used it can cause sodicity, salinity and other problems to soils.

Hegde *et al.* (1992) reported higher concentration of chlorides in ground waters around the sewage drains of Hubli city. In the present investigation also higher concentration of chlorides was recorded in the ground waters around sewage drains of Hubli-Dharwad. The contamination of heavy metals through sewage water was not been as these elements were present in the below detectable levels in ground waters of Hubli-Dharwad. The SAR of ground waters of Hubli-Dharwad was below ten and RSC was below 2.5 me L^{-1} , which are below permissible limits for irrigation. The use of these waters for irrigation may not cause problems to soils such as salinity and sodicity.

Ground water sources of Hubli were of good and marginally saline in nature (Table 30) while ground water sources of Dharwad were mostly marginally saline in nature. The sewage of Hubli was of good to marginally saline and Dharwad was of good in nature (CSSRI, Karnal).

The sewage water had appreciable amounts of micronutrient elements such as Fe, Cu and Zn which are deficit in most of the soils of Karnataka. Thus sewage water can be used as a source of micronutrients in crop production. The concentration of heavy metals such as Cd, and Ni

Table 30 : Classification of ground waters and sewage water of Hubli and Dharwad.

Place	pH	E.C. dS m ⁻¹	SAR	RSC (me/L)	Classification*
Hubli					
Bore well	6.9	1.92	3.54	1.86	Good
Bore well	6.8	1.51	2.92	2.2	Good
Open well	7.1	2.24	3.69	0.98	Marginally saline
Sewage water	6.5-7.4	1.20-2.20	2.73-4.32	0.28-6.05	Good- Marginally saline
Dharwad					
Open well	6.8	2.35	3.46	1.66	Marginally saline
Bore well	6.9	2.12	2.91	1.12	Marginally saline
Sewage water	6.6-7.65	0.81-1.90	1.73-3.73	1.72-7.42	Good

* CSSRI, Karnal.

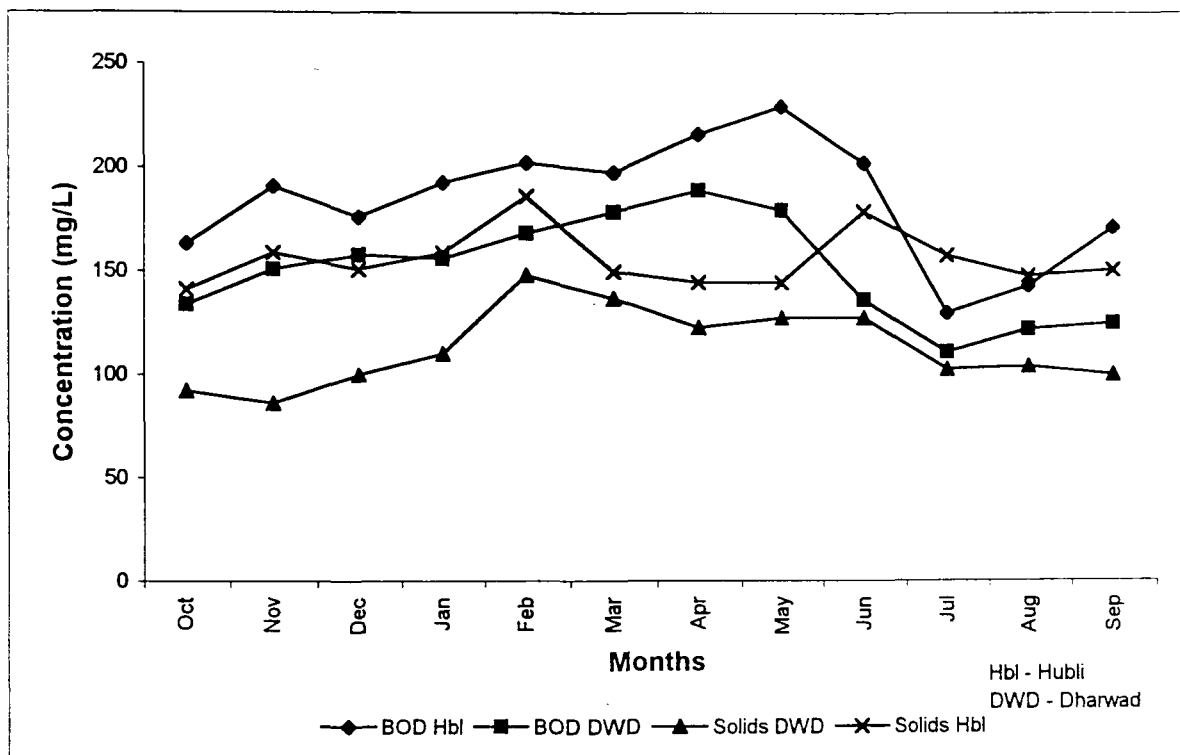
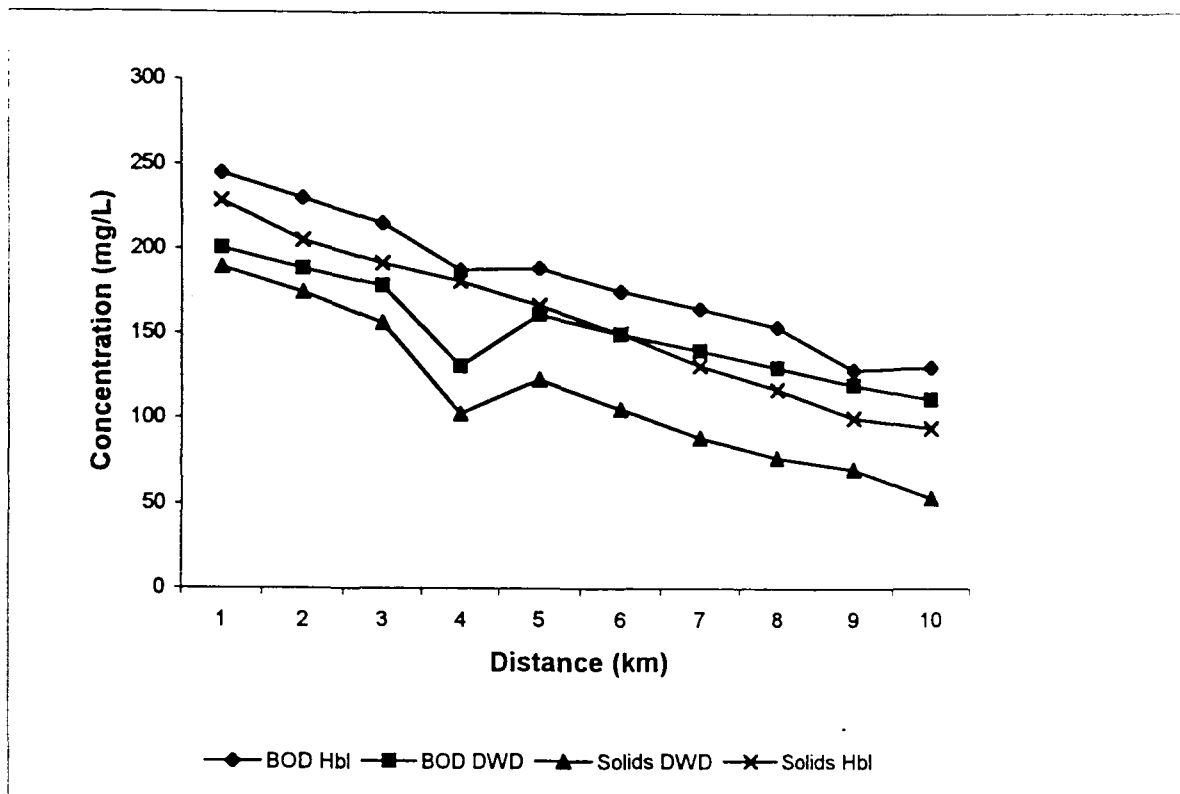


Fig. 8 : Average content of BOD and total suspended solids in sewage of Hubli and Dharwad at different intervals of distance and time

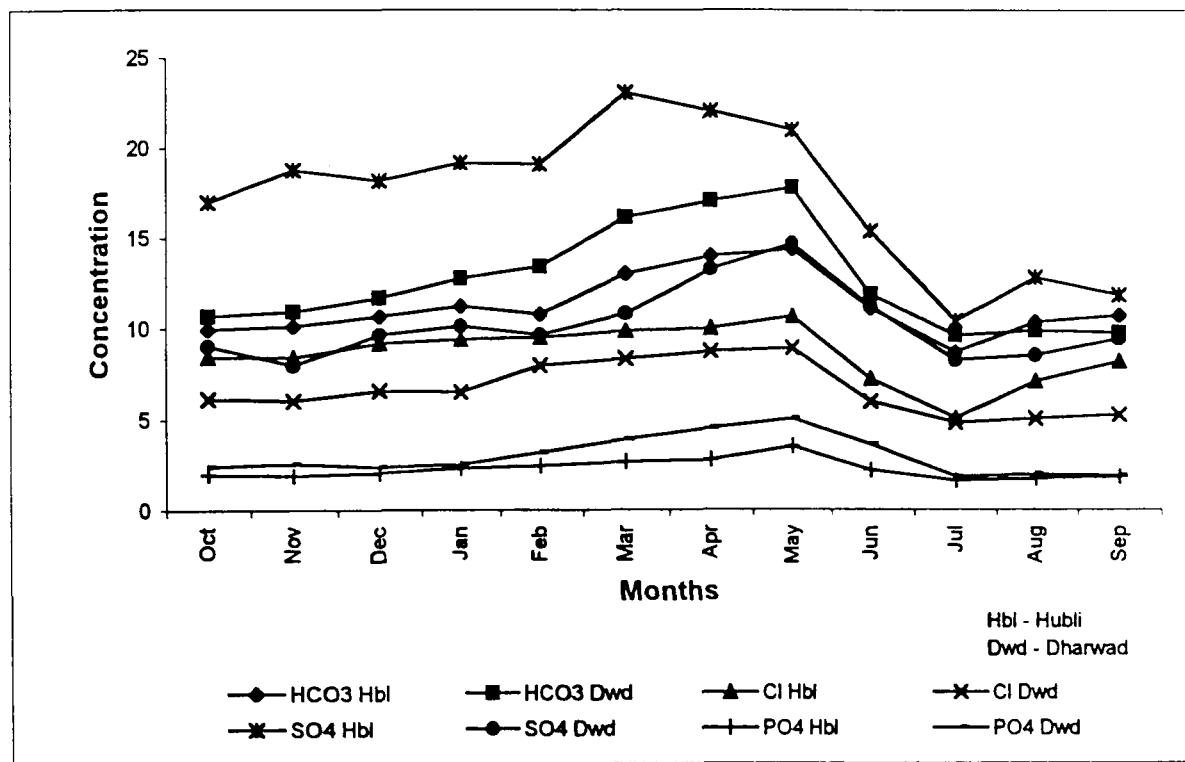
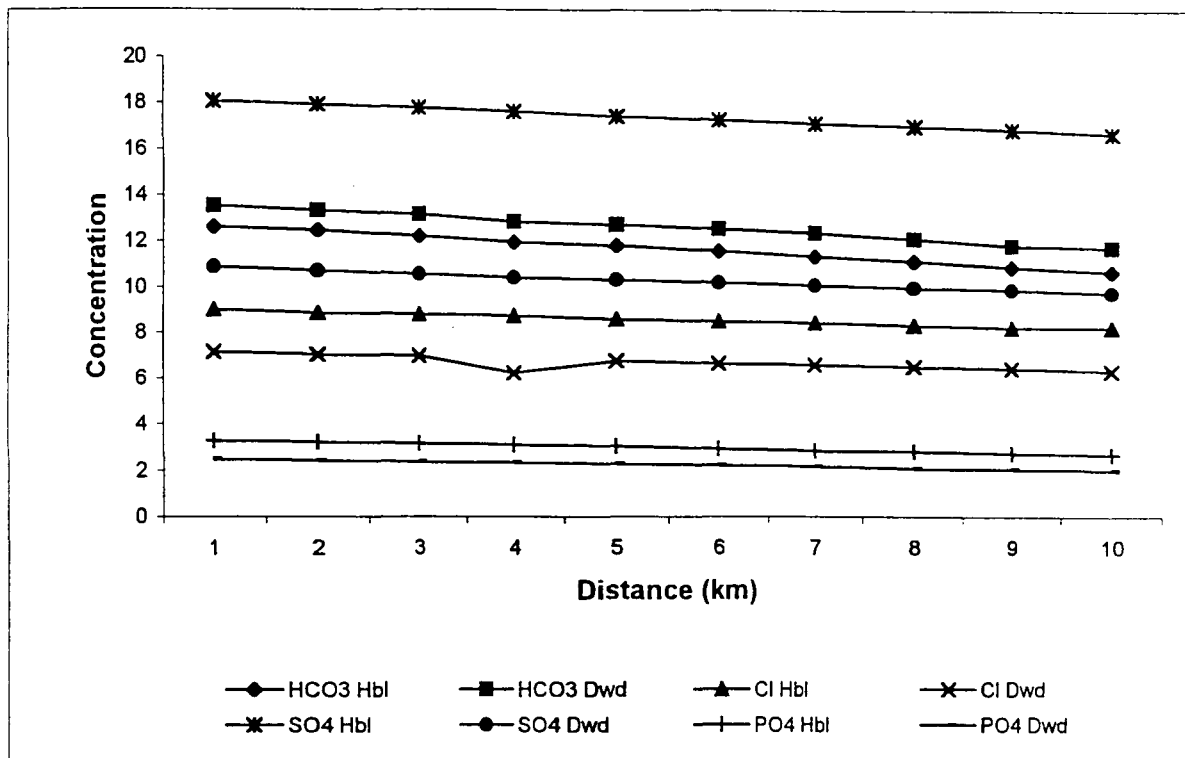


Fig. 9 : Average content of HCO₃ (me/L), Cl (me/L), SO₄ (ppm) and PO₄ in sewage of Hubli and Dharwad at different intervals of distance and time

were present in below detectable levels indicate that with the present composition of sewage accumulation of these heavy metals in soil and crops above permissible limits may not be a problem in sewage irrigated fields of Hubli and Dharwad. Though the content of Pb in sewage of Hubli and Dharwad was detected, it was below permissible limit of 5 ppm (Food and Agricultural Organisation, 1985) during the course of the investigation. Sewage water samples in Dharwad at one km from the sewage outlet higher of Pb (0.134 ppm) due to the discharge of waste water of Karnataka State Road Transport Corporation depot to the sewage stream. Seasonal variations of these may be attributed to the dilution effect by rainfall and amount of water used by the community.

The Mn concentration of sewage of Hubli and Dharwad was more than 0.2 ppm this is the maximum concentration recommended for irrigation by Food and Agricultural Organisation, (1985), suggesting that prolonged use of such sewage may cause manganese toxicity in soils.

5.2 EFFECT ON SOIL PROPERTIES

Sewage irrigated profile samples had lower BD and higher volume of expansion and maximum water holding capacity (MWHC) as compared to the sewage unirrigated profiles. This may be due to the addition of organic matter by sewage irrigation. Similar decrease in BD and increased MWHC was reported by Nagaraj (1981); Pradeep (1993) and Salakinkop (1998). Increased BD and decrease in the volume of expansion and MWHC with an increase in the distance from the sewage outlet may be attributed to lesser frequency of application of sewage and also less organic matter content in

these places in the sewage water. Similar decrease in the BD with rates of sewage application was reported by Day *et al.* (1972).

Clogging the soil pores by suspended solids with sewage irrigation is the main cause for the reduction in infiltration rate of soil as suggested by Thomas *et al.* (1966). In the present study also reduction in the infiltration rate of soils irrigated with sewage was noticed both in Hubli and Dharwad which may be due to clogging of pores by suspended solids and also due to dispersion by exchangeable sodium.

An increase in the pH of the sewage water irrigated profile samples was noticed. This may be attributed to the increased concentration of exchangeable sodium in these profiles (Table 24). The pH of soils irrigated with sewage at the outlet of Hubli was as high as 8.9 with an ESP of 16.78 in the lower depths suggesting that indiscriminate use of this sewage can lead to sodication of soils. The magnitude of increase in pH decreased with an increase in the distance along the sewage outlet. This may be attributed to the rates of application of sewage water by the farmers. The present findings are in corroboration with the reports of Dodolina (1971); Rajannan and Oblisami (1979); Azad *et al.* (1987) and Adhikari *et al.* (1994).

Sewage irrigation increased the EC both in Hubli and Dharwad soils and it increased with depth however, it was less than 4.0 dS m^{-1} to be called as saline suggesting that there may not pose immediate problem of salinisation particularly on well drained soils. The results are in confirmation with the findings of Jame *et al.* (1984). Hundal and Sandhu (1990) reported that decrease in the EC with an increase in the distance from the sewage

outlet which was also evident in the present investigation. The increase in the EC of soils was attributed to addition of more water soluble ions through sewage irrigation.

Relatively higher content of organic carbon in sewage irrigated profiles was registered which may be due to addition of organic matter by sewage and decrease in organic carbon content with increase in the distance from the sewage outlet may be attributed to lesser rates of application of sewage by farmers which had resulted in lower accumulation of organic matter at these places. The present findings are in confirmation with the findings of Jayaramani and Perumal (1984); Azad *et al.* (1987) and Hundal and Sandhu (1990). Thus, sewage water can also act as one of the sources of organic matter to the soil, where maintenance of the adequate amount of organic matter is a constraint.

Lower pH of the sewage results in the dissolution of native CaCO_3 and there by increasing the concentration of Ca in soil (Bouwer and Chaney, 1974). Increased concentration of cations like Ca, Mg, Na and K may be due to addition of these cations to soils by sewage which contains appreciable quantities of these cations. In the present study higher concentration of exchangeable sodium was observed at lower depth (30cm onwards) of sewage irrigated profiles. The ESP of more than 15 was noticed in profile near by sewage outlet in Hubli. Thus indicates that sodication process had already begun at lower depths by way of secondary salinisation hence, it should be used for irrigation sparingly or with caution. Increase in exchangeable cation concentration in sewage irrigated soils was also reported by Wallingford *et al.* (1975) and Epstein *et al.* (1976).

Increase in the nutrients status of the soil with sewage irrigation was reported by Adhikari *et al.* (1994); Hundal and Sandhu (1990) and Feigin *et al.* (1978 and 1979) reported that the amount of nitrogen added to the soil through sewage irrigation may be equal to or even more than the standard fertilisation to the crop. In the present study also the available N status was high up to five km from the sewage outlet and it was low in status at ten km from the sewage outlet at Hubli, while at Dharwad high N status was registered at the sewage outlet and it was medium and low in status at five km and ten km away from the sewage outlet respectively. Increased available N contents upto 918.18 kg ha⁻¹ with sewage irrigation was reported by Lance and Whisler (1972).

The available P₂O₅ status was high in the profile near the sewage outlet at both in Hubli and Dharwad, and it was medium to low in the profile irrigated with the sewage at five km away from the sewage outlet. The present findings are in confirmation with the results of Sawhney and Hill (1975) and Adhikari *et al.* (1994).

The available K₂O status of sewage irrigated profile was high at all the distance from the sewage outlet. The present findings are in corroboration with the results of Adhikari *et al.* (1994) who reported that the available nutrient status of soils irrigated with sewage was medium to high in status.

Available micronutrients status (Zn, Cu, Fe and Mn) of sewage irrigated profile was high due to the addition of these micronutrients by sewage water. It decreased with increase in the depth of the profile.

Jeyabaskaran and Sreeramulu (1996) attributed this to the complexation of these micronutrient cations by organic matter. In the present study, this is evident from positive and highly significant correlation between these micronutrient cations and organic carbon content of soil. Stanford *et al.* (1986) reported that leaching of these metals ion to deeper layer would occur in low pH soils.

At present sewage irrigation in and around Hubli-Dharwad soils has not resulted in the accumulation of heavy metals in soils as they are below detectable limits. This may be due to the alkaline nature of these soils and also due to the precipitation by carbonates.

SUMMARY

VI. SUMMARY

Land treatment of sewage water implies recycling where pollution become nutrients for plant growth. Energy crises, shortage of irrigation water and rising price of fertilizers and soil amendments are among the major problems faced by the country today. Under such circumstances, recycling of urban water as resource material in agriculture can help in meeting a part of nutrient requirements in addition to source of water. Since most of the sewage water in India does not get any treatment and the composition of which varies widely, resulting in varied effect on soil and surface water.

Therefore, a study on characterisation of Hubli-Dharwad urban sewage and its impact on soil properties was carried out in Hubli and Dharwad during October 1998 to September 1999. Sewage water samples were analysed for different parameters such as pH, EC, BOD, TSS, cations, anions and heavy metals on monthly interval for a period of one year at and every kilometer from the sewage outlet upto 10kms in both Hubli and Dharwad. Three profiles in farmers field irrigated with sewage such as near the sewage outlet, five km and ten km along the sewage drain were selected for the study in both Hubli and Dharwad. Two profiles wherein sewage irrigation was not practiced were also taken for the study. The findings of the experiments are summarised below.

Most of the parameters of the Hubli sewage were higher than the Dharwad sewage. Lowest concentration of different parameters were recorded during rainy season (July-August '99) while higher concentration

being during summer season (March-May '99) indicating the seasonal difference of the sewages of Hubli and Dharwad. The pH, EC, BOD, SAR of both Hubli and Dharwad sewages were within the range prescribed for irrigation purpose. The chloride content of both Hubli and Dharwad remained more than 4.0 me L^{-1} during most of the months and more than 10.0 me L^{-1} during March to April '99 in Hubli suggesting the restriction on the use of sewage water through sprinkler irrigation and also for solanaceous crops. The bicarbonate content was more than the recommended for sprinkler irrigation. Except Mn, concentration of heavy metals was below the permissible limits in both the sewages.

A decrease in the infiltration rate, bulk density and increase in the volume of expansion and MWHC of sewage irrigated profiles were noticed than profiles without sewage irrigation in both the places.

A relatively higher pH (8.90 in Hubli and 8.85 in Dharwad) values were recorded in the profile samples at lower depths near the sewage outlet being irrigated with sewage. The profile samples with more than 30 cm depth near the sewage outlet in Hubli was non-saline sodic in nature and the rest of the profile samples were alkaline in reaction with respect to pH.

Electrical conductivity of sewage irrigated profiles was higher than profiles without sewage irrigation. Relatively higher organic carbon content (1.23 % in Hubli and 0.92 % in Dharwad) was observed in surface samples of profiles irrigated with sewage near the sewage outlet.

Exchangeable cations and CEC of sewage irrigated profiles were higher than those of sewage unirrigated profiles and decreased with an

increase in the distance from the sewage outlet. The exchangeable Ca and Mg of sewage irrigated profiles were higher than profiles without sewage irrigation. The exchangeable sodium percentage of more than 15 was registered at lower depths in the soil profile near the sewage outlet of Hubli.

A decrease in the nutrient status of the sewage irrigated profiles with increase in the distance was noticed. The nutrient status of the sewage irrigated profiles remained higher than those without sewage irrigation.

The micronutrient and heavy metal content of the sewage irrigated profiles were higher than the sewage unirrigated profiles and they were present within the permissible level.

The ground waters of Hubli and Dharwad were of good to marginally saline in nature and also it had higher concentration of chlorides making it unfit for sprinkler irrigation.

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VII. REFERENCES

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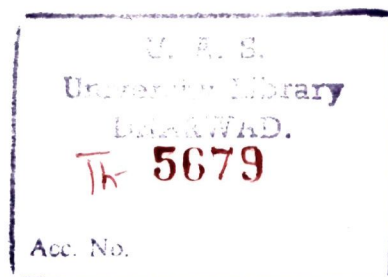
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CHARACTERISATION OF HUBLI - DHARWAD URBAN SEWAGE AND ITS IMPACT ON SOIL PROPERTIES

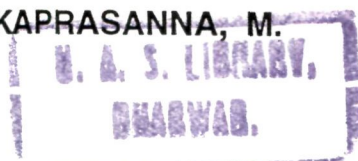
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ABSTRACT

In the present study, the sewage water samples of Hubli and Dharwad cities were analysed for different parameters such as pH, EC, BOD, suspended solids, cations, anions and heavy metals at monthly intervals for a period of one year and at every kilometre from the sewage outlet upto ten kms to characterised sewage and to know the suitability of these city sewages for irrigation. Three profiles in farmers' field irrigated with sewage such as near the sewage outlet, 5 km and 10 km along the sewage drain and two profiles wherein sewage irrigation was not practiced were taken to study the effect of sewage water irrigation on different soil properties.

The study revealed that except HCO_3 content, remaining parameters of Hubli sewage were higher than the Dharwad sewage. Lowest concentration of different parameters were recorded during rainy season (June - October), while higher concentration was recorded during summer (February - May). A decrease in the concentration of the said parameters were recorded as the distance from the sewage outlet increased. The pH, EC, BOD, suspended solids and SAR of both Hubli and Dharwad sewage were within the permissible limits, chloride and manganese concentration was more than the permissible limits for irrigation purpose. Heavy metals such as Cd and Cr were present in below detectable limits and the concentration of Pb was within the permissible limits.

Sewage irrigated profiles had very low infiltration rate, lower BD, increased volume of expansion and MWHC than sewage unirrigated profiles. Higher pH, EC, CEC and content of exchangeable cations, organic carbon were recorded in the sewage irrigated profiles. An ESP > 15 was registered at lower depths in the soil profile irrigated with sewage near the outlet both in Hubli and Dharwad.

Sewage irrigated profiles had higher nutrient status than unirrigated profiles and it decreased as the distance from the outlet increased. The content of N, P_2O_5 and K_2O in 0-30 cm layer of sewage irrigated profiles in Hubli ranged from 179 to 586, 19 to 61 and 552 to 840 kg ha^{-1} , respectively. While sewage unirrigated profiles in Hubli had average N, P_2O_5 and K_2O content of 170, 13.5 and 538 kg ha^{-1} , respectively in 0-30 cm layer. The N, P_2O_5 and K_2O content of sewage irrigated profiles in Dharwad ranged from 250 to 484, 14.5 to 46 and 611 to 864 kg ha^{-1} in 0-30 cm layer. While the average content of N, P_2O_5 and K_2O in sewage unirrigated profiles was 233, 11.6 and 538 kg ha^{-1} , respectively in 0 - 30 cm. Higher content of micronutrients in sewage irrigated profiles was also recorded. The content of heavy metals in sewage irrigated profiles were within the permissible limits.