From a comparison of the thermal and AF decay curves of different specimens, it can be concluded that the samples showing blocking temperature at 350° C are hard (e.g. T5, J4, V3, V4), while those with a single blocking or Curie temperature of 580° C are typically soft (e.g. T3, J6). It then follows that the chromite mineral with the end member magnetite is magnetically hard. The typical step-like appearance of thermal demagnetization curves and the lower blocking temperature around 200° C for Kondapalli specimens can be attributed to their association with titanoferous magnetite[5]. This is possible because the country rock in this locality is a strongly magnetic charnockite.

The present study shows that the chromite mineral possessing end member magnetite is magnetically hard and has a blocking temperature of approximately 350° C. Conversely, by determining the blocking temperature and hardness of the chromite ore, it will be possible to identify the nature of chromite mineralization in the ore.

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Temporal changes in the chemical quality of groundwater in Ludhiana area, Punjab, India

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The temporal changes in the chemical quality of groundwater of Ludhiana area have been studied. The results from 1983 to 1992 have been compared. The study indicates that samples containing cyanide have increased as it cannot be absorbed and remains in the hydrogeological environment. Other trace elements do not show any significant change. Remedial measures to control pollution of groundwater have been discussed.

LUDHIANA is one of the most industrialized cities in the state of Punjab where largely electroplating units, bicycle industry, woolen and dyeing units are the dominant industries in addition to other small-scale industrial units. Groundwater is the only source of drinking water supply to the city and its quality is getting degraded due to increasing industrialization and urbanization[1-5]. An attempt has been made to study the temporal changes in the quality of groundwater around the industrial area where a decade ago trace element geochemistry of groundwater was investigated in detail[3].

The area studied is a part of the Indo-Gangetic Alluvial plain mainly composed of unconsolidated clay, silt, sands of different grades along with varying proportions of gravels, pebbles and kankar. The area forms a complex inter-mixture of multiple aquifer system (Figure 1). However, the top aquifers are generally unconfined in nature. Clay lenses of varying thickness occur at various depths and are generally not extensive in nature specially up to a depth of 95 m and get pinched out at shorter or longer distances. In general, the sand is thicker in the central part compared to northern and western parts[1]. The subsurface geology indicates no regional confining impermeable strata up to 95 m.

Budha Nallah forms a part of the palaeochannel of river Sutlej. The study of sub-surface geology of boreholes around Budha Nallah indicates high permeability of sediments around it.

A perusal of water level data indicates that the depth to water in the area ranges from 3 m to 15 m below the land surface. The water level in the area along Budha Nallah is shallow and ranges between 3 and 5 m below ground level[1]. The water table tends to deepen gradually away from Budha Nallah and in other parts of the city, it varies from 10 to 15 m below land surface. The unsaturated zone is highly permeable and primarily consists of sands of various grades, allowing the industrial effluents to reach groundwater quickly. Groundwater flow direction is from south-east to north-west with variations from south-south-east to north-north-west. However, around Budha Nallah, groundwater flow is from east-north-east to west-south-west. Hydraulic parameters do not show much variation within the area studied. Specific yield of top phreatic aquifers ranges between 20 and 25%. Hydraulic conductivity of top phreatic aquifer also remains uniform (20–30 m/day). The uniformity of hydraulic parameters is also reflected in the contour map (Figure 2) and it has been observed that hydraulic gradient remains almost uniform (1.2 m/km) except in the Central part where the steeper hydraulic gradient ranging between 1.5 and 1.9 m/km is attributed to heavy pumping in the central part of the area.

Samples of unsaturated zone were also analysed for chromium and cyanide at selected sites at an interval of 1 m depth. The results are shown in Table 1. In the unsaturated zone, the movement of pollutants is controlled by hydraulic conductivity, moisture content of

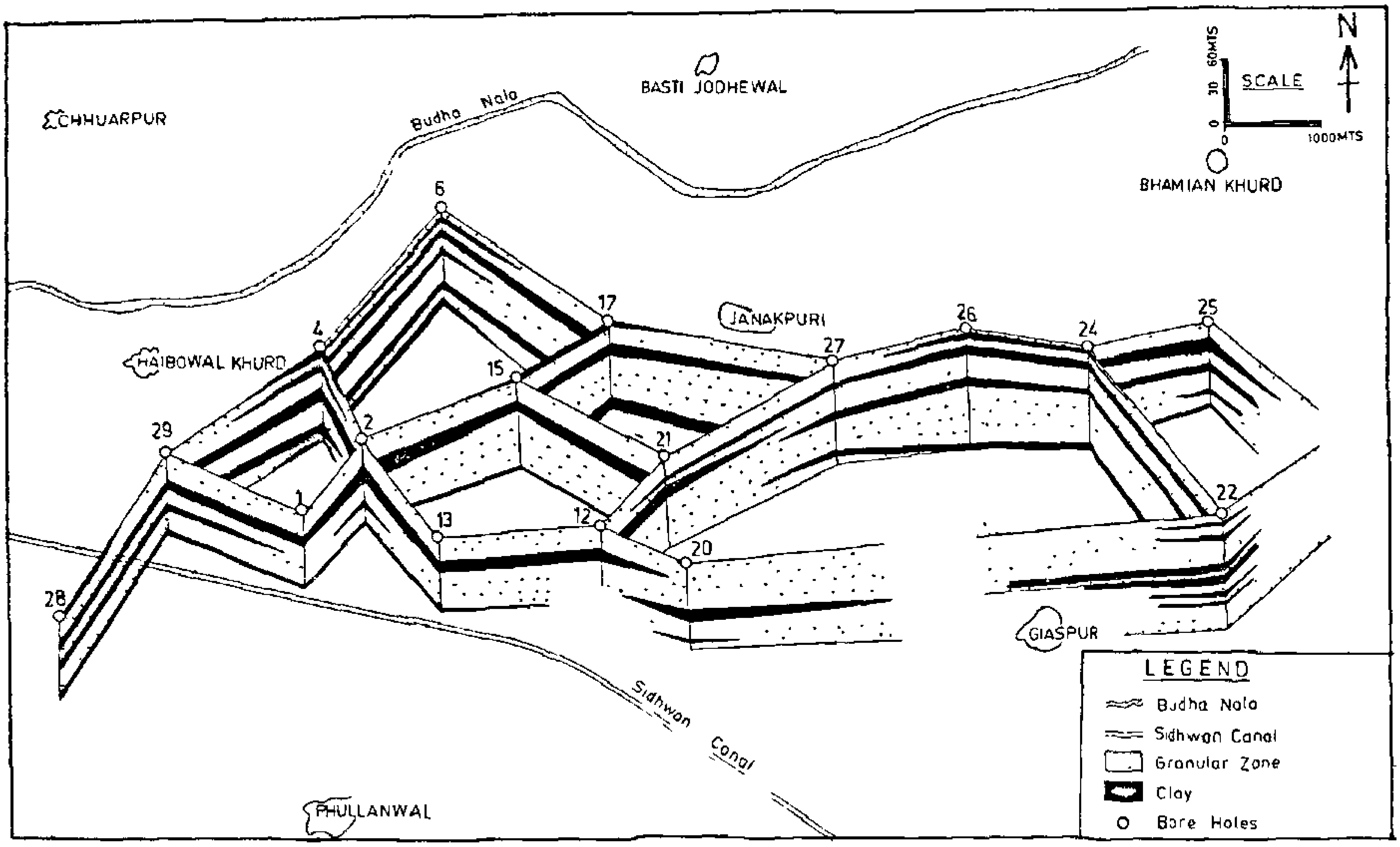

Figure 1. Multiple aquifer system in Ludhiana area (modified after Bhatnagar *et al.*[1]).

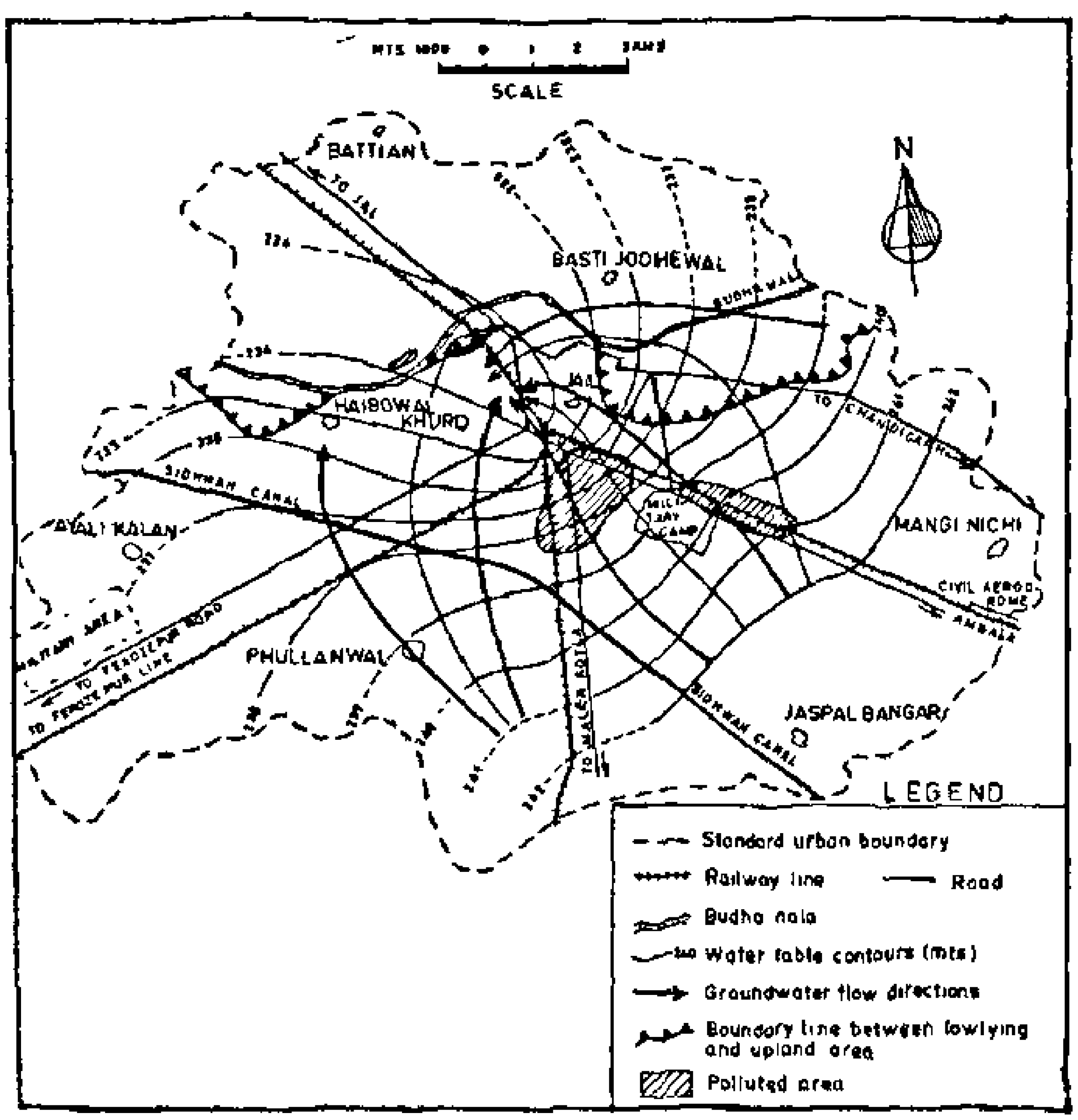

Figure 2. Polluted area demarcated on the basis of results of 1992. Base map of Bhatnagar *et al.*[1] has been used.

soil, climate etc. Downward movement of the solute through unsaturated zone with percolating water may take considerable time to reach the saturated zone. On reaching the saturated zone, the pollutants spread out laterally moving in the direction of groundwater flow. Thus pollution plumes are likely to move further along the direction of groundwater flow. In the area around Budha Nallah on Tajpur Road, where the depth to water is about 6 m, the behaviour of pollutants from unsaturated zone to saturated zone is understandable. Up to 5 m depth in sediments, cyanide concentration has been found to be 0.12 μg/g whereas in groundwater around this site from hand pumps it is 0.26 mg/l. In other cases, pollutants are infiltrating fast to reach the saturated zone where they either float on the top of the aquifer if pollutants are of low density and immiscible or move into the aquifer if contaminated water is buoyant.

The chemical quality of groundwater was earlier studied[3]. On the basis of polluted area of groundwater demarcated earlier, detailed sampling of groundwater was undertaken during 1992 in association with the Punjab Pollution Control Board[6]. In 1992, 101 samples from hand pumps (up to 30 m depth), shallow tubewells (up to 60 m depth) and deep tubewells (up to 100 m depth) were collected and analysed following standard methods[7]. The ground water of top aquifers is largely

Table 1. Chemical analysis (μg/g) of sediment samples collected

Location of sample	Depth below ground level (m)	Nickel	Total chrome	Cyanide
Research & Development Centre, Ludhiana	1	6.10	5.24	1.08
	2	2.15	2.92	0.24
	3	2.02	2 58	0.30
	4	1.74	2.86	0.10
	5	1.8	2.64	Nd
Backside of Punjab Wool Combers	1	5.14	12.84	Nd
	2	1.86	8.92	Nd
	3	2.50	3 14	Nd
	4	3.50	4.88	Nd
	5	2.51	2.04	Nd
Transport Ngr, Ludhiana	1	6.08	4.12	1.12
	2	5 36	4 87	0.82
	3	5.24	1.57	Nd
	4	4.52	1.68	Nd
	5	4.04	1 32	Nd
Budha Nallah on Tajpur Road	1	6.74	4 02	1 24
	2	2.92	3.97	0.92
	3	4.40	2.85	0.60
	4	5.12	3.51	0.32
	5	3.10	3.09	0.12

Nd: not determined.

Table 2. Concentration ranges (in mg/l) showing distribution of chromium and cyanide in groundwater

Concentration range	Chromium (hexavalent)		Cyanide	
	1983 NOS (%)	1992 NOS (%)	1983 NOS (%)	1992 NOS (%)
Not detectable	24(40.68)	87(86.14)	21(38.89)	19(18 81)
< 0.01	12(20.34)	–	–	20(19.80)
0.01–< 0.02	10(16.95)	–	6(11.11)	37(36.63)
0.02–< 0.03	2(3.39)	–	5(9.26)	11(10 89)
0 03–< 0.04	–	–	7(12.96)	5(4.95)
0.04–< 0.05	–	–	5(9.26)	3(2.97)
0.05–< 0.06	2(3.39)	2(1.98)	6(11.11)	2(1.98)
0.06–< 0.07	1(1.69)	–	1(1 85)	–
0.07–< 0.08	–	–	–	–
0.08–< 0 09	–	–	1(1.85)	–
0 09–< 0 10	–	–	–	–
0.10–< 1.0	2(3.39)	8(7.92)	2(3 70)	4(3.96)
1.0–< 5	3(5 08)	4(3.96)	–	–
5–< 10	–	–	–	–
10–< 15	3(5 08)	–	–	–
Total NOSs	59	101	54	101

NOS: Number of samples.

contaminated by chromium and cyanide[3-5]. The maximum permissible concentration of Cr^6 and cyanide in drinking water according to WHO[8] and ISI Standards[9] is 0.05 mg/l. The concentration ranges and the distribution of chromium and cyanide (Table 2) indicate that samples containing cyanide increased whereas those containing chromium decreased. Other trace elements (Ni, Zn, Pb) do not show any significant change and their concentration remains within the permissible range for drinking water use[6].

On the basis of the results, the polluted area of groundwater for 1992 has been demarcated (Figure 2). This area remains almost the same as it was in 1983. The pollution plumes are confined to the south-east parts of the city around industrial area, Janta Nagar and along Ludhiana-Ambala G. T. Road. Local pollution plumes exist around Budha Nallah which flows in a lowlying area and is one of the palaeochannels of River Sutlej as revealed by LANDSAT and IRS data. Ludhiana city is located in an upland area. As already mentioned, ground water flow direction is from south-east to north-west, i.e. towards the Budha Nallah. The main cause of groundwater pollution in Ludhiana is attributed to the disposal of industrial effluents on land without treatment in the city industrial area which get infiltrated down into the aquifer system and not the Budha Nallah. The Budha Nallah, however, receives sewage, industrial effluents from 20 points and pollutes the river Sutlej further downstream. Local pollution plumes, however, around Budha Nallah do occur.

It is suggested that remedial measures to control pollution of groundwater such as treatment of industrial effluents before disposal, setting up of special courts for summary trials and setting up of treatment plant for sewage need to be taken up on priority besides generating environment awareness amongst industrialists and the general public. In the critical polluted areas demarcated, installation of shallow tubewells/hand pumps should be banned. The area also requires regular monitoring of the quality of groundwater.

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Potential of wastelands for sequestering carbon by reforestation

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Indian soils are largely carbon-depleted but can be brought back to their native carbon-carrying capacity by reforestation. The current stock of organic carbon in Indian soils (24.3 Pg) can be increased to 34.9 Pg, the difference representing the potential for sequestering additional carbon in soils. Reforestation of 35 m ha of wastelands with suitable tree and grass species can sequester 0.84 and 1.06 Pg of carbon in vegetation and soil respectively. Restoration, maintenance and enlarging the carbon stocks of Indian soils are an urgent developmental priority.

THE increasing levels of CO_2 in the atmosphere leading to global warming, rise of sea level etc are a potentially serious threat to agriculture and environment[1]. The impact of global warming on soils is immediate because soils interface between geosphere and environment. Soil temperature affects the decomposition of soil organic matter[2,3], nutrient uptake and plant growth. Increasing soil temperature combined with aridity causes extensive loss of organic carbon from soils[2]. However, with reforestation and other suitable measures for ecological rehabilitation, it is possible to increase carbon levels of tropical soils[4–6]. Increasing CO_2 levels in the environment may also increase plant growth in some instances[7,8]. Soils and vegetation therefore represent potential sinks for this additional carbon[9] and reforestation had been suggested as a possible means of mitigating global warming[10,11]. However, quantitative studies are few and it is important to know what kinds of soils store substantial carbon below ground and devise suitable soil, water and crop management strategies to increase this capacity.

Each soil has a carbon-carrying capacity i.e., an equilibrium carbon content depending on the nature of vegetation, precipitation and temperature[2]; when the equilibrium is disturbed as for example by forest clearing, intensive cultivation etc., soil carbon rapidly declines. In the arid and semi-arid zone tropical soils, as for example in India, nearly 50% of the carbon is lost[2]. Jenny and Raychaudhuri's classical study on Indian soils[12], showed depletion to be as high as 60–70% in many soils. Many of the arid zone soils are affected by high salinity and alkalinity and become barren[13]. Wastelands in India are estimated at over 100 million ha[14] (of which 70% are badly degraded) and are extremely carbon-depleted; organic carbon can be as low as 0.2%. Soils with the greatest potential for C accumulation are those that are severely C-depleted but still retain the requisites (eg., nutrients, biology and structure) for primary production or can be suitably managed to increase