JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 11 2004

ENVIRONMENTAL EVALUATION OF SEWAGE IRRIGATION SYSTEM, ROORKEE, INDIA

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Irrigation is one of the widely accepted uses of sewage effluent because it contains nutrients of value to crops. However, its use needs to be approached with caution, as it can be harmful to human beings, animals or vegetation as it may be charged with viruses, bacteria and other organisms, or may contain toxins and carcinogens. The Municipal Board of Roorkee, India has promoted sewage irrigation on the land at a location four kilometers northwest of Roorkee, between the villages of Saliar and Ibrahimpur. Vegetable farms use the sewage for irrigation. The untreated sewage of the old Roorkee area is pumped from the pumping station to the sewage farm, through sewer lines. During the lean period of agricultural activity, it is directly disposed of to the Solani river, which pass through the town. The present study has been undertaken to ascertain the possibility of contamination of groundwater and soil in the upper aquifer due to the ongoing practice of sewage irrigation. The results of the study show little to no deterioration in the quality of groundwater at present in the shallow aquifer in the vicinity of the disposal area. However, higher values of solids, minerals and heavy metals in the sewage-irrigated soils highlight the enrichment of these compounds.

INTRODUCTION

Sewage usually contains substantial proportions of organic and inorganic matter and is also an excellent medium for the dissemination of microorganisms (Henry and Heinke, 1989). It may, however, result in serious nuisance such as bad odor, taste, corrosion and death of the living organisms present in the receiving water body. If not disposed off properly, it can be harmful to human beings, animals or vegetation as it may be charged with viruses, bacteria and other organisms, or may contain toxins and carcinogens.

Amongst the methods of disposal, land application of partially treated or raw sewage is currently the most widely employed option among the towns and small cities in developing countries in general and India in particular as the resources are not sufficient for providing adequate sewage collection and treatment systems. Out of 142 class I cities and 190 class II towns, 52 cities and 43 towns are disposing their wastewater on land (Hill, 1982). Sewage may be applied to agricultural land, forest land, disturbed land or dedicated land disposal sites. Trace metals are trapped in the soil matrix and nutrients are taken up by plants and converted to useful biomass. In the first three cases, sewage is used as a valuable resource to improve the characteristics of the land. The treated sewage acts as a soil conditioner to facilitate nutrient transport, increase water retention and improve soil tilth. Sewage also serves as a partial replacement for expensive chemical fertilizers (Metcalf & Eddy, 1995). Agricultural reuse has also been observed to be consistent with the need to maintain and increase food production for rapidly expanding urban populations in the developing countries because the installation of sewered sanitation has generally lagged behind improved provisions of water recirculation systems (Green and Hanburg, 1987).

The Central Pollution Control Board, Ministry of Environment & Forests and Government of India, also acknowledged the merits of land treatment and recognized the process as an extension of conventional treatment systems. The manual on sewerage and sewage treatment published in 1994 by the Ministry of Urban Affairs and Employment, Government of India, recommends with emphasis that under no conditions should application of raw sewage on sewage farms be permitted. It further suggests that though sewage after primary treatment can be applied to the farms, the temptation of providing only primary treatment and eliminating secondary treatment merely on cost considerations should be resisted (Murmann, 1977).

The effects of sewage irrigation on surface and subsurface soil were evaluated in Iraq by Mutlak et al. (1980) and in Lima by Geake et al. (1986). Amongst few Indian studies, Bansal (1998) concluded that application of sewage for irrigation of agricultural fields had been observed to increase crop production but simultaneously resulted in the accumulation of toxic substances in the soil and in the produced crop. Gupta (1999) pointed that water or industrial effluents for irrigation in sewage farms must be free from soluble salts and from concentrations of specific chemical substances that may be a hazard to soil with respect to salinity, sodicity, alkalinity and toxicity. Further, a relatively high proportion of sodium and/or high concentrations of bicarbonates in water may reduce the rate of infiltration into soil significantly.

STUDY AREA

The present study evaluates the status of soil and groundwater of the area in the vicinity of the sewage disposal farm near Roorkee town. The area of study is Roorkee town (Longitude 77º 53’00" and Latitude 29º52’30"), located in the State of Uttaranchal. The town is situated on the right bank of the Solani river, which is a tributary of the Ganga river. The Municipal Board of the town has promoted sewage irrigation on the land at a distance of 4 km north west of Roorkee town, situated between the villages of Saliar and Ibrahimpur (Figure 1). Farmers presently use the sewage for irrigation on nearby vegetable farms. The main cash crops and vegetables are potato, onion, cabbage, carrot, radish, sugarcane, and wheat and paddy. The total land area of this sewage farm is 100.25 acres (40.6 ha), which is divided into 24 plots (Figure 2). These plots are auctioned for cultivation, once in three years, to the local farmers. The untreated sewage of old Roorkee area is pumped from the Mahigran sewage pumping station to the sewage farm. During the lean period of agricultural activity, the sewage is directly disposed off to the Solani river. The lithology of the area indicates that the top soil layer (3-6 m) consists of very fine to sandy loam, except in the southern part where clayey soil is found (Singhal et al., 2003).

MATERIALS AND METHODS

Field Experiments

Field experiments were conducted during December 1998 to February 1999 comprising groundwater and soil monitoring, infiltration studies and soil moisture studies at the sewage farm. Available historical data of groundwater table was collected from the State Groundwater Department, Roorkee. This data was used for evaluation of the gradient of the water table and also to establish the nature of water table fluctuation in the vicinity of the area.

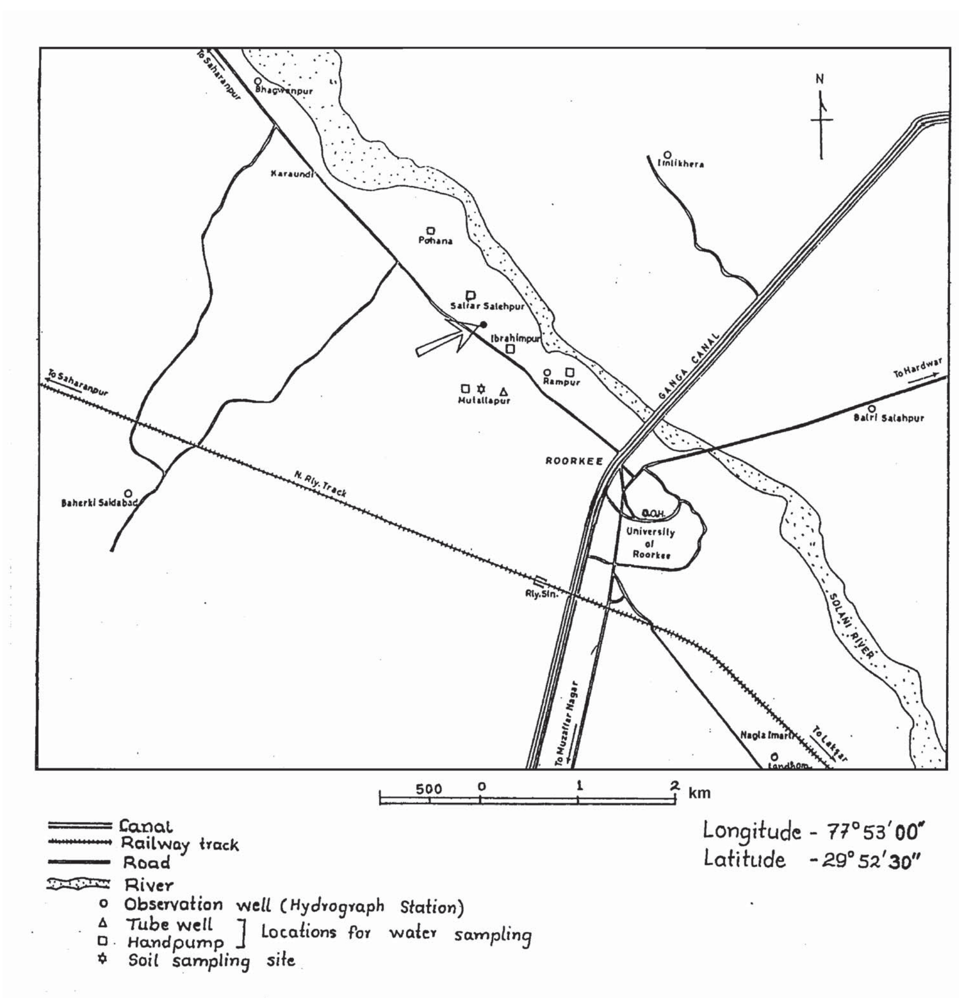
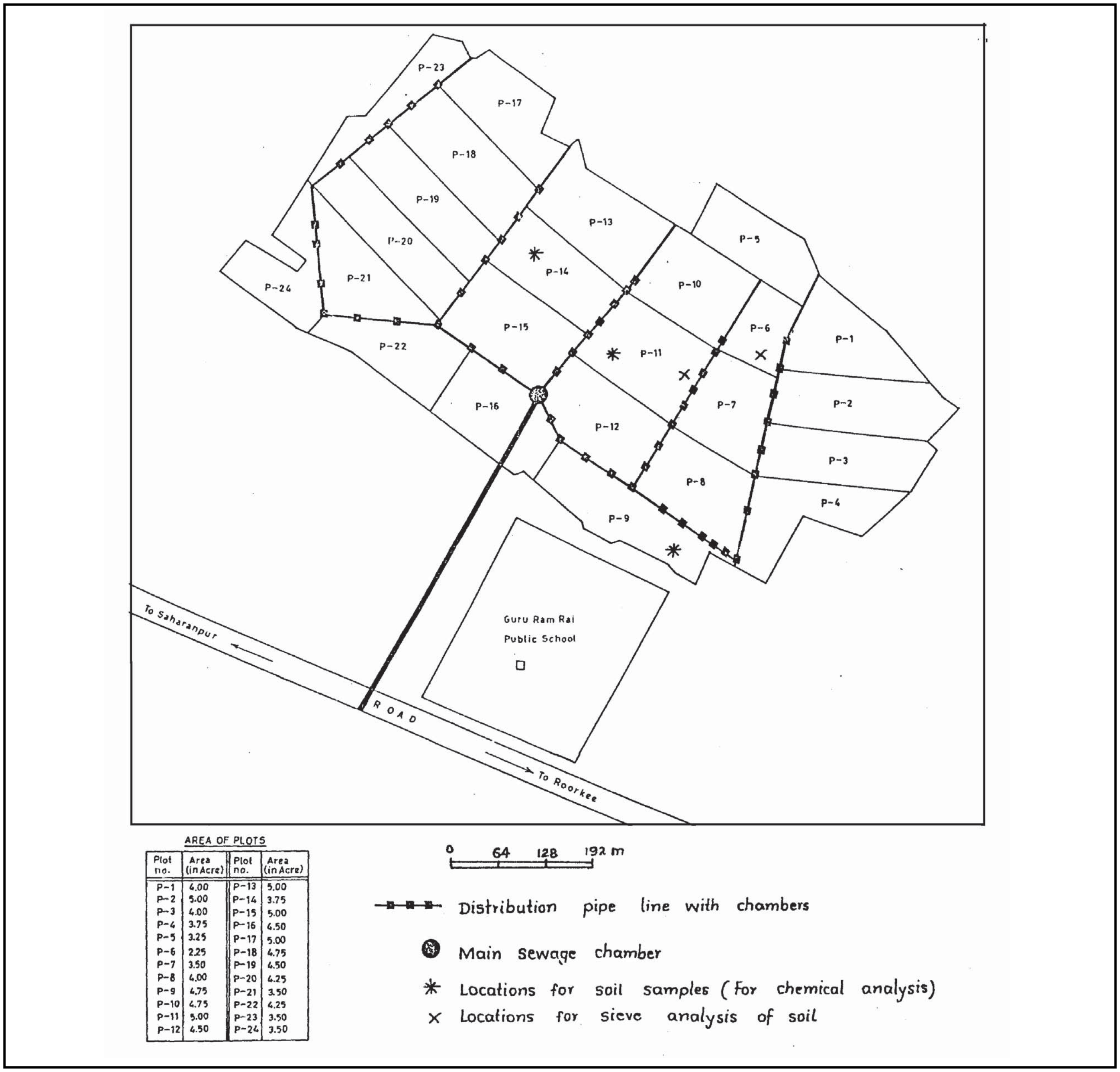


Figure 1. Roorkee sewage farm site. (, ●)



Plot no.	Area (in Acre)	Plot no.	Area (in Acre)
P-1	4.00	P-13	5.00
P-2	5.00	P-14	3.75
P-3	4.00	P-15	5.00
P-4	3.75	P-16	4.50
P-5	3.25	P-17	5.00
P-6	2.25	P-18	4.75
P-7	3.50	P-19	4.50
P-8	4.00	P-20	4.25
P-9	4.75	P-21	3.50
P-10	4.75	P-22	4.25
P-11	5.00	P-23	3.50
P-12	4.50	P-24	3.50

Figure 2. Division of Plots of sewage farm.

Assessment of Quality of Groundwater and Soil

Samples of sewage and groundwater (withdrawn from tubewell depth about 175 ft) used for irrigating the farmland were collected. Groundwater samples were collected from the sewage farm site and also from another site located about 10 km away from the sewage farm (treated as background site). In order to examine the vertical extent of a possible impact, groundwater samples were collected from the private hand pumps (depth range about 60 ft) and government hand pumps (depth range about 130 ft) from locations around the sewage farm. The raw sewage and groundwater samples were analyzed for the physical, chemical and biological parameters as per standard methods (APHA, 1998). Soil samples were collected at depth of 0-70 cm from agricultural fields irrigated with sewage and also from a field irrigated with tube well water. The samples were air dried, powdered and sieved through 2-mm sieve for analysis (Head, 1986).

Infiltration tests were conducted to estimate the rate of flow of irrigation water reaching the groundwater table by flooding (concentric ring) type infiltrometer (Singh, 1992). Soil moisture content was measured by depth moisture gauge and was used to estimate the extent of evapotranspiration and leaching fraction. A hole was excavated by hand auger at two plots of the sewage farm. The depth of the hole was 8.5 ft (2.5 m) and soil samples were collected at every 1 ft (0.30 m) interval for vertical profiling of the soil quality.

The evapotranspiration (*ET*), for any time period between two successive sampling was obtained from the following equation (Metcalf & Eddy, 1995):

$$ET = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} * G_i D_i \qquad (1)$$

where:

M_{1i} = soil moisture percentage at the time of first sampling in the ith layer

M_{2i} = soil moisture percentage at the time of second sampling in the ith layer

n = number of soil layers considered in the entire root zone

G_i = apparent specific gravity of the ith layer of the soil

D_i = depth of ith layer of soil, within the root zone depth

The fraction of applied water that passes through the entire rooting depth and percolates below is called the leaching fraction (*LF*) estimated as (Michael, 1978):

$$LF = \frac{D_d}{D_i} = \frac{D_i - ET}{D_i},$$

$$D_i = \frac{d_s}{d_w} * \frac{MP}{100} * \frac{EC_s}{EC_i} * D_s \qquad (2)$$

where:

LF = leaching Fraction
D_d = depth of water leached below the root zone, inches
D_i = depth of water applied at the surface, inches
ET = evapotranspiration, inches
d_s = density of soil
d_w = density of water
MP = moisture Percentage of soil
EC_s = electrical Conductivity of soil
EC_i = electrical Conductivity of irrigation water
D_s = depth of soil

RESULTS AND DISCUSSION

Examination of groundwater level data and evaluation of flow direction

The water table elevation contour maps of the study area for the years 1987 (pre and post monsoon) and 1997 (pre and post monsoon) have been presented in Figure 3 (a) and (b) and Figure 4 (a) and (b).

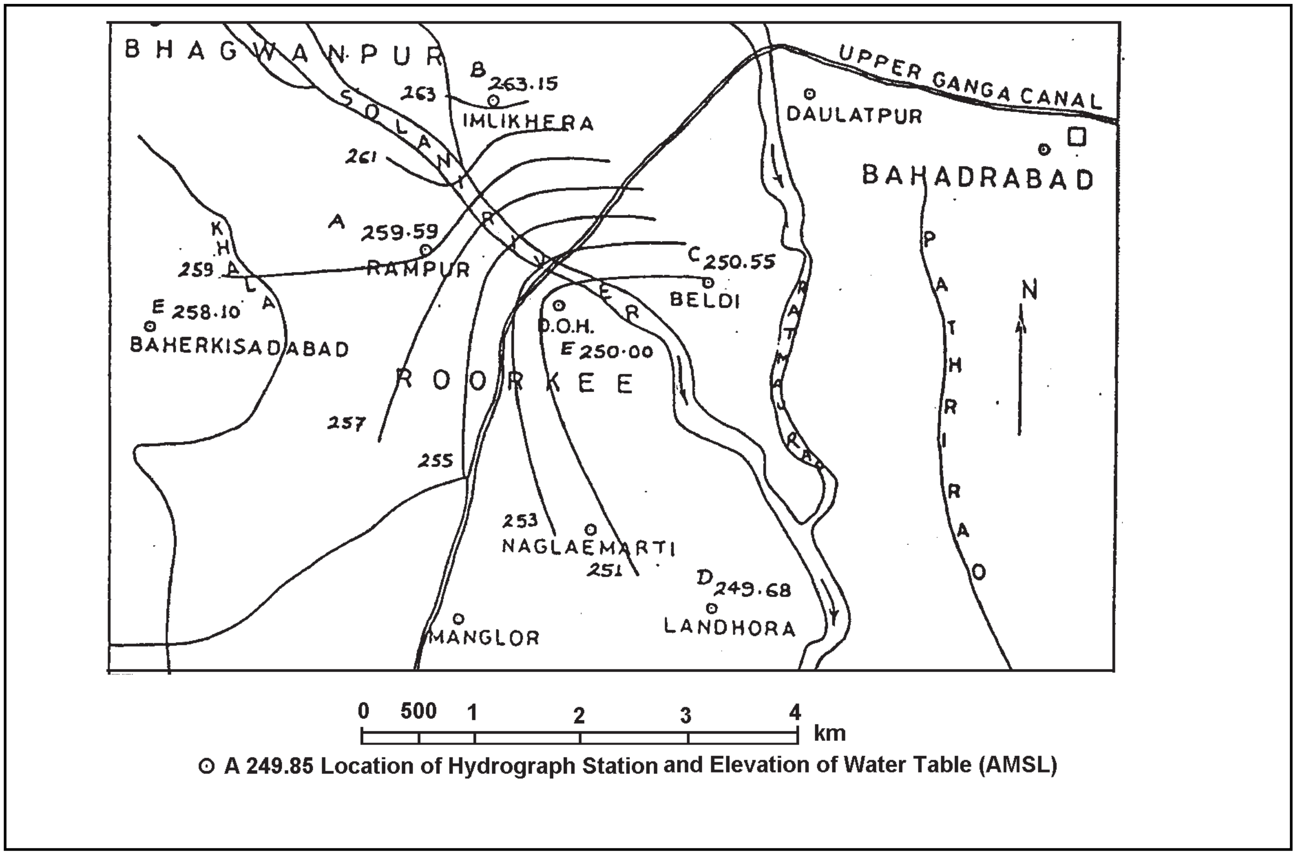


Figure 3(a). Water table elevation contour map (Pre-Monsoon 1987).

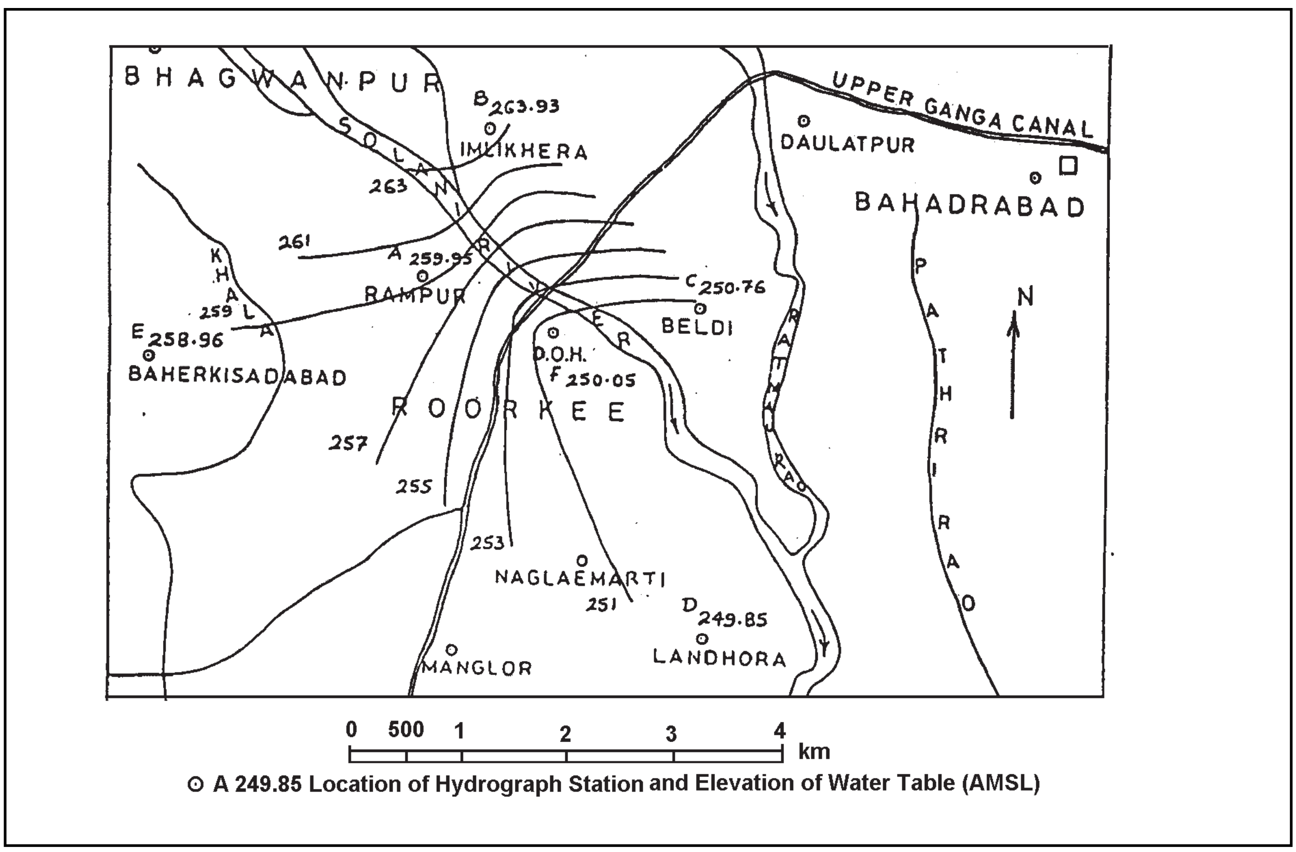


Figure 3(b). Water table elevation contour map (Post-Monsoon 1987).

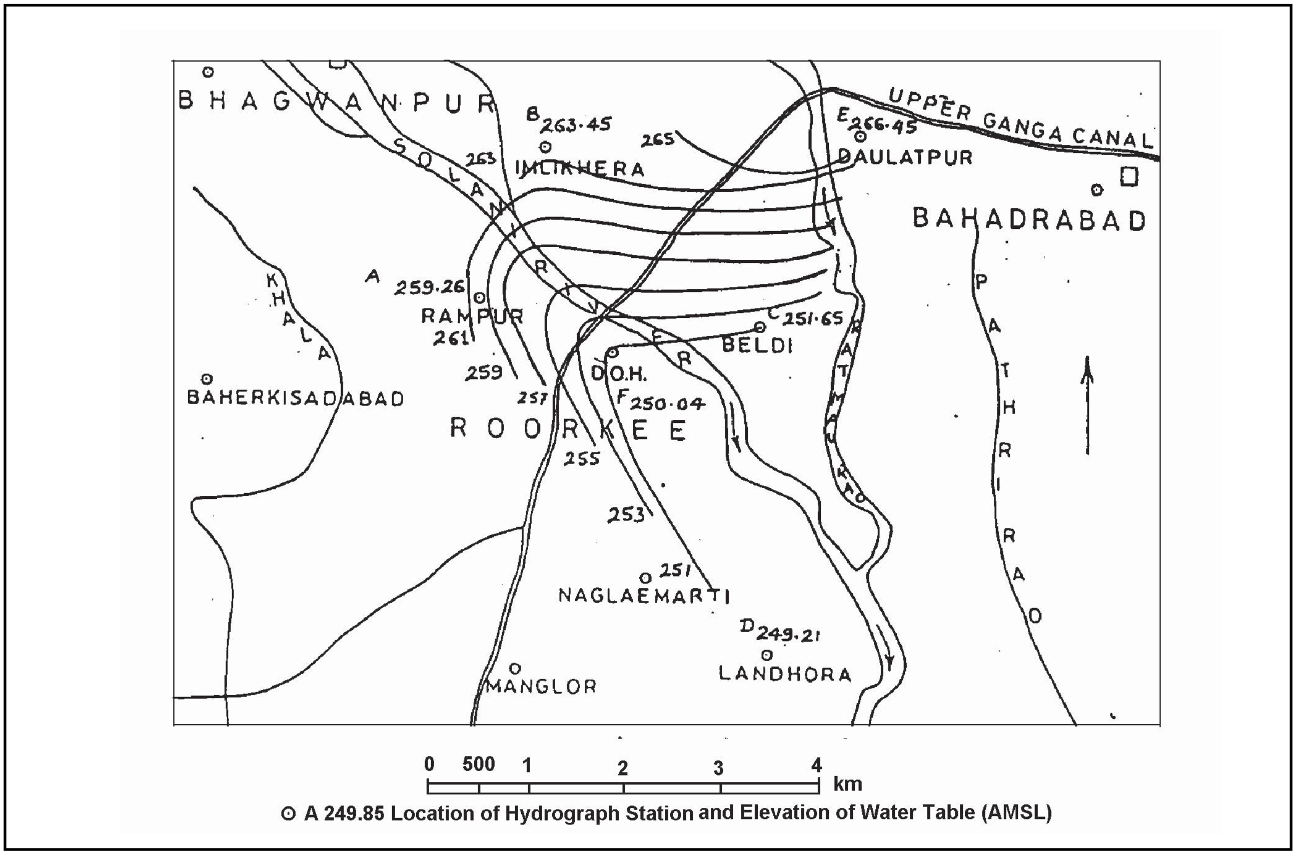


Figure 4(a). Water table elevation contour map (Pre-Monsoon 1997).

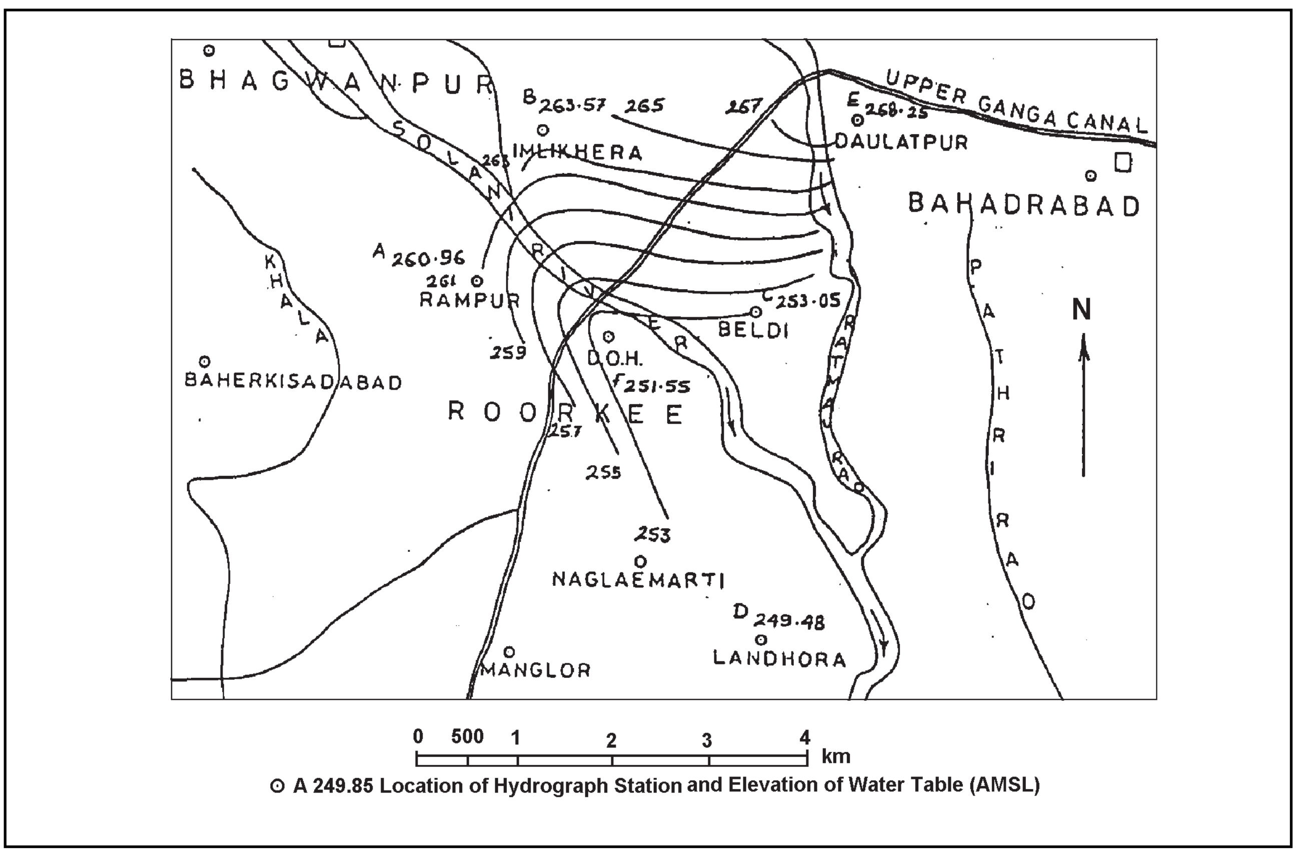


Figure 4(b). Water table elevation contour map (Post-Monsoon 1997).

From the gradients, which have been worked out from these figures, it is observed that the groundwater flow on the right bank of Solani river is towards the southeast, being almost parallel to the river and that no river aquifer interaction is noticeable. However, on the left bank, the groundwater flow appears to be towards the south and the influent nature of the river is strongly indicated. No significant seasonal or long term variation has been observed in these patterns. A major inference which can be drawn from the above finding is that Roorkee town, located downstream of the sewage farm, is highly vulnerable to any contamination in groundwater caused due to sewage irrigation, considering that the water supply to the residents is solely through groundwater.

Type and size of soil and infiltration test

The type and size of soil in the sewage farm was estimated in two plots (no. 6 and 11) through sieve analysis. Physically the soil texture was observed of slightly clayey nature in plot no. 6. On the other hand in plot no. 11 the composition of soil was observed to be silty sand impregnated with admixtures of clay fraction. The results of analysis are shown in Figure 5. From this figure, it may be inferred that the soil of sewage farm has a size (d_{50}) of 0.20 mm. The results of infiltration test performed in plot no. 11 are presented in Table 1. The infiltration rate has been estimated as 7.24 cm/hr (21.06 min/in). Corresponding to this value, the suggested hydraulic loading (application) rate for sewage farm has been estimated as 24 L/m^2.d from Table 2, which relates the infiltration rate expressed in min/in (min/ 10^2 mm) to the allowable loading rates in gal/ft^2.d (L/m^2.d). On the basis of Table 2, the present texture of the soil emerges as sandy loam, which is suitable for sewage farming.

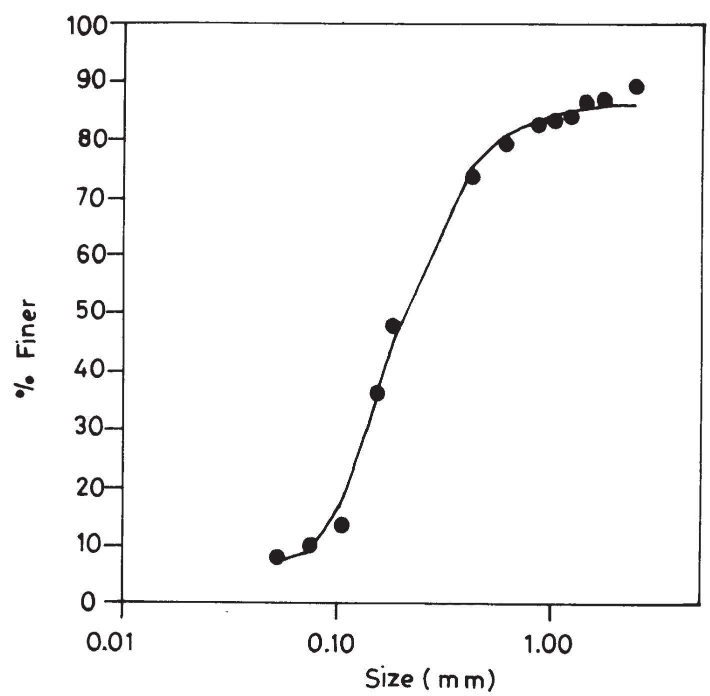


Figure 5. Sieve analysis of sewage farm soil.

Estimation of moisture content

The results of soil moisture content are shown in Figure 6. The results indicate that the values of soil moisture content in plot no. 6 varied from 49.8% to 98.0% in the depth range of 1 ft to 5 ft and in plot no. 11, the soil moisture content varied from 49.6% to 99.2% in depth range of 1 ft to 8 ft As per the above moisture content study, the rate of moisture movement emerges in the range of 4 - 5

Table 1. Infiltration Capacity Measurement

Watch time	Total time (min)	Elapsed time (min)	Volume (cm^2)	Infiltration capacity (cm/hr) Vol./(Elapsed Tim e *Area)
01:37	2	2	365	26.68
01:42	7	5	380	11.11
01:52	17	10	660	9.65
02:07	32	15	1200	11.69
02:27	52	20	750	5.48
02:57	82	30	1040	5.07
03:42	127	45	1850	6.01
04:42	187	60	2970	7.24
05:42	247	60	2970	7.24

Date : 26.2.1999
Type of soil : Silty sand
Area : 410.43 cm (Inner ring)

Table 2. Hydraulic Loading Rates

Sl. No.	Soil Texture	Appropriate Infiltration Rate		Application Rate based on bottom area	
		min/in	min/10^2mm	gal/ft^2.d	L/m^2.d
1	Gravel, coarse sand	<1	< 4	Not recommended	Not recommended
2	Coarse to medium sand	1-5	4 –20	1.2	48
3	Fine sand, loamy sand	6-15	21-60	0.8	32
4	Sandy loam, loam	16-30	61-120	0.6	24
5	loam, porous silt loam	31-60	121-240	0.45	18
6	Silty clay loam	61-120	241-480	0.2	8
7	Clays, colloidal clays	>120	< 4800	Not recommended	Not recommended

min/inch. The leaching fraction, as estimated from the soil moisture data, was 0.14 in plot no. 6 and 0.12 in plot no.11. This shows that for the period under observation, the fraction of applied water that passes through the entire root depth and percolates downwards is 14% and 12% while 86% and 88% is consumed by evapotranspiration.

Water quality assessment

The guidelines for assessing the suitability of water quality for irrigation have been presented in Table 3, along with the observed water quality of sewage and tubewell waters.

With regard to the problem of salinity, the conductivity of sewage has been observed from 0.607 to 0.694 mmhos/cm while conductivity of tubewell water is 0.305 to 0.371 mmhos/cm. Further, the TDS of sewage ranged from 434.72 to 485.61 mg/l while the TDS of tubewell water has been 214.87 to 259.83 mg/l. This shows the suitability of the tubewell water for irrigation but places moderate restriction on the use of the sewage. The sodium adsorption ratio (SAR) of sewage and tubewell water ranged from 0.99 to 1.97. On the basis of this and the observed electrical conductivity ranges, slight to moderate restriction on use of both sewage and tubewell waters for irrigation is envisaged with respect to the problem of salinity.

Regarding the specific ion toxicity, the sodium of sewage ranged from 85.1 to 92.0 mg/l and that of the tubewell water from 29.6 to 32.6 mg/l. It shows that the toxicity of both the waters with respect

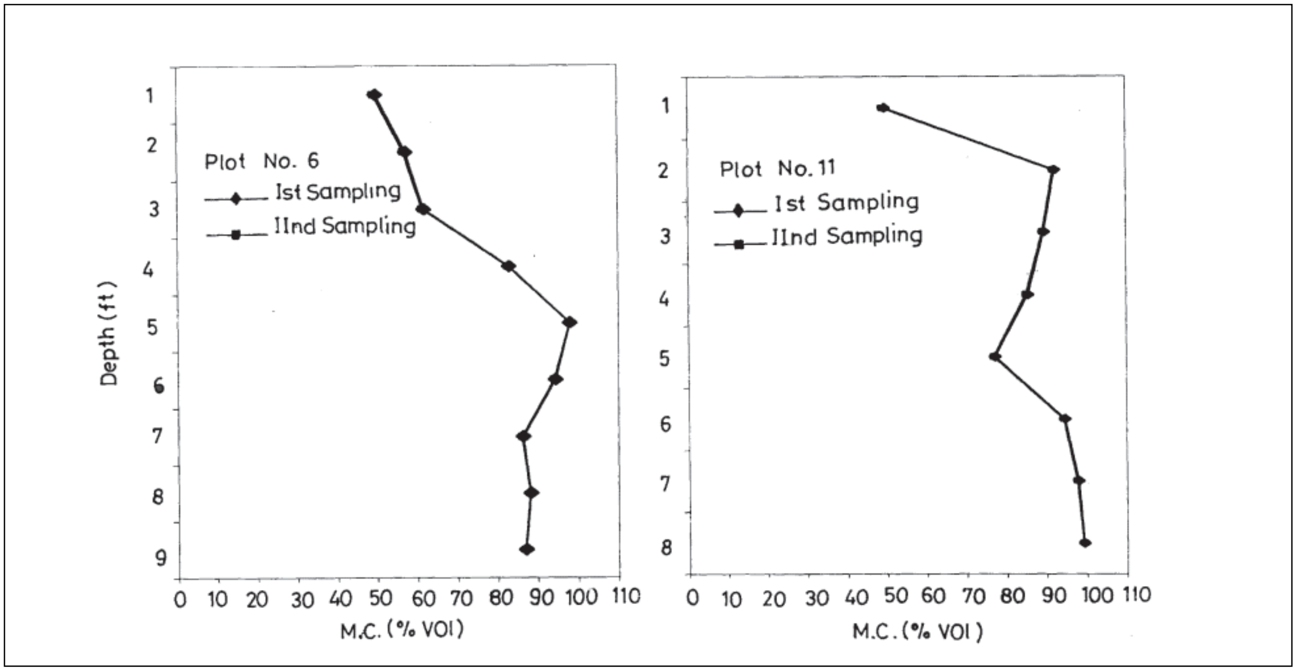


Figure 6. Moisture content analysis.

to sodium is very high. Further the chlorides in sewage ranged from 60.99 to 65.5 mg/l while in tubewell water, they ranged from 1.42 to 1.99 mg/l. These results do not exhibit chloride toxicity.

The total nitrogen of sewage ranged from 65.85 to 68.9 mg/l while in tubewell water, it was not detected. This exhibited severe restriction in use of the sewage. Further, the bicarbonates in sewage ranged from 427.76 to 438.28 mg/l while for tubewell waters, they ranged from 190.36 to 218.32 mg/l. The ranges observed indicate moderate restriction in the use of both for irrigation. Values of pH for both sewage and tubewell water ranged from 7.2 to 7.6, which appeared to fall within permissible limits. The sewage was also observed to be unsuitable for irrigation with respect to the microbial status as the faecal coliforms ranged from 244 to 460 per 100 ml as against 100/100 ml (permissible).

Finally, the concentrations of heavy metals, viz. Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn of both sewage and tubewell waters, were observed within the permissible range for irrigation waters, except the concentration of Mn which was slightly high in sewage (0.29 to 0.32 mg/l).

To summarize, the above results suggest that the tubewell water is more or less fit for irrigation, but suitability of the applied raw sewage comes under serious doubt as moderate to severe violations of water quality standards has been observed in many parameters.

High values of parameters like total solids (1895 to 2513 mg/l), suspended solids (912 to 1393 mg/l), sodium (267 to 420 mg/l) and chlorides (245 to 388 mg/l) have also been reported from other municipal sewage farms in India (Pattabi et al., 1999).

The observed values of water at different depths were checked against WHO standards for impact on receiving water quality. The results are presented in Tables 4 and 5.

As evident from the tables, general water quality of both the strata around the sewage farm appears to be within the permissible limits except at a village (Saliyar), which is upstream of the farm (considering groundwater flow direction). The water quality of the middle strata at this village has been found to be relatively worse. Pollution from local anthropogenic sources has been envisaged as the prime reason. Further concentrations of various heavy metals viz. Cd, Co, Cu, Fe, Pb, Mn, Ni

Table 3. Quality of Groundwater and Wastewater Used for Irrigation

Sl. No.	Potential Irrigation Problem	Units	Guidelines (as per WHO Standards)			Observed Values		
			Degree of restriction on use			Sewage	Tubewell water at Sewage Farm Site	Tubewell water at the distant reference site
			None	Slight to moderate	Severe			
1	Salinity							
	EC_w	mmhos/cm	< 0.7	0.7-3.0	> 3.0	0.607-0.694	0.343-0.371	0.305-0.320
	TDS	mg/l	< 450	450-2000	> 2000	434.72-485.61	242. 91-259.83	214.87-224.59
2	Permeability							
	SAR= 0-3		and $EC_w \geq 0.7$	0.7-0.2	< 0.2	SAR	SAR	SAR
	3-6		≥1.2	1.2-0.3	< 0.3	1.89-1.97	1.04-1.13	0.99-1.0
	6-12		≥1.	1.9-0.5	< 0.5	and	and	and
	12-20		≥2.	2.9-1.3	< 1.3	EC_w	EC_w	EC_w
	20-40		≥5.0	5.0-2.9	< 2.9	0.607-0.694	0.343-0.37	0.305-0.320
3	Specific ion toxicity							
	Sodium (Nα)	mg/l	< 3	3-9	> 9	86.1-92.0	31.5-32.6	29.6-29.8
	Chloride (Cl)	mg/l	< 140	140-350	> 350	60.99-65. 51	1.67-1. 99	1.42-1.49
	Boron (B)	mg/l	< 0.7	0.7-3.0	> 3.0	-	-	-
4	Miscellaneous							
	Nitrogen (Total N)	mg/l	< 35	5-30	> 30	65.85-68. 9	ND	ND
	Bicarbonate (HCO_3)	mg/l	< 90	90-500	> 500	427.76-438.28	190. 36-218.	193.08
	pH	unit	Normal range 6.5 – 8.4			7.2-7.3	7.4-7.6	7.4-7.5
5	MPN	MPN/100ml	Not to be more than100/100 ml			244-460	ND	ND

and Zn for water in both the strata also fall well within the permissible range prescribed by WHO.

Soil quality assessment

The soil characteristics of three sewage-irrigated plots have been compared with the soil characteristics of another farm irrigated with the groundwater extracted from a tubewell. The results obtained are presented in Table 6 (a). The soils irrigated with sewage display a higher electrical conductivity, moisture content, chlorides and the concentrations of Ca, Mg, Na, and K as compared to the tubewell-irrigated soils. Further, Table 6 (b) shows that the concentrations of heavy metals in sewage irrigated soils are higher as compared to the tubewell-irrigated soils. The higher values of the solids, minerals and heavy metals in the sewage irrigated soils directly highlights the impact of application of sewage and subsequent enrichment of these compounds in the soil medium.

The physicochemical characteristic of soil at 1ft interval from different sites of sewage farm is presented in Figure 7. It may be noticed from Figure 7 that chlorides display a nearly uniform vertical variation whereas EC displays higher values in the upper zone in plot 6 and in middle zone in plot 11 respectively. Accumulation of minerals in different zones may possibly be explained by the texture of the soil, which is more clayey in plot 6 and sandy loam in plot 11 respectively.

The concentration of trace elements in soil samples at a depth interval of 1 ft has been exhibited in Table 7 (a) and (b) for plots 6 and 11 of the sewage farm respectively. It may be observed that plot 11 exhibited very high values of all the elements in comparison to plot 6 indicating a stronger influence of sewage irrigation (more intensive irrigation) faced by the same. Further, an accumulation

Table 4. Quality of Groundwater from Private Handpump Water (Depth Range 60 ft)

S.No.	Site/Village	Parameters Range																
		pH	Temp. (°C)	EC (mmhos/cm)	TDS (mg/l)	TSS (mg/1)	COD (mg/1)	BOD (mg/1)	Cl^- (mg/1)	CO_3^{--} (mg/1)	HCO_3^- (mg/l)	SO_4^{--} (mg/l)	Total P (mg/l)	Total N (mg/l)	Ca^{++} (mg/l)	Na^+ (mg/l)	Mg^{++} (mg/l)	K^+ (mg/l)
1.	Pohana	7.4	19.9- 20.8	0.392- 0.421	274.17 295.16	0.13- 0.21	7-14	2-4	19.15	ND	361.12	2.0- 3.0	NU	ND	44.2- 45.0	60.9- 61.6	26.3- 27.2	3.73- 3.84
2.	Saliyar	7.1-7.2	21.8- 22.0	0.607- 0.655	425.54 458.73	0.28- 0.32	14	4-6	148.92	ND	305.04 309.92	4.0	ND	ND	47.6- 48.2	98.5- 98.9	39.8- 40.6	5.63- 5.81
3.	Guru Ram Rai Public School (Adjacent to Sewage Farm)	7.4	20.7- 22.0	0.405 - 0.448	282.58 314.18	0.14- 0.17	ND	ND	1.29- 1.42	ND	300.16	2.0	ND	ND	37.4- 37.9	42.3- 44.6	20.4- 20.7	3.86- 3.87
4.	Ibrahimpur	7.6-7.7	20.1- 22.4	0.292 - 0.337	205.26 235.93	0.10- 0.12	7	1.43-2	1.42- 2.08	ND	290.36	2.0	ND	ND	33.8- 34.3	40.7- 41.6	21.2- 21.5	4.42. 4.63
5.	Mutallapur	7.4-7.6	20.1 - 21.6	0.521 - 0.527	364.69 369.14	0.43- 0.65	7	2-4	20.32- 25.35	ND	302.0 - 319.8	2.0	ND	ND	32.4- 33.1	46.3- 47.4	27.6- 28.9	7.42- 7.76
6.	Rampur	7.4-7.5	21.2- 22.5	0.446 - 0.498	312.45 348.69	0.21 - 0.28	ND	ND	19.07	ND	295.28 297.72	3.0	ND	ND	32.6 - 33.4	44.5- 45.7	26.6 - 26.8	6.51- 6.84
WHO Standards (for drinking water)		***6.5-8.5***	***Not to exceed 40°C***	***2.350***	***1000***	***100***	***30***	***10***	***250***	-	-	***250***	***5***	***1***	***100***	***50***	***50***	***12***

Table 5. Quality of Groundwater from Government Handpump Water (Depth Range 130 ft)

S.NO.	Site/Village	Parameters Range																
		pH	Temp. (°C)	EC (mmhos/cm)	TDS (mg/l)	TSS (mg/1)	COD (mg/1)	BOD (mg/l)	Cl^- (mg/1)	CO_3^{--} (mg/1)	HCO_3^- (mg/1)	SO_4^{--} (mg/l)	Total P (mg/1)	Total N (mg/1)	Ca^{++} (mg/1)	Na^+ (mg/1)	Mg^{++} (mg/1)	K^+ (mg/l)
1.	Pohana	7.5-7.7	21.0- 21.9	0.251 - 0.269	176.06- 188.75	0.06- 0.08	ND	ND	1.42- 2.13	ND	251.32	1	ND	ND	32.8- 33.1	40.03- 41.75	13.47- 14.32	2.62- 2.93
2.	Saliyar	6.9-7.0	21.7- 21.9	1.487- 1.649	1041.65 1154.47	0.70- 0.96	49-56	10- 16	558.78- 572.64	ND	387.96- 386.48	6	1.70- 1.95	ND	125.6- 126.0	257.4- 258.5	79.6- 80.9	14.9&- 15.46
3.	Ibrahimpur	7.6-7.8	21.4- 22.1	0.285 - 0,339	200.01- 237.73	0.08- 0.10	ND	ND	0.71 - 0.92	ND	289.14- 290.36	1	ND	ND	38.2- 38.9	41.0- 41.5	17.9- 18.3	3.56- 3.62
4.	Mutallapur	7.4-7.5	20.9- 21.8	0.418- 0.461	292.13- 323.14	0.35- 0.40	ND	ND	5.64 - 5.67	ND	285.52	2	ND	ND	33.4- 33.7	39.1 - 39.3	22.3- 22.6	5.26- 5.32
S.	Rampur	7.2-7.7	21.2- 22.1	0.264 - 0.325	184.92- 226.97	0.12- 0.14	ND	ND	1.42	ND	265.96	1	ND	ND	31.2- 31.4	38.0- 38.1	19.1 - 19.3	3.13- 3.16
WHO Standards (for drinking water)		***6.5 - 8.5***	***Not to exceed 40°C***	***2.250***	***1000***	***100***	***30***	***10***	***250***	--	--	**250**	***5***	***1***	***100***	***150***	**50**	***12***

of trace elements was observed in the middle zone (4 - 6 ft) in general in both plots, the extent being much more in plot 11.

More detailed studies on transport and transformation kinetics are needed to understand and comment on the observed accumulation behavior, which is a result of interplay of various processes active in the soil environment.

CONCLUSIONS

On the basis of this study, following conclusions can be drawn:

(i) In the present study, the groundwater flow direction has been estimated from northwest to southeast (towards Roorkee town). Thus the town is vulnerable to any possible contamination in groundwater from sewage farm.

Table 6(a). Characteristics of Sewage and Groundwater Irrigated Soil

SI. NO.	Location	Characteristics Range								
		pH	Temp. (°C)	EC (mmhos/cm)	Moisture (%)	Cl^- (mg/l)	Ca^{++} (mg/l)	Mg^{++} (mg/1)	Na^+ (mg/1)	K^+ (mg/1)
1.	Sewage irrigated soil at Plot No. 9	7.29- 7.30	18. 9- 21.0	0.103 - 0.104	46.82 - 46. 93	11.57- 11.58	28.1 - 28.7	21.8 - 22.6	30.2 - 30.8	95.6 - 96. 3
2.	Sewage irrigated soil at Plot No. 11	7.37- 7.39	18.8- 19.4	0.081 - 0.083	44.36 - 45.07	10. 03 - 10.13	41. 9 - 42.3	12.5 - 12.8	25.5 - 25. 9	78.2 - 78. 6
3.	Sewage irrigate soil at Plot No. 14	7.32- 7.33	18. 9- 19.7	0.094 - 0.097	45.64 - 45.73	10.81 - 10.90	37. 3 - 37.9	32.0 - 32.6	34.0 - 34. 3	101. 0 - 104.4
4.	Tubewell irrigated soil at Mutallapur	7.12- 7.13	18. 3 - 21.3	0.050 - 0.051	32.12- 32.58	4.64 - 4.77	18.2 - 18.7	3.76 - 3.92	23.3 - 23.7	64.2 - 64. 8

Table 6(b). Heavy Metals of Sewage and Groundwater Irrigated Soil

SL. NO.	Location	Heavy Metals Range (mg/1)								
		Cd	Co	Cr	Cu	Fe	Pb	Mn	Ni	Zn
1.	Sewage irrigated soil at Plot No. 9	0.123 - 0.124	0.121 - 0.123	0. 210 - 0. 214	0.166 - 0.168	150. 0 - 151. 3	0. 273 - 0. 279	3. 34 - 3.46	0. 250 - 0. 253	0. 951 - 0. 956
2.	Sewage irrigated soil at Plot No. 11	0.115 - 0.117	0.114 - 0.117	0. 257 - 0. 262	0.133 - 0.136	121. 0 - 121. 2	0. 281 - 0. 284	2.43 - 2.47	0. 152 - 0. 158	0. 953 - 0. 954
3.	Sewage irrigate soil at Plot No. 14	0.121- 0.122	0.170 - 0.172	0. 323 - 0. 336	0.152 - 0.154	174. 3 - 174. 9	0. 292 - 0. 297	3.30 - 3.32	0. 161 - 0. 168	0. 951 - 0. 953
4.	Tubewell irrigated soil at mulallapur	BDL	0.025 - 0.031	0.132 - 0.136	0. 071- 0. 072	31. 50 - 32. 90	0. 152 - 0. 154	1.04 - 1.06	0. 064 - 0. 072	0. 361 - 0. 369

Table 7(a). Heavy Metals of Sewage Irrigated Soil at 1 ft Interval

SL. NO.	Depth (ft)	Location	Heavy Metals Range (mg/l)							
			Co	Cr	Cu	Fe	Pb	Mn	Ni	Zn
1.	1.0	Plot No. 6 of sewage farm site	0.074	0.040	0.026	41.8	0.210	0.658	0.020	0.053
2.	2.0	-do-	0.344	0.031	0.047	53.0	0.233	0.802	0.050	0.114
3.	3.0	-do-	0.102	0.092	0.040	58.6	0.187	0.909	0.026	0.166
4.	4.0	-do-	0.132	0.057	0.032	65.0	0.175	1.010	0.049	0.276
5.	5.0	-do-	0.138	0.110	0.058	72.3	0.210	1.090	0.061	0.152
6.	6.0	-do-	0.159	0.075	0.021	60.8	0.198	0.961	0.022	0.128
7.	7.0	-do-	0.110	0.119	0.027	53.9	0.152	0.805	0.024	0.288
8.	8.0	-do-	1.146	0.083	0.034	61.8	0.210	1.040	0.035	0.200
9.	9.0	-do-	1.142	0.087	0.036	61.3	0.200	1.080	0.029	0.100

Table 7(b). Heavy Metals of Sewage Irrigated Soil at 1 ft Interval

SL. NO.	Depth (ft)	Location	Heavy Metals Range (mg/l)							
			Co	Cr	Cu	Fe	Pb	Mn	Ni	Zn
1.	1.0	Plot No. 11 of sewage farm site	0.268	0.468	0.128	125.0	0.408	2.29	0.251	0.365
2.	2.0	-do-	0.240	0.389	0.110	133.0	0.292	2.25	0.203	0.334
3.	3.0	-do-	0.294	0.485	0.159	150.0	0.315	2.15	0.272	0.370
4.	4.0	-do-	0.375	0.747	0.303	197.0	0.420	1.17	0.452	0.525
5.	5.0	-do-	0.425	0.825	0.320	206.0	0.490	1.05	0.479	0.575
6.	6.0	-do-	0.463	0.738	0.280	199.0	0.572	3.44	0.451	0.618
7.	7.0	-do-	0.568	0.686	0.245	197.0	0.887	3.60	0.372	0.824
8.	8.0	-do-	0.538	0.572	0.250	181.0	0.794	2.50	0.301	0.924

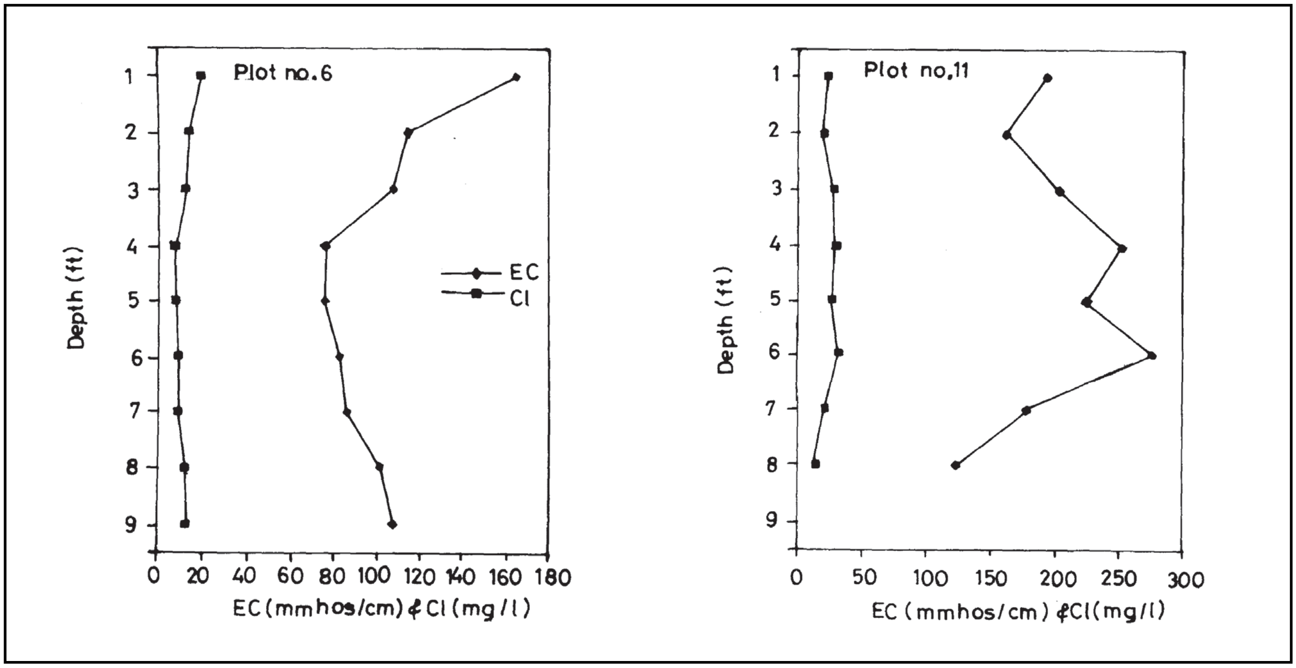


Figure 7. Physicochemical analysis of sewage irrigated soil.

(ii) The analysis of the water table data shows that especially in the vicinity of the sewage farm, no river aquifer interaction is noticeable before and during the rainy season.

(iii) The suitability of sewage farm with respect to soil characteristics appears to be marginal.

(iv) The leaching fraction, estimated from the soil moisture data has been found as 12% to 14% with evapotranspiration being responsible for 86% to 88%.

(v) The water quality of private handpump and government handpump around the sewage farm appears to be within the permissible limits except at Saliyar village.

(vi) The physicochemical characteristics and heavy metals concentration of soil of different plots of the sewage farm and nearby farm irrigated with the tubewell water indicate that the soils irrigated with sewage had a higher accumulation of minerals and heavy metals as compared to the tubewell irrigated soils at all the sites.

(vii) It is concluded from the study that the tubewell water is more or less fit for irrigation but suitability of sewage comes under serious doubt as moderate to severe violation of water quality standards has been observed in many parameters.

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