Impact of pollution due to tanneries on groundwater regime

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Most parts of India are facing anthropogenic groundwater pollution. Such types of pollution are mainly enrichments of various chemical parameters such as nitrate, hardness, metallic trace elements and microbiological organisms. The overexploitation of groundwater in some parts of the country induces water-quality degradation. Untreated industrial effluents discharged on the surface cause severe groundwater pollution in the industrial belt of the country. This poses a problem of supply of hazard-free drinking water in the rural parts of the country. More than 50% of the tanneries in the country exist in Tamil Nadu. There are about 80 tanneries operating in and around Dindigul town in upper Kodaganar river basin, Tamil Nadu. The untreated effluents from these tanneries have considerably affected the quality of groundwater in this area. In order to assess the extent of groundwater deterioration, detailed analysis for groundwater quality has been carried out. The dissolved chemical constituents in groundwater and their concentration have been studied. The correlation matrix has been established and studied between chemical parameters. A good correlation has been observed between EC and Cl, as also EC and Na. Progressive reduction in correlation coefficients for Mg^{2+}, $(Na^+ + K^+)$, Ca^{2+} and SO_4^{2+} is observed as 0.91, 0.87, 0.86 and 0.56 respectively. It is found that the quality of groundwater in this area has deteriorated mainly due to extensive use of chemicals (NaCl) in the leather industries.

THE study area is located in the southern part of India, close to Kodaganar river basin, mainly in hard rock terrain. The area is known for its leather industries[1], some of them have been established as early as 1939. Since then tanneries are spreading and at present more than 80 are well established. Most of these are located in the central part of Dindigul town and along Madurai, Vattalagundu and Ponmandurai roads. During the past few decades, the groundwater is being contaminated giving rise to health problems and epidemics. In fact, processing of leather requires a large amount of freshwater along with various chemicals. Every 10 kg of raw skin tanned requires about 350 l of freshwater. Water sources are minimal at Dindigul town. The water-table is deep due to overexploitation for irrigation and tanning through dug wells, dug-cum-bore wells and bore wells[2–4]. Various chemicals used in tanning include lime, sodium carbonate, sodium bi-carbonate, common salt, sodium sulphate, chrome sulphate, fat liquors, vegetable oils and dyes. Wastewater discharged for 100 kg of skin and hide processed varies from 3000 to 3200 l. The biggest polluting material in the tanning industry, which is difficult to get rid off is common salt. For every 10 tons of salted hide and skin processed, 2–3 tons of salt is removed and in addition another one ton of salt is removed while pickling[5–7]. Tannery waste is characterized by its strong colour (reddish to dull brown), high BOD, high pH and high dissolved solids. Tannery effluents, puerile, when discharged untreated, pollute the receiving stream and if allowed to percolate into the ground for a prolonged period seriously affect the groundwater table of that locality. The other major chemical constituents of waste from tanneries are sulphide and chromium. These chemicals mixed with water are discharged from the tanneries. They pollute the groundwater permanently and make it unfit for drinking, irrigation and for general consumption. It has been established[8,9] that a single tannery can cause pollution of groundwater around a radius of 7 to 8 km. The impact of the effluents is so stupendous that the water then becomes unfit for drinking and irrigation. TDS of the groundwater is as high as 17,000 mg/l. Sodium chloride is the major dominant chemical present in groundwater, which makes it unsuitable for drinking and irrigation. Among the dissolved constituents, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^- and SO_4^{2-} are in excess of the levels recommended for either drinking or irrigation[10].

In view of these, it is required to assess the quality of groundwater in the area. A large number of samples have been collected and quantitatively examined. Measurement of the concentration of various constituents as dissociated ions like HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+ and measurement of EC have been carried out for the area under study. An attempt has been made to correlate these aqueous ionic species with electrical conductivity and other chemical parameters to show the proportionate contribution of these constituents towards salinization of the groundwater.

The study area is located about 400 km southwest of Chennai city. It lies between 10°13′44″–10°26′47″ N lat. and 77°53′08″–78°01′24″ E long., and falls in Survey of India Toposheet No. 58F/15 & J/3, in the state of Tamil Nadu, India (Figure 1). The study area spreads over about 240 km^2, covering parts of Dindigul, Attur, Reddiarchattram and Sanarpatti blocks. This area is a form of basin and is characterized by undulating topography with hills located in the southern parts, and sloping towards north and northeast. The highest elevation (altitude) in the hilly area (Sirumalai Hill) is of the order of 1350 m amsl, whereas in the plains its ranges 360 m amsl, in the southern portions to 240 m in the northern part. No perennial streams exit in the area, except for short-distance streams encompassing 2nd and 3rd order drainage[11–14]. Run-off from precipitation within the basin ends in small streams flowing towards the main river Kodaganar. The average rainfall[15] is of the order of 915.1 mm for the period 1971–2001.

The study area is covered with Achaean granites and gneisses, intruded by dykes[16–18]. The rocks are mainly

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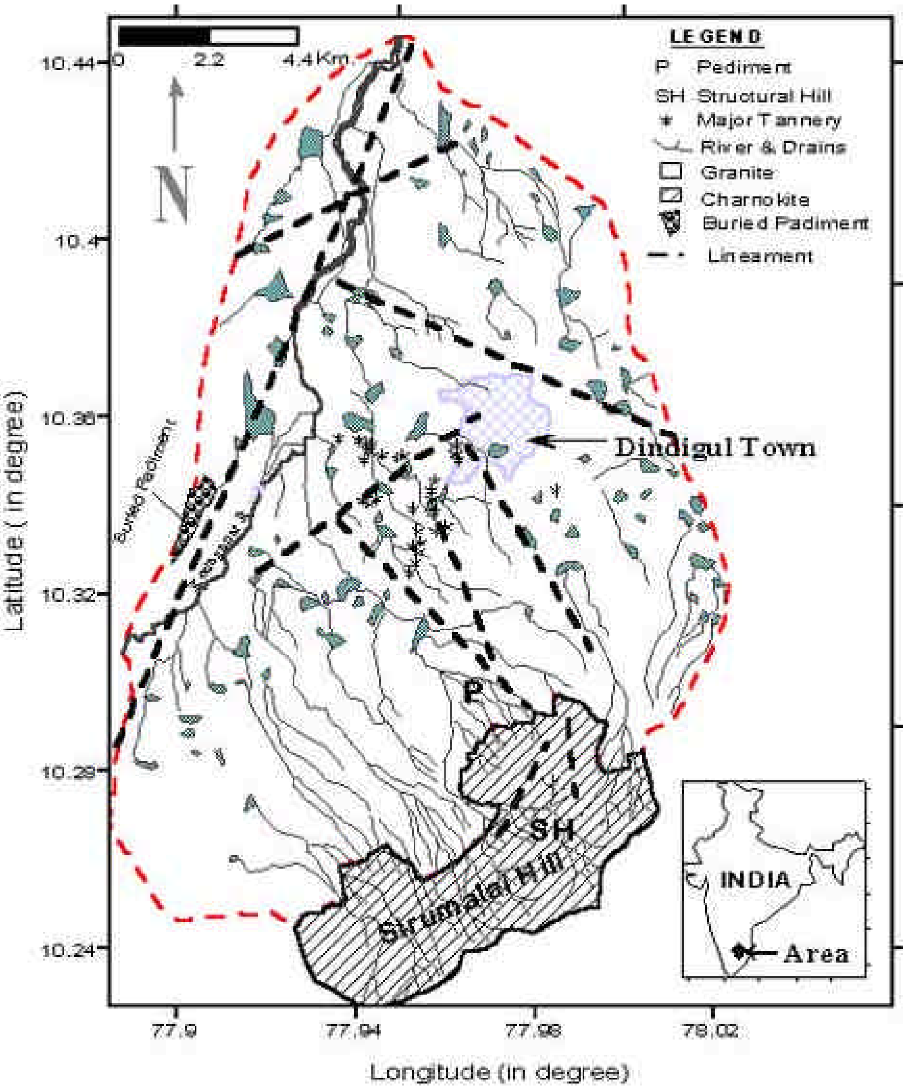

Figure 1. Location map.

Table 1. Minimum, maximum, mean and standard deviation of groundwater

	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3
Minimum	349	38	1	26	1	31	25	13	1
Maximum*	17000	1741	936	4850	215	756	10390	961	252
Mean	2496	288	145	348	21	377	1079	185	35
Standard deviation	2507	307	163	545	34	140	1560	161	44

Ions in mg/l; *Maximum value obtained in the sample collected from the adjutancy of the tannery. Samples were collected in January 2001.

composed of grey and pink feldspar with quartz grains, biotite and hornblende[19]. These formations are crossed by sets of joints and fractures, which have also caused weathering of coarser rocks. Weathering occurs due to mechanical and mostly chemical processes that take place while water in the fractures interacts with the formation. The shallow, hard and massive rocks are exposed mostly in the southern part of the basin. Black cotton and red sandy soils are common in the area. The thickness of weathered zone varies from 3.1 to 26.6 m. Such shallow zones may not be a stable source for the large demands of groundwater[13,14]. There are many lineaments which are oriented mainly towards NNE–SSW, NEE–SWW, NW–SE directions. But the major lineament runs in the NNE–SSW direction for several kilometres, situated NW of Dindigul town along the Kodaganar river (Figure 1). The weathered zone facilitates the movement and storage of groundwater through a network of joints, faults and lineaments, which form conspicuous structural

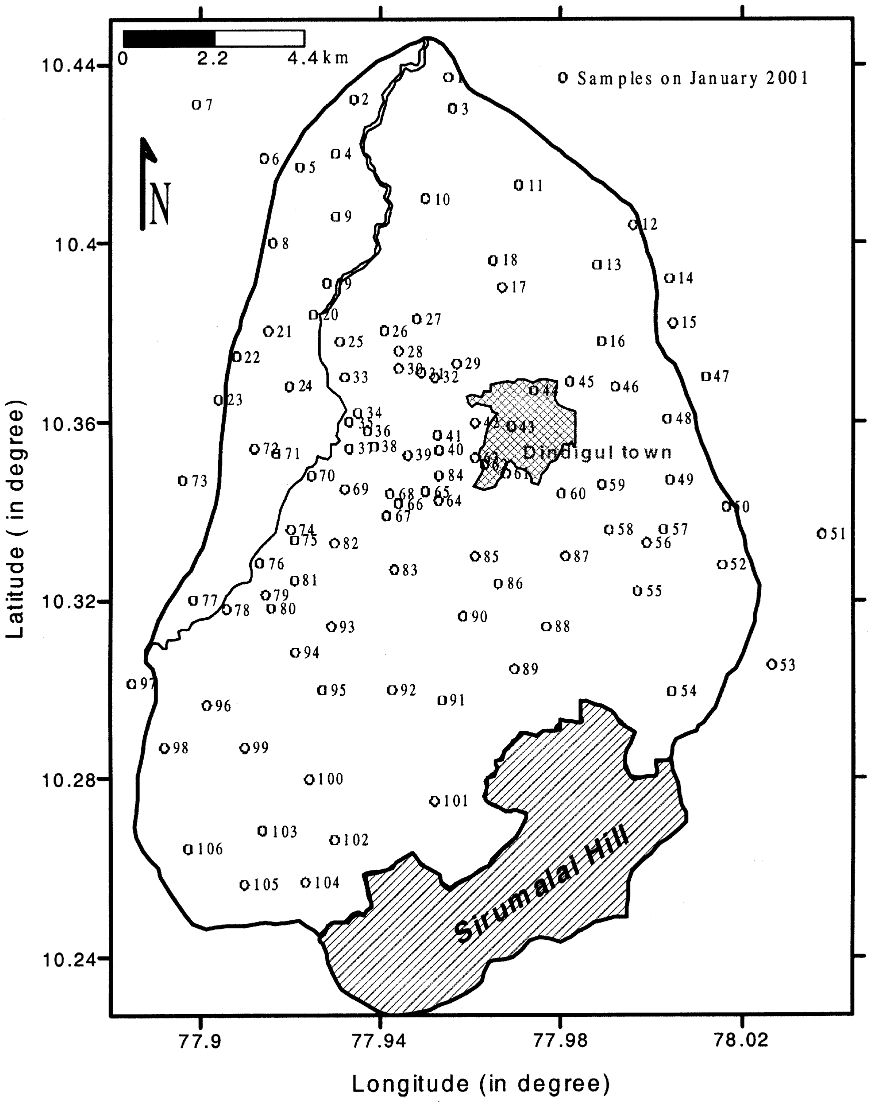

Figure 2. Location of the sampling.

Table 2. Classification of groundwater

Type of water	TDS	Percentage
Freshwater	0–1000	24.53
Brackish water	1000–10,000	72.64
Saline water	10,000–1,00,000	2.83
Brine water	>1,00,000	0.00

TDS in mg/l; Sample collected and analysed during January 2001. Classification based on Freeze and Cherry[22].

Figure 3. Classification of water based of concentration of TDS

TDS	Water type	Percentage
Up to 500	Desirable for drinking	3.77
500–1000	Permissible for drinking	20.75
<3000	Useful for irrigation	75.47
>3000	Unfit for drinking and irrigation	24.53

TDS in mg/l; Samples collected during January 2001.

features. Apart from the structural controls on the groundwater movement, the terrain is covered with pediment and buried pediment at the southern and western sides of the area. The other most dominant formation is the charnokite, which is found in the southern and southeastern part of Sirumalai Hills. This formation is less weathered, jointed or fractured compared to the previous one[15] and could therefore be considered as impermeable.

Groundwater mostly occurs in weathered as well as in fractured zones, which are under unconfined, semi-confined and confined conditions[2,11]. These aquifer conditions may be changed rapidly and vary over a wide range from place to place. The thickness of the weathered/fractured zone varies even over a small region. The shallow aquifers are in phreatic condition, which may not be a stable source for large demands of groundwater. However, the deeper aquifers are partly confined, i.e. they are being recharged from the

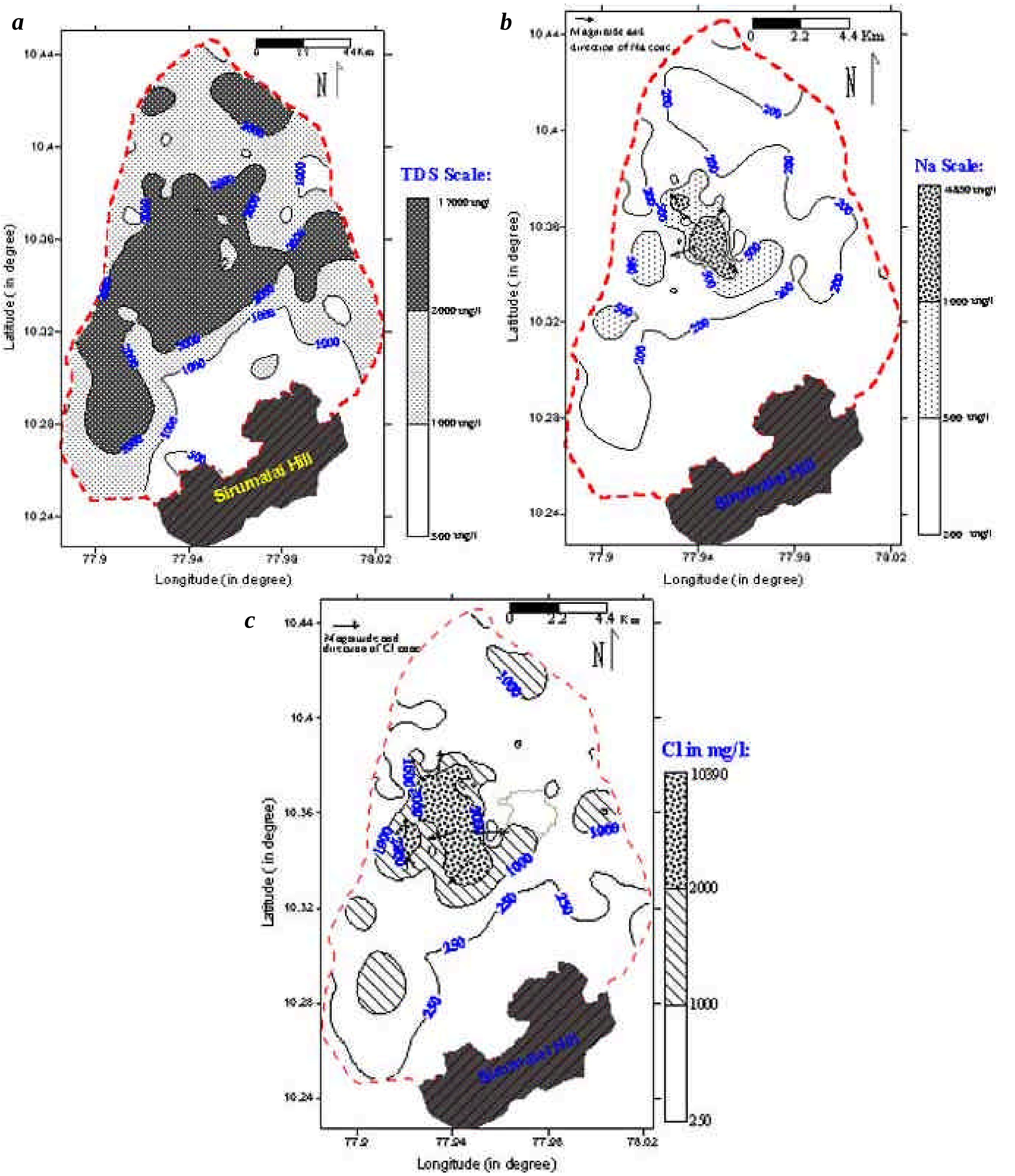

Figure 3. ***a***, TDS contours; ***b***, Na contours; ***c***, Cl-contours (in mg/l; January 2001).

shallow unconfined aquifers through dug-cum-bore wells/ bore wells[19].

For the assessment of groundwater quality, 106 water samples were collected during January 2001 from the represented dug wells and dug-cum-bore wells distributed throughout the area. These are under use at 0.5 m below the water-table and were pumped for more than 5 min. Methods of collection and analysis of water samples fol-

Table 4. Correlation matrix

	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-
pH	1.00	–	–	–	–	–	–	–	–	–	–	–
EC	–0.19	1.00	–	–	–	–	–	–	–	–	–	–
TDS	–0.19	1.00	1.00	–	–	–	–	–	–	–	–	–
TH	–0.23	0.93	0.93	1.00	–	–	–	–	–	–	–	–
Ca^{2+}	–0.28	0.86	0.86	0.96	1.00	–	–	–	–	–	–	–
Mg^{2+}	–0.14	0.91	0.91	0.94	0.80	1.00	–	–	–	–	–	–
Na^{+}	–0.09	0.88	0.88	0.65	0.54	0.69	1.00	–	–	–	–	–
K^{+}	0.06	0.04	0.04	–0.001	0.007	–0.008	0.03	1.00	–	–	–	–
HCO_3^-	0.07	–0.17	–0.17	–0.31	–0.40	–0.18	0.04	0.33	1.00	–	–	–
Cl^-	0.16	0.99	0.99	0.93	0.86	0.92	0.87	0.004	–0.21	1.00		–
SO_4^{2-}	–0.29	0.56	0.56	0.47	0.45	0.43	0.55	0.16	0.0006	0.49	1.00	–
NO_3^-	–0.29	0.19	0.19	0.19	0.25	0.10	0.13	0.09	–0.13	0.13	0.61	1.00

Number of water samples: 106; on January 2001.

lowed are essentially the same as given by APHA[20] and Browen *et al.*[21].

The concentration of various parameters is expressed in mg/l. The precise locations of the sampling points were determined in the field through the development of GARMIN-12 Channel Instrument, based on the principles of Global Positioning System (GPS), and the exact longitude and latitude of the sampling. The location of the sampling points is shown in Figure 2.

The statistical parameters, viz. minimum, maximum, mean and standard deviation of different chemical constituents of groundwater samples are shown in Table 1. In order to know the distribution pattern of the concentration of different elements and to demarcate the higher concentration zones, contour maps for various elements were also generated.

The major part of the TDS is consistent with HCO_3^-, SO_4^{2-} and chlorides of Ca^{2+}, Mg^{2+} and Na^+. These ions usually comprised about 90% of the TDS[22]. Several hydrochemical processes, which may include movement of groundwater through rocks containing soluble mineral materials, concentration of water by evaporation, and contamination of water due to industrial and municipal waste disposals, may cause an increase in the dissolved solids. The groundwater has been classified as given in Table 2.

The groundwater falls under three categories, while most of the samples are brackish water with TDS ranging from 1000–10,000 mg/l. Water, with TDS less than 500 mg/l is considered good for drinking purposes and water with more than 1000 mg/l is considered unsafe to use[10]. According to Davis and DeWiest[23], water can be classified based on the concentration of TDS as given in Table 3.

Table 3 clearly shows that more samples are found unfit for drinking and irrigation purposes. TDS varied from 349 to 17,000 mg/l and is more likely to be increased due to the disposal of untreated waste from the tanneries. The isoclines of TDS are shown in Figure 3 *a*. These values are more than the permissible limit[10] in and around the tannery cluster compared to other parts of the area. The trend of TDS contours clearly showed that the contamination level is possibly moving along the river course.

Among the cations, Na^+ is the most dominant in groundwater. Sodium concentrations of more than 50 mg/l make the water unsuitable for domestic use. High concentrations of Na^+ and Ca^{2+} in the groundwater are attributed to cation exchange among minerals and to the sewage concentration, in addition to the filtration of pollutants from effluents. In the study area, sodium varies from 26 to 4850 mg/l. It is noticed that 33.96% samples is found to be more than permissible limit of potable water. High sodium concentration in irrigated areas could be due to the repeated use of water. The iso-concentration map of sodium in shown in Figure 3 *b*. One can notice that groundwater in Dindigul town and its surrounding area has high concentration of sodium (> 200 mg/l). The possible source of bicarbonate in the groundwater is from sewage and also from various human activities[24]. Water with high concentration of bicarbonates when used for irrigation, may cause white deposits on fruits and leaves, and thus result in health hazards.

Abnormal concentrations of Cl (25 to 10,390 mg/l) have been found in shallow groundwater, and its possible source are the tanneries where sodium chloride is used as raw material. The equal value contour map of Cl is shown in Figure 3 *c*. The values are high in and around the various location points close to Dindigul residential areas and also in those places where tanneries are located. The gradient of the concentration of Na^+ and Cl^- is not in agreement with the topographic pattern. In terms of magnitude and direction, it is randomly distributed. This is quite possible due to non-uniform abstraction of domestic, irrigation and industrial purposes.

The correlations of EC with different chemical constituents of 106 groundwater samples have been studied. The correlation matrix is presented in Table 4. It can be seen that the highest correlation has been found between chloride and EC, which is in the order of 0.99 (Figure 4 *a*). The correlation coefficient for other constituents such as Mg^{2+}, Na^+, and SO_4^{2-} correlated with EC reduces progressively. The correlation values are 0.91, 0.88 and 0.56 respectively (Figure 4 *a* and *b*) which indicate proportionately lesser contribution of these constituents towards polluting the groundwater. Good correlation is also found between Mg^{2+} and Cl^-, Na^+ and Cl^- as well as Ca^{2+} and Cl^-, which are 0.92, 0.87 and 0.86 respectively (Figure 4 *c*). Thus the groundwater is extensively polluted due to use of salt in the tanneries.

Our study found the areas between Kodaganar river and Dindigul town to be more polluted. Most of these contaminants are used in the tanning processes. However, their presence in the effluents and waste is well established.

A good correlation existed between EC, and Cl (0.99), Mg (0.91), Na (0.88) and Ca (0.86). Groundwater is affected by the extensive use of salt from the leather industries to a large extent.

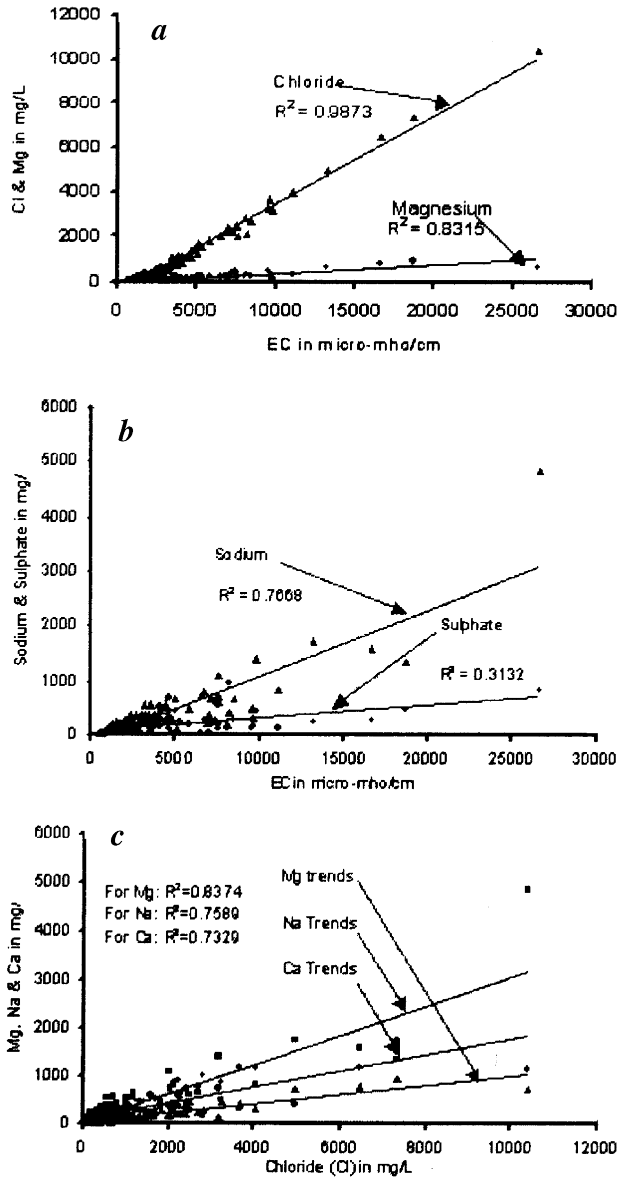

Figure 4 *a–c*. Cross plot of different chemical constituents.

Pollution level is increasing in these areas due to effluents from tanneries.

Improper drainage system and dumping of leather waste materials in open ground are also responsible for groundwater contamination and related health hazards.

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Lake deposits of the northeastern margin of Thar Desert: Holocene(?) Palaeoclimatic implications

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The understanding of past climates, particularly Holocene climate, changes in continental settings is significant for improving the predictive capability of models used for building future climate change scenarios. Continental sedimentary systems such as lake and river basins support large agricultural communities; even the desert margins support a substantial rural population. Therefore, understanding of the responses of these systems to future climate changes on decadal, century, and millennial scales needs to be strengthened in order to determine the varying limits of land, soil, water and vegetation resource structure on the demographic structure. In this context, we document the lake/pond deposits of the northeastern margin of Thar Desert along a rainfall gradient (200–600 mm) from west to east. The potential of the lake deposits and the associated sedimentary facies for the reconstruction of post-Last Glacial Maximum climate history is discussed, and the need for developing a chronological database on this important archive of continental Holocene climate is recognized.

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THE Holocene palaeoclimatic history of the Thar Desert and its margins encompassing over 200,000 km^2 is of societal and environmental significance, and has a bearing on testing the response models of near surface systems to century and millennium scale climatic changes[1]. Previous workers have inferred past climatic changes from lake records in the Thar Desert[2–7]. These studies indicate heaviest summer precipitation between 10.8 and 10.0 Ka, fluctuating lake levels in the early Holocene, maximum lake levels between 7.2 and 5.6 Ka, and desiccation around 5.6 Ka. A dry phase at around 3 Ka is also inferred on the basis of aeolian/fluvio-aeolian[8–10] and lake records of Rajasthan and Gujarat[11], and Haryana[12]. Model calculations for the Thar reveal that between 3.5 and 10 Ka, the summer rainfall was almost twice the present-day value and winter precipitation about 20% higher[3].

Several lakes are present in the western part of India (Figure 1) and the lake deposits within them are of considerable palaeoclimatic significance because of their position along a rainfall gradient (600–200 mm), and their proximity to the Himalayan front, the Ganga Plain and the desert (Figure 2). Here we present the morphology of lakes/palaeolakes, associated landforms, nature of lacustrine deposits and their regional variability, along a 150 km NW–SE transect, in three precipitation zones, i.e. up to 300 mm, 300–500 mm and greater than 500 mm, from the Thar Desert to the Yamuna plains (Figure 2). Fifteen-pit sections (Figure 2) of the palaeolake deposits up to 3 m depths have been logged and about 10 well sections up to 10 m depths in the surrounding areas have also been studied.

The study area has three climatic zones from west to east (Figure 2). These are dry arid in Rajasthan (including the Nohar–Bhadra area), semi-arid in Haryana (including the Riwasa–Charkhi Dadri area) and sub-humid in Ganga Plain (including the Kotla Dahar area). The Haryana Plain shows the sharpest precipitation gradient compared to the Thar Desert and Ganga Plain. Meteorological data[13] of the three representative stations of these three zones are summarized in Table 1.

The Nohar–Bhadra area receives less than 300 mm rainfall annually, two-thirds of which is received during June–September. The mean temperature (42°C) is highest during May and lowest (5°C) during January. The Riwasa–Charkhi Dadri area receives 300–500 mm rainfall mainly during summer monsoon, i.e. June–September. The potential evapo-transpiration is 40 mm in December and 222.3 mm in June. The Kotla Dahar area has 600–700 mm rainfall, and the annual average temperature ranges between 18.8 and 31.7°C. A more exhaustive record of 1941–2002 from Nuh station shows a range of 300–1221 mm rainfall, with an average of 608.3 mm.