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Determinents for Contamination Risk Zoning of Groundwater – A Case Study of an Industrial Town of Punjab

G.S. Gill[1] and Harish Arora[2]

[1]Centre of Advanced Study in Geology, Panjab University, Chandigarh
[2]Paramount Exhibitors, Mohali, Punjab

Abstract : Ludhiana is one of the biggest city of Punjab occupying central place and has a dubious distinction of being one of the most polluted settlement of the country due to rapid growth of industrialization. Out of about 25,000 industries (large. medium and small scale), 631 are highly polluting and others are marginally polluting. The only surface water feature flowing in the area is the Buda which serves as a favourite site for dumping of industrial effluents and household waste.The area has been demarcated into three zones viz. Industrial zone, Mixed use zone and Residential zone.

The effluents, surface water, groundwater and soil samples of the area are tested for physico-chemical properties and trace element concentrations. The groundwater regime parameters such as depth to water table, subsurface geological correlation, fence diagramme and soil parameters such as grain size distribution and clay mineralogy is also worked out. This has helped in establishing relationship between the soil-water determinant and extent of pollution.

The quality of groundwater and soil has deteriorated up to different levels in different zones depending upon the density and nature of industries, type of soil and condition of groundwater. The distribution of major pollutants in the groundwater of various localities demarcates three distinct zones on the extent of pollution. Similarly the distribution of aquifers , conditions of groundwater regime and the nature of soil zones help in marking the 'Contamination Risk Zones' for groundwater pollution.

Keywords: Determinants, Contamination Risk Zoning Ground Water, Soil characters, Heavy Metals.

INTRODUCTION

The pollution of groundwater and soils of Ludhiana caused due to industrial effluents has been subject of interest of many workers. Significant contribution has been made by a number of workers since last two decades. Majority of work confines to the study of Budha Nala, a tributary of Satluj, which drains of most of the industrial effluents. Gill and Arora (1997) summarized the impact of rapid industrialation on the groundwater of Ludhiana city. Singh (1998) discussed the groundwater pollution and the significance of unsaturated zones in Ludhiana area. Mehta and Marwaha (1999) worked on the groundwater pollution in the Ludhiana city and concluded that the shallow aquifer gets polluted due to the industrial effluents discharged in the Budha Nala. They have recommended the 'dilution' as the remedial measure to check the pollution. Singh and Parwana (1999) studied the pollution of sediments and groundwater in Ludhiana area. They concluded that the pollutants like nickel, chromium and cyanide show decreasing concentration with increasing depth in the soil.

Through the possible ways of the contaminant movement from the surface to the aquifer has been discussed by many workers in other parts of the world but no serious attempt seems to have been made to work out this mechanism in the research area. The application of sedimentological parameters in understanding the pollution mechanism and the movement of pollutants through the soil profile has not attracted the serious attention of scientists particularly in India. Most of the work on soils relates to their genesis and development. Clay content of a soil is the most significant constituent which reflects upon the genesis and development of a soil profile and plays an important role in the distribution of the pollutants in the soil cover. The impact of the characteristics of particular soil on distribution of heavy metals is demonstrated by Fuller (1977) and Doner (1978). Copper moved least readily through all soil columns. The least mobility of metals was observed in a mineral soil with relatively high pH, cation exchange capacity and exchangeable base content. A number of researchers have commented upon the role of the Soil Organic Matter (SOM) on the availability and distribution of metals. Some of the important contributions towards this end have been made by Leeper (1972), Bondietti et al., (1973), Page (1974), Santillan-Medrano and Jurinak (1975), Sposito et al., (1976), Sinha et al., (1978), Desai and Ganguley (1979), Saar and Weber (1980), and Wolverton et al. (1983).

MATERIALS AND METHODS

The basic materials studied during the field work carried out in the research area included surface water/ industrial Effluents, Groundwater and Soil. The pedological and hydrogeological field investigations carried out during the field work include exposition of soil profiles and demarcation of soil horizons, measurement of depth to water table, collection of samples of the materials under study from various sites and determination of some of the chemical parameters of surface water/insustrial effluents, groundwater and soil.

The depth to water table of the research area was measured in the field from available sites, which include open wells and hand pumps. The water level in the hand pump was measured by opening the top cover and recording depth with the help of metric tape. In addition to this, some approximate information about the depth of water table was also obtained from the owners of hand pumps and tube wells at some of the sites.

The effluent sample were collected directly from the industrial discharge or from the industrial drain-Budha Nala, which carries along with surface waters, the industrial waste from most of the factories. Groundwater samples were collected from tube wells and hand pumps. The effluents and water samples collected in the field were immediately subjected to measurement of chemical parameters such as pH and electrical conductivity with the help of soil and water analysis kit.

The soil samples were analysed from determination of pH, electrical conductivity, organic matter, cation exchange capacity and major and trace elements. The soil samples collected during the field work were subjected to sedimentological analysis, such as petrography, clay mineralogy, texture, bulk density and soil moisture content. Varied types of laboratory methods were employed for each analysis.

The groundwater conditions of the research area are depicted by the study of distribution and demarcation of aquifers and by the behavior of water table through space and time. The sedimentology of soils includes pedomorphological description of the soil profiles along with various laboratory investigations.

SUBSURFACE GEOLOGY AND AQUIFER DISTRIBUTION

The various lithologs procured from the department of Public Health, Punjab Government shows that the subsurface geology mainly comprises clay, sand, gravel and pebbles including kankars. The top soil comprising clay and sandy-clay varies in its thickness from less than a meter to more than 5 m. Five subsurface lithological section have been prepared from the borehole data, four section are cutting across the research area in East-West direction and one section is in North-South direction. The location of different section lines is shown in (Fig. 1)

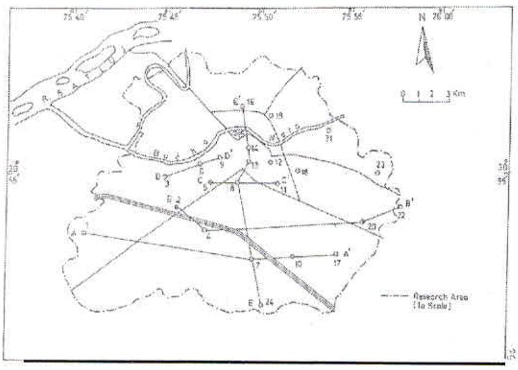

Fig. 1 : Location of lithologs and correlation section lines.

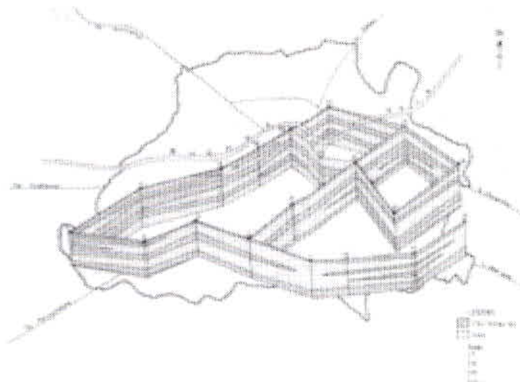

Fig. 2 : Fence diagram showing aquifer distribution.

The groundwater occurs by occupying the pore spaces of the unconsolidated alluvial deposits in the zone of saturation. In the research area water bearing formations include sand of various grades. The subsurface geology discussed above gives an important information to study the vertical and lateral variations of different aquifer zones and demarcation of different aquifers by impervious clay beds. The area forms a complex intermixture of multiple aquifer system The clay lenses, which are occurring at various depths, are generally not exhaustive in nature. These beds occurring down to a depth of about 75 m pinch out abruptly at a shorter or longer distance in both West to East and South to North sections. In general three major aquifer zones within 100 m of depth are encountered in the research area. The topmost aquifer is generally unconfined in nature. The thickness and number of these aquifer zones varies in different parts of the city. These zones are extensive in nature and are separated by clay beds of varying thickness. The maximum thickness of these impervious horizons measure up to about 30 m but in such cases they are normally punctuate thick lenses of sand. In order to show the aquifers distribution in various parts of the research area, the borehole data of different agencies was used to construct a fence diagram (Fig.2). The western part of the area contains 2 to 3 aquifers within the depth of 100 m. These aquifers are 4 m to 25 m in thickness.

In the northern part of the area three granular zones ranging in thickness from 7 m to 120 m are present up to a depth of about 65 m. These are interspersed by clay beds/lenses of 5 to 8 m thickness. In two to three aquifers measuring up to 90 m in thickness represent the eastern part of the area. At some places the clay beds pinch out giving rise to one or two thick aquifers with more than 100 m thickness. The middle aquifer in this part is comparatively thick than the other two and is punctuated by a few thin clay lenses. The Southern part of the city is characterised by the presence of three thick aquifers, the thickness of the middle aquifer measuring up to 45 m. In the central part of the research area, four aquifers of varying thickness are present up to a depth of 75 m. The lower most aquifers, which start at a depth of about 35 m are the thickest horizon. The cumulative thickness of sand is more in the central part and southern part as compared to northern and western part. The area in the vicinity of Budha Nala has comparatively thin aquifers but the permeability seems to be higher due to the presence of kankars and sandstones in both pervious and impervious layer. The clay bands of this area are also not very thick as in case of other parts of the city. The Central Groundwater Board has constructed piezometer at Punjab Agricultural University down to a d~pth of 300 m and on the basis of the lithological log and electrical log deciphered, four potential granular zones were 32-35 m, 62-66 m, 157-160 m, and 210-213 m.

DEPTH TO WATER TABLE

A review of the water level data collected from various sites indicates that the depth to water in the research area ranges from 3 m to 15 m below the land surface. Some areas in the western part of the city near Budha Nala have shallowest water level (about 3 m) while deeper water levels have been observed in the central part of the city where population density is probably the maximum. This deep water level zone is perhaps a result of heavy pump age from groundwater for city. On the basis of water level data collected from number of sites a depth to water table map has been prepared (Fig.3).

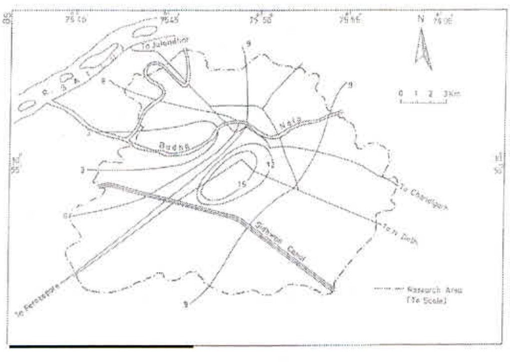

Fig. 3 : Depth to water table (in m.)

The water level however has been noticed to be unstable. There is long term as well as short term fluctuations in the water table. In the long term changes it has been observed that the water level of the area is constantly declining so much so that the dug wells monitored by CGWB (Saini and Kakar 1980) have all gone dry. The data pertaining to period of 13 years from the two piezometers established by CGWB at P .A.U. Ludhiana shows that the water levels have been steadily declining and there is a net decline of about 4 m in the water levels of both shallow and deep aquifers (CGWB, 1998). The short term fluctuations of water table are in response to the recharge and discharge factors and it plays an important role in pollution studies of an area. In the shallow water level areas the water table rises during post monsoons periods. Fluctuations levels for the period June 96 to June 97 is given in (Fig. 4) which shows that there is general decline of 0.30 to 0.55 m in the central part of the area and a rise of 0.15 to 0.55 m in the northern part of the area.

WATER TABLE ELEVATION

To study the form and gradient of water table the water table contour map based on the reduced water levels above M.S.L. has been prepared (Fig. 5). The maximum and minimum water table

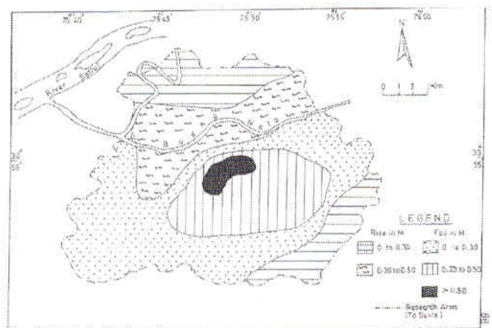

Fig. 4 : Fluctuation in water level of research area.

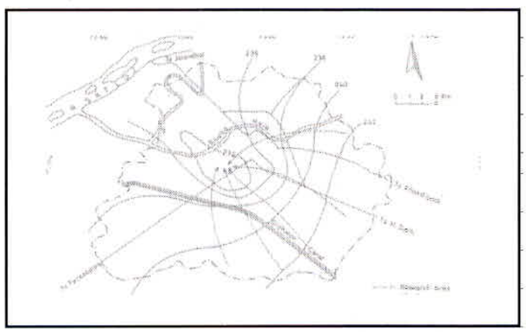

Fig. 5 : Elevation to water table.

elevations are 242 m and 234 m above mean sea level. The hydraulic head differences of 8 m makes the water flow from south east to northwest with variations from south-southeast and north-northwest. This causes a groundwater depression in the central part of the city t which may be due to withdrawal of groundwater from unconfined aquifers. The comparison of water table contour maps of Bhatnagar *el al.* (1981) does not show much change of the gradient of the present day. But the water table contours in the area have lower value by 2 m. As a net result of the change it is obvious that during zero natural flow in Budha Nala there is only sewage water flowing in the Budha Nala. Due to this regular flow at a high hydraulic head than groundwater coupled with high permeability rates of flood plains, there is a return flow of sewage to groundwater from Budha Nala.

From the geological and hydrogeological Studies it is evident that the area is underlain by Indo-Gangetic alluvium of Quaternary age. It is comprised of unconsolidated sandst pebblest claYt kankars and their admixture in various proportions. There are three major aquifer zones, the top most being unconfined in nature. The aquifers are separated by clay beds of thickness up to 30 m. Unconfined aquifers are interconnected through the gaps due to discontinuity of the impervious layers. The shallow water table in some of the areas brings in direct contact between the water and the pollutants of the effluents. Under such conditions it is anticipated that contaminated surface waters infiltrates into the top aquifers and thereby move on to the deeper levels.

PEDOMORPHOLOGY AND SEDIMENTOLOGY

The soils of the research area were studied for their morphological properties by describing manually exposed soil profiles in the field. In all, thirteen soil profiles were exposed at different sites (Fig. 6) during the course of field work.

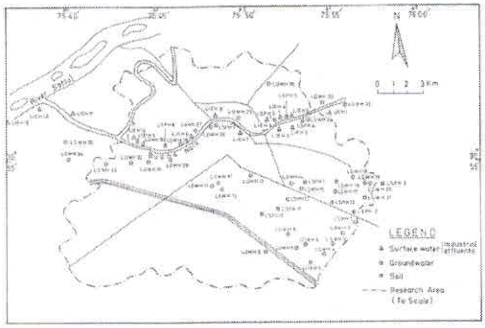

Fig. 6 : Location of sample collection for water, soil and effluents.

The morphological characteristics have been considered the most important for distinguishing one type of soil from the other. Each soil horizon in a profile is differentiated from the adjacent one on the basis of these properties. These properties are also important in description of a soil profile as the various statistical data obtained from laboratory analyses cannot be safely interpreted without them. The morphological properties of a soil profile are partly the result of inheritance from the parent material and partly soil forming processes. The description of such properties therefore serves as a fundamental basis for identification, classification and interpretation of different soils. The important morphological characteristics described in field include color, texture, carbonate content concentrations (if any), compactness and nature of boundary. The soils of the research area were subjected to such sedimentological investigations clay mineralogy, textural analysis and determination of bulk density and soil moisture content.

CLAY MINERALOGY OF SOILS

The patterns of the investigated samples show relatively weak and diffuse diffractions except the one showing high peaks around 10.2A. This is a common feature which is probably due to the presence of other poorly-crystalline components. However, obviously diffused pattern increased the uncertainty in the interpretation of specific clay mineral types, particularly of interstratified minerals. Therefore the present interpretation is made, following the basic diffraction peaks on the X-ray pattern.

Generally the air dried samples show high peaks around lo.2Åt which does not show any effect upon glycolation or heating. This indicates the general dominance of illite amongst the clay mineral assembly. Some of the air-dried samples show peaks between 14.2Å to 14.9Å and 15.2Å and 15.8Å. It is apparent from the diagrams for the glycol-treated samples that montmorillonitic layers are expanded with variable proportions between 17.6Å and 18.oÅ which may depend on the pretreatment and the state of hydration on the addition of ethylene glycol. Investigations of the water absorption in montmorillonite as a function of water vapour pressure shows that the basal reflections are very variablet depending on the cation populations as well as the degree of hydration which may affect the degree of expansion of the glycolation treatment (Gjems, 1963). The contraction of the lattice by heating is overlapping with high peaks of illite between 10.oÅ and 10.5Å. These features again indicate the presence of expanded-layer minerals more like montmorillonite.

In addition, the weak diffraction (14.2Å -14.9Å) on the air dried diffractograms, usually shows lower order diffractions, shifting towards the low-angle side on glycol treatment and towards high angle side on heating, which may indicate, to some extent, the presence of vermiculite. The kaolinite peak at 7.1 Å to 7.3Å) is weak in case of air dried samples. This diffraction does not show any change on glycolation. Heating the samples leads to the destruction of peaks.

Thus it is clear from the above discussion that the clay minerals constituting the soils of the research area include kaolinite, illite, vermiculite and montmorillonite . While kaolinite and illite are present in all the samples, the vermiculite and montmorillonite are not uniformly distributed. Vermiculite is present only in three soil profiles, LSPH-3, LSPH- 8 and LSPH-IO. In the former it is present in the lower horizon from 27-35 cms while in the other two profiles on surface horizons (0-10 cms and 0-6 cms) contain vermiculite. Though all the soil profiles contain montmorillonite in one or the other horizon, only two of them LSPH-5 and LSPH-13 have uniform representation of the mineral in all the horizons from which samples have been subjected to X-ray diffraction. In rest of the profiles LSPH-3, LSPH-8 and LSPH-IO contain montmorillonite only in surface horizons (2-8 cms, 0-10 cms and 0-6 cms).

Most dominant clay minerals in the soils of the research area seem to be illite which exhibits strong reflections in all the samples. Kaolinite is the next mineral in the order of abundance. It shows mild to strong reflections in most of the samples. The concentration of vermiculite and / montmorillonite is low to negligible in the soils of the research area. The presence of small amounts of interstratified mixed-layered minerals cannot be ruled out

TEXTURAL ANALYSIS

Grain size distribution in the soiJs of the research area has been determined as percent of sand, silt and clay content. The grain size variation and the representative class with respect to depth in each soil profile is given in Table 1. A major part of the soils is composed of sand-sized fraction except for few horizons in the lower part in some of the profiles. Sand percent varies between 28 to 82 in surface horizon except one profile which is totally made of sand whose concentration in three horizons varies from 86.2% to 88% (LSPH-7). Silt content constitutes 7.0% to 54.4% in the soils of the research area, the deeper horizons being generally richer than the surface horizons. The distribution of clay in the soils exhibits that deeper horizons represent maximum value of the finer fraction percentage (upto 35.8%) than the surface horizon where the amount of clay does

Table-1 : Grain size distribution (in % age) in soil profiles.

Sample No.	Depth (in cm)	Sand %	Silt %	Clay %	Class
LSPH 1/3	0-3	52.6	35.2	12.20	Sandy-Loam
LSPH 1/2	3-26	51.2	34.4	14.40	Loam
LSPH 1/1	26-43	48.0	38.2	13.80	Loam
LSPH 2/2	0-9	28.0	47.2	24.8	Loam
LSPH 2/1	9-23	27.2	36.8	34.2	Clay Loam
LSPH 3/3	0-10	78.8	12.0	9.2	Loamy-Sand
LSPH 3/2	10-13	72.7	18.5	8.8	Loamy-Sand
LSPH 3/1	13-23	73.0	14.2	12.8	Loamy-Sand
LSPH 4/3	0-6	75.0	19.4	5.6	Loamy-Sand
LSPH 4/2	6-25	56.0	29.6	14.4	Sandy-Loam
LSPH 4/1	25-32	41.0	41.4	17.6	Loam
LSPH 5/4	0-7	61.2	26.4	12.4	Sandy-Loam
LSPH 5/3	7-22	54.2	32.2	13.6	Sandy-Loam
LSPH 5/2	22-25	72.2	21.2	6.80	Loamy-Sand
LSPH 5/1	25-39	83.8	13.0	3.20	Loamy-Sand
LSPH 6/3	0-7	51.8	26.8	19.6	Sandy-Loam
LSPH 6/2	7-21	48.0	32.6	19.4	Sandy-Loam
LSPH 6/1	21-36	9.8	54.4	35.8	Silty-Clay Loam
LSPH 7/3	0-4	88.0	7.0	5.0	Sand
LSPH 7/2	4-16	87.4	7.8	4.8	Sand
LSPH 7/1	16-24	86.2	8.6	5.2	Sand
LSPH 8/5	0-2	82.0	10.8	7.2	Loamy-Sand
LSPH 8/4	2-8	81.8	11.6	6.6	Loamy-Sand
LSPH 8/3	8-12	80.2	12.0	7.8	Loamy-Sand
LSPH 8/2	12-27	77.5	15.7	6.8	Sandy-Loam
LSPH 8/1	27-35	79.3	13.6	7.1	Sandy-Loam
LSPH 9/4	0-8	47.2	32.4	20.4	Loam
LSPH 9/3	8-20	55.3	29.8	14.9	Sandy-Loam
LSPH 9/2	20-25	74.6	16.2	9.2	Loamy-Sand
LSPH 9/1	25-33	82.6	12.2	5.2	Loamy-Sand
LSPH 10/3	0-6	76.2	12.9	10.9	Loamy-Sand
LSPH 10/2	6-12	70.4	18.0	11.6	Loamy-Sand
LSPH 10/1	12-24	68.0	20.2	11.8	Sandy-Loam
LSPH 11/3	0-7	39.8	35.6	24.6	Loam
LSPH 11/2	7-19	45.6	43.4	11.0	Sandy-Loam
LSPH 11/1	19-24	62.8	18.0	19.2	Sandy-Loam
LSPH 12/3	0-6	39.8	35.6	24.6	Loam
LSPH 12/2	6-12	45.6	43.4	11.0	Sandy-Loam
LSPH 12/1	12-27	62.8	18.0	19.2	Sandy-Loam
LSPH 13/4	0-5	78.8	14.3	6.9	Loamy-Sand
LSPH 13/3	5-10	78.6	14.2	7.2	Loamy-Sand
LSPH 13/2	10-16	60.4	21.4	18.2	Sandy-Loam
LSPH 13/1	16-27	55.2	30.2	14.6	Sandy-Loam

not exceed 24.8%. The soils of the research area are represented by six textural classes viz. sand, loamy-sand, sandy-loam, loam, silty-clay loam, clay loam. Depthwise distribution of these classes is given in Table 2. Only one soil profile is composed of sand size fraction which is dominant in all its three horizons. Loamy-sand is present in seven out of 13 profiles. In five profiles, it is dominant only in upper horizons while in two of the profiles, it is concentrated in deeper horizons only. Sandy-loam class of texture is most common in the soils of the research area and is represented in 10 profiles. The deeper horizons are more frequently composed of this class rather than the surface horizons which consist of sandy-loam only in 3 profiles. In deeper horizons they are present at a depth varying form 6 cm to 35 cm.

Loam is present in six profiles .and is dominant. only in the surface horizon where the depth does not increase beyond 9 cm. In two profiles where the lower zones consist of loam, the depth up to which loam has been reported goes upto 43 cms. Silty-clay loam and clay loam are represented only in single horizon of one profile each. The depth up to which silty- clay loam exists is 21 to 36 cm. Clay loam occurs in a horizon at the depth of 9 to 23 cm.

The clay and silt content of soils increase with depth with corresponding decrease in sand

Table-2 : Depthwise distribution of textural classes of soil profiles.

Profile/ Classes	Sand	Loamy Sand	Sandy Loam	Loam	Silty Clay Loam	Clay Loam
LSPH-1	×	×	0-3 cm	3 –26 cm 26-43 cm	×	×
LSPH-2	×	×	×	0-9 cm	×	9-23 cm
LSPH-3	×	0-10 cm 10-13 cm 13-23 cm	×	×	×	×
LSPH-4	×	0-6 cm	6-25 cm	25-32 cm	×	×
LSPH-5	×	22-25 cm 25-39 cm	0-7 cm 7-22 cm	×	×	×
LSPH-6	×	×	0-7 cm 7-21 cm	×	21-36cm	×
LSPH-7	0-4 cm 4-16 cm 16-24 cm	×	×	×	×	×
LSPH-8	×	0-2 cm 2-8 cm 8-12 cm	12-27 cm 27-35 cm	×	×	×
LSPH-9	×	20-25 cm 25-33 cm	8-20 cm	0-8 cm	×	×
LSPH-10	×	0-6 cm 6-12 cm	12-24 cm	×	×	×
LSPH-11	×	×	7-19 cm 19-24 cm	0-7 cm	×	×
LSPH-12	×	×	6-12 cm 12-27 cm	0-6 cm	×	×
LSPH-13	×	0-5 cm 5-10 cm	10-16 cm 16-27 cm	×	×	×

proportion. With the result the top layers of the soils are more sandy in nature. Sandy-loam texture is the most common texture of the soils of the research area and it is more frequent in the horizons marked at a depth varying from 6 cm to 35 cm.

BULK DENSITY

Bulk density is one of the most commonly used indices for the evaluation of soil physical conditions. For any given soil, bulk density can be correlated with water transmission characteristics and also with soil strength (Alexander, 1980). A knowledge of relationship between bulk density and pore-size distribution is important for judging the effect of soil compaction on the aeration, porosity and the amount of water stored in the soil because bulk density is determined by the total soil space i.e. the space occupied by solids and pore spaces combined.

It is well known that the values of soil bulk density are dependent on a number of factors, such as the system of packing, organic matter content, man activity and sampling depth (Adams, 1973). The values of bulk density increase with the sampling depth. This behaviour could be mainly attributed to the low organic matter contents and the relatively compaction effect in the deep layers.

The values of bulk density of the soils of the research area lie within a small range of 1.17 gm/cm3 to 1.48 gm/cm3 (Table-3). The soils cover (0-2 to 0- 10 cms) has the bulk density of 1.17 to 1.40 *gm/cm3*. This value varies from 1.20 to 1.48 *gm/cm3* in lower most (sub-soil) horizons of each soil profile. In majority of the soil profiles, the bulk density increases with depth. This may be due to low organic content and the compaction resulting from the weight of the overlying soil layers. The values of bulk density also exhibit relationship with texture. The coarse textured soils relatively have more of bulk density as compared to the soils composed of finer particles (Fig. 7). Since the particles of sandy soils generally lie in close contact, it has high bulk density. The soils with high bulk density are inhibitive to root penetration and have low permeability and infiltration.

SOIL MOISTURE CONTENT

The amount of water contained in the voids of a soil in its natural state is termed the natural moisture content of the soil. The amount of voids or magnitude of porosity of a soil depends very much upon the packing of the soil particles as well as on the size and shape of the particles, which is a subject matter already I discussed under petrography and texture. The soil water along with its dissolved salts makes up the soil solution, which is very important as a medium for supplying nutrients to growing plants and causing mobility of other metallic, constituents. The exchange of nutrients between the soil-solids and the soil solution and between" the 'soil solutions and the plants is influenced by the concentration of salts in the soil and the content of soil water. The water retention and movement in soils depends upon two basic forces viz. cohesion-attraction of molecules for each other and adhesion -attraction of water molecules for solid surfaces of soil components (Sekhon and Arora, 1967). Together these forces make it possible for the soil solids to retain water and control its movement.

The soils of the research area, because of variations in soil texture, structure and organic content, vary widely in content and in their capacity of retaining or holding the moisture. The values of the moisture contents in the soils of the research area vary between 6.11 and 18.78 by weight percent and between 8.43 and 22.53 by volume percent. The minimum values lies in top soil horizon composed of sand in the profile LSPH- 7 and the maximum value is represented by a sub-soil horizon of silty-clay loam texture in the profile LSPH-6. The soil profiles dominated by coarse textural classes like sand, loamy-sand and sandy- loam exhibit low to medium values of

Table-3 : Bulk density in gm/cm³ in soil profiles.

Sample No.	Depth (in cm)	Texture	Bulk density (gm/cm³)
LSPH-1/3	0-3	Sandy-Loam	1.26
LSPH-1 /2	3-26	Loam	1.34
LSPH-1/1	26-43	Loam	1.32
LSPH-2/2	0-9	Loam	1.17
LSPH-2/1	9-23	Clay Loam	1.23
LSPH-3/3	0-10	Loamy-Sand	1.32
LSPH-3/2	10-13	Loamy-Sand	1.40
LSPH-3/1	13-23	Loamy-Sand	1.46
LSPH-4/3	0-6	Loamy-Sand	1.20
LSPH-4/2	6-25	Sandy-Loam	1.22
LSPH-4/1	25-32	Loam	1.26
LSPH-5/4	0-7	Sandy-Loam	1.34
LSPH-5/3	7-22	Sandy-Loam	1.36
LSPH-5/2	22-25	Loamy-Sand	1.36
LSPH-5/1	25-39	Loamy-Sand	1.38
LSPH-6/3	0-7	Sandy-Loam	1.27
LSPH-6/2	7-21	Sandy-Loam	1.33
LSPH-6/1	21-36	Silty-Clay Loam	1.20
LSPH-7/3	0-4	Sand	1.38
LSPH-7/2	4-16	Sand	1.44
LSPH-7/1	16-24	Sand	1.42
LSPH-8/5	0-2	Loamy-Sand	1.26
LSPH-8/4	2-8	Loamy-Sand	1.28
LSPH-8/3	8-12	Loamy-Sand	1.28
LSPH-8/2	12-27	Sandy-Loam	1.30
LSPH-8/1	27-35	Sandy-Loam	1.28
LSPH-9/4	0-8	Loam	1.38
LSPH-9/3	8-20	Sandy-Loam	1.44
LSPH-9/2	20-25	Loamy-Sand	1.48
LSPH-9/1	25-33	Loamy-Sand	1.48
LSPH-10/3	0-6	Loamy-Sand	1.40
LSPH-10/2	6-12	Loamy-Sand	1.46
LSPH-10/1	12-24	Sandy-Loam	1.46
LSPH-11/3	0-7	Loam	1.17
LSPH-11/2	7-19	Sandy-Loam	1.26
LSPH-11/1	19-24	Sandy-Loam	1.40
LSPH-12/3	0-6	Loam	1.26
LSPH-12/2	6-12	Sandy-Loam	1.34
LSPH-12/1	12-27	Sandy-Loam	1.40
LSPH-13/4	0-5	Loamy-Sand	1.34
LSPH-13/3	5-10	Loamy-Sand	1.36
LSPH-13/2	10-16	Sandy-Loam	1.38
LSPH-13/1	16-27	Sandy-Loam	1.38

average soil moisture content 6.23 to 12.99% by weight and 8.80 to 16.48% by volume, with exceptions, if any, only in the sub-soil horizons. Other soil profiles in which fine textured material is more abundant have higher values of average soil moisture content (12.81 to 16.48% by weight and 16.74 to 19.77% by volume). The relation between the soil moisture content and the texture of the soil (Table-4) reveals that the coarse textured soils have low to medium values of average soil moisture content. This relationship is represented by Figs.8 and 9. The clay, silt and silt plus clay content of the soils of the research area are positively correlated at the 1% level with the soil moisture content of soil. The correlation coefficients 'r' between soil moisture content and clay, silt and silt plus clay contents is 0.890015, 0.908814 and 0.964697 respectively.

A critical examination of geohydrological parameters reveals that the subsurface geology is dominantly composed of fine to medium sand interspersed by clay/silt horizons. The presence of gravels and pebbles including kankars in minor amounts is also noticed in the deeper horizons. In the southern fringe there are four to six sandstone horizons which are coarser in the deeper portions. The frequent presence of thick clay layers, marks the subsurface lithology of the northern part of the research area. The sand layers are fine in the upper portion and medium to coarse towards deeper horizons. The fence diagram exhibits the extent and distribution of aquifers separated by clay horizons/lenses. The aquifers are thickest in the southern part and comprise maximum layers in the western part. The water table is shallow upto 3 m near Budha Nala. Seasonal fluctuation in the water table sometimes results in direct mixing of surface water and groundwater. The general hydraulic gradient of groundwater is towards northwest.

The dominance of illite in clay mineral assemblage, indicates a moderate capacity for cation adsorption. Small amounts of kaolinite, vermiculite and montmorillonite do not play any

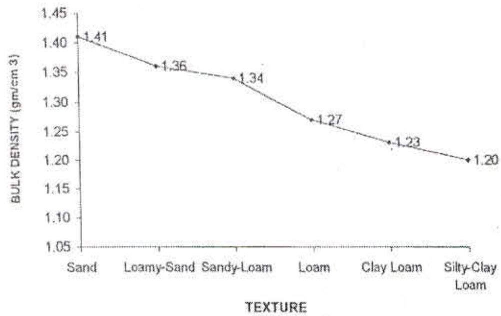

Fig. 7 : Relation between texture and bulk density

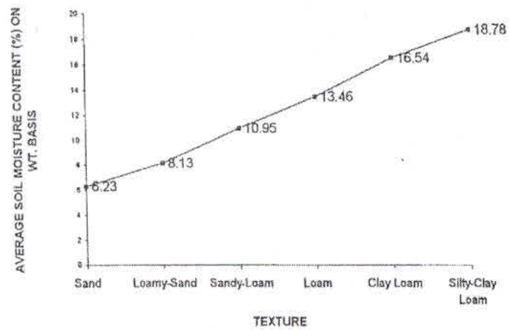

Fig. 8 : Relation between soil texture and average soil moisture content (%) on wt. basis.

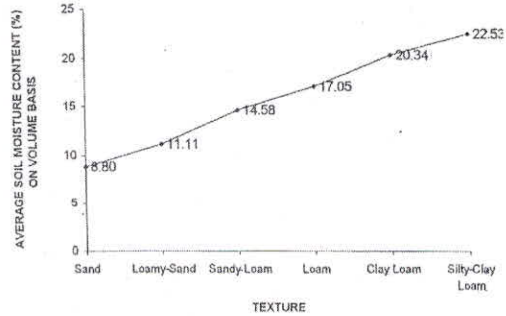

Fig. 9 : Relation between soil texture and average soil moisture content (%) on volumes basis.

Table-4 : Distribution of soil moisture content (in % age).

Sample No.	Depth (in cm.)	Texture	Moisture Content (%)	
			on weight basis	on volume basis
LSPH 1/3	0-3	Sandy-Loam	12.51	15.76
LSPH ½	3-26	Loam	12.70	17.01
LSPH 1/1	26-43	Loam	13.22	17.45
Average Moisture Content for LSPH-1			**12.81**	**16.74**
LSPH 2/2	0-9	Loam	16.42	19.21
LSPH 2/1	9-23	Clay Loam	16.54	20.34
Average Moisture Content for LSPH-2			**16.48**	**19.77**
LSPH 3/3	0-10	Loamy-Sand	8.29	10.94
LSPH 3/2	10-13	Loamy-Sand	9.26	12.96
LSPH 3/1	13-23	Loamy-Sand	9.22	13.46
Average Moisture Content for LSPH-3			**8.92**	**12.45**
LSPH 4/3	0-6	Loamy-Sand	8.19	9.82
LSPH 4/2	6-25	Sandy-Loam	11.23	13.70
LSPH 4/1	25-32	Loam	13.63	17.17
Average Moisture Content for LSPH-4			**11.01**	**13.56**
LSPH 5/4	0-7	Sandy-Loam	10.39	13.92
LSPH 5/3	7-22	Sandy-Loam	11.51	15.65
LSPH 5/2	22-25	Loamy-Sand	8.67	11.79
LSPH 5/1	25-39	Loamy-Sand	6.78	9.35
Average Moisture Content for LSPH-5			**9.33**	**12.67**
LSPH 6/3	0-7	Sandy-Loam	11.61	14.74
LSPH 6/2	7-21	Sandy-Loam	12.44	16.54
LSPH 6/1	21-36	Silty-Clay Loam	18.78	22.53
Average Moisture Content for LSPH-6			**14.27**	**17.93**
LSPH 7/3	0-4	Sand	6.11	8.43
LSPH 7/2	4-16	Sand	6.20	8.92
LSPH 7/1	16-24	Sand	6.39	9.07
Average Moisture Content for LSPH-7			**6.23**	**8.80**
LSPH 8/5	0-2	Loamy-Sand	7.07	8.90
LSPH 8/4	2-8	Loamy-Sand	7.10	9.08
LSPH 8/3	8-12	Loamy-Sand	7.35	9.40
LSPH 8/2	12-27	Sandy-Loam	7.79	10.12
LSPH 8/1	27-35	Sandy-Loam	7.50	9.6
Average Moisture Content for LSPH-8			**7.36**	**9.42**
LSPH 9/4	0-8	Loam	13.34	18.40
LSPH 9/3	8-20	Sandy-Loam	11.34	16.32
LSPH 9/2	20-25	Loamy-Sand	8.25	12.21
LSPH 9/1	25-33	Loamy-Sand	6.97	10.31
Average Moisture Content for LSPH-9			**9.97**	**14.31**
LSPH 10/3	0-6	Loamy-Sand	8.70	12.18
LSPH 10/2	6-12	Loamy-Sand	9.63	14.05
LSPH 10/1	12-24	Sandy-Loam	10.02	14.62
Average Moisture Content for LSPH-10			**9.45**	**13.61**
LSPH 11/3	0-7	Loam	14.53	17.0
LSPH 11/2	7-19	Sandy-Loam	13.60	17.13
LSPH 11/1	19-24	Sandy-Loam	10.85	15.19
Average Moisture Content for LSPH-11			**12.99**	**16.44**
LSPH 12/3	0-6	Loam	10.43	13.14
LSPH 12/2	6-12	Sandy-Loam	10.69	14.32
LSPH 12/1	12-27	Sandy-Loam	11.62	16.26
Average Moisture Content for LSPH-12			**10.91**	**14.57**
LSPH 13/4	0-5	Loamy-Sand	8.29	11.10
LSPH 13/3	5-10	Loamy-Sand	8.32	11.31
LSPH 13/2	10-16	Sandy-Loam	11.23	15.49
LSPH 13/1	16-27	Sandy-Loam	11.35	15.66
Average Moisture Content for LSPH-13			9.79	13.39

important role to affect the mobility of metals through cation exchange. Dominance of coarse texture, particularly in upper soils does not favour the retention of heavy metals due to binding by clay particles. Soils dominated by sand have good drainage and aeration, rapid infiltration and low moisture retention. By contrast soils dominated by silt and clay have slow water and air movement. The bulk density of soils in majority of the soil profiles: increases with depth. It is also related to texture of the soil profile.

GEOCHEMICAL INVESTIGATIONS

The samples collected from industrial effluents/surface water, groundwater and soils of the research area were subjected to geochemical investigations. The data so obtained has been critically examined and valid inferences regarding the distribution and mobility of pollutants have been drawn.

The effluents from the industrial wastes and untreated sewage of Ludhiana city are discharged into Budha Nala which is a natural drain passing through the city. These effluents get mixed with the surface water flowing through the Nala which is used for irrigation of fields at some of the places. These industrial and domestic effluents are a source of major health hazard for the natural resources of groundwater and soil. The chemical analysis of these effluents includes the determination of various physico-chemical characters including pH electrical conductivity (EC), total dissolved solids (TDS) chloride (Cl), iron (Fe) calcium (Ca) magnesium (Mg) sodium (Na) and potassium (K) (Table 6) along with the distribution of various heavy metals such as lead (Pb) copper (Cu) zinc (Zn) chromium (Cr) cadmium (Cd) manganese (Mn) nickel (Ni) cobalt (Co) and arsenic (AS). (Fig. 10 to 18).

A critical review of the distribution pattern of various geo-chemical parameters in the effluent samples indicates that the value for most of them increases downstream in the Budha Nala. These

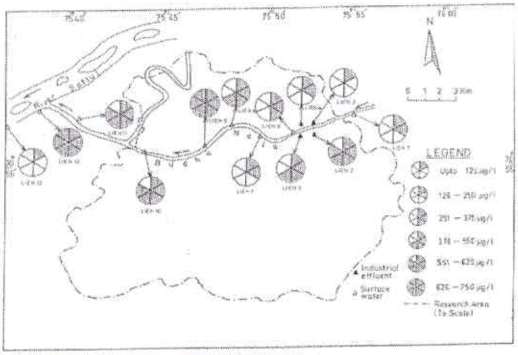

Fig. 10 Distribution of lead content in surface water/ industrial effluents of the research area.

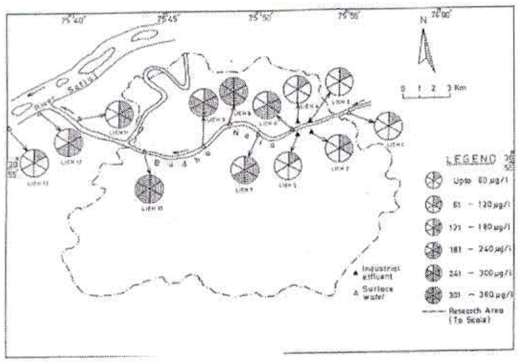

Fig. 11 : Distribution of copper content in surface water/industrial effluents of the research area.

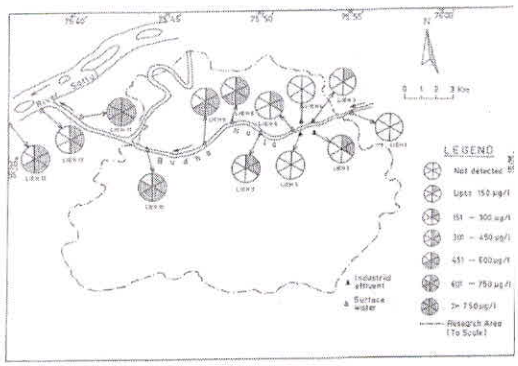

Fig. 12 : Distribution of zinc content in surface water/industrial effluents of the research area.

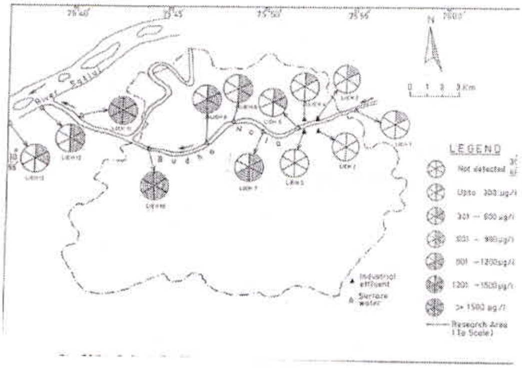

Fig. 13 : Distribution of chromium content in surface water/industrial effluents of the research area.

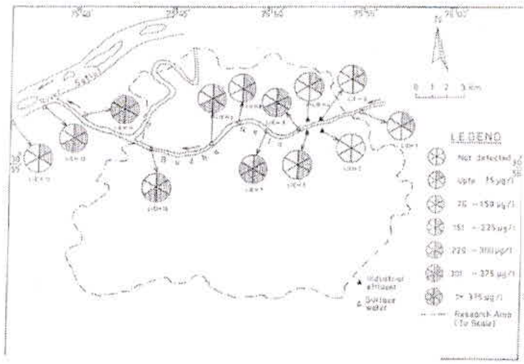

Fig. 16 : Distribution of nickel content in surface water/industrial effluents of the research area.

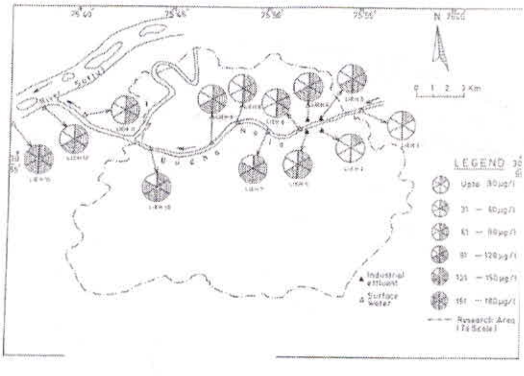

Fig. 14 : Distribution of cadmium content in surface water/industrial effluents of the research area.

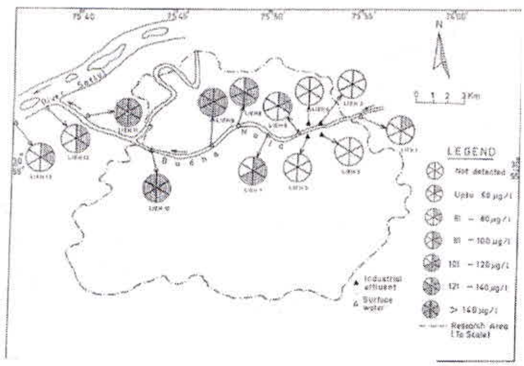

Fig. 17 : Distribution of cobalt content in surface water/industrial effluents of the research area.

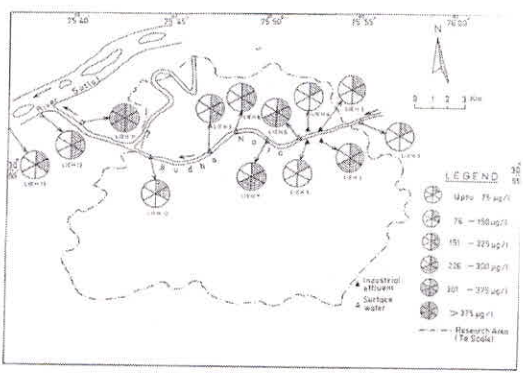

Fig. 15 : Distribution of manganese content in surface water/industrial effluents of the research area.

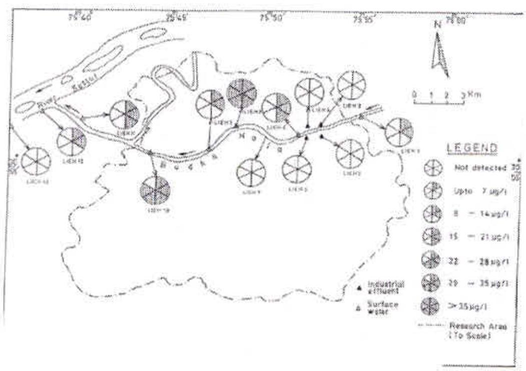

Fig. 18 : Distribution of arsenic content in surface water/industrial effluents of the research area.

parameter show lesser concentration towards both end when the industrial effluents have either not entered the Budha Nala stream as on the eastern end or the effluent loaded surface water has started mixing with the water of Satluj as on the western end. The samples taken directly from the industrial discharge also show comparatively larger value for some of the parameter. The effluent samples collected near Khaire Bet have uncommon high concentration of zinc, chromium, manganese and nickel. Similarly the samples collected from Gopal Nagar show highest concentration of copper. The amount of lead is found to be maximum in the effluents loaded surface water near village Maniwal. The surface water near Kundan Puri has highest concentration of arsenic.

GROUNDWATER

The samples tested for chemistry of groundwater have been grouped into three categories according to land-use pattern, Industrial zone, Mixed-Use zone and Residential Zone. The geochemical parameters determined from these are discussed under two subheads, Qualitative parameters and Health related parameters. The qualitative measures are those which affect the aesthetic and organoleptic quality of the groundwater. These include pH, EC, TDS, CO_3, HCO_3, CI and Fe. Certain inorganic constituents of water are described under the heading 'Health Related Parameters' on the basis of toxicological, epidemiological and clinical evidences. Such parameters include total hardness, calcium, magnesium, sodium, potassium, lead, copper, zinc, chromium, cadmium, manganese, nickel, cobalt and arsenic. (Table 5 to 7).

A critical review of average concentration in the three zones demarcated in the research area exhibits that mixed-use zone shows the highest values of pH, bicarbonate, Iron, total hardness, magnesium, sodium, copper, zinc, cadmium and manganese while the industrial zone has the maximum values for EC, TDS, carbonate, chloride, calcium, lead, chromium, nickel, cobalt and arsenic. In mixed-use zone the groundwater of only six localities viz. Guru Nanak Nagar, Janta Nagar, Dashmesh Nagar, ViII. Mangli Nichi, Bhamian Kalan and New Chander Nagar has TDS values within the desirable limits. In residential zone the TDS value is more than the desirable limits only in Urban Estate Phase I and Hambran Bus stand. The iron content in the groundwater of Dhandari Khurd in industrial zone and Saleem Tabri, Kundan Puri, Badi Haibowal and Mohalla Atal Nagar in mixed-use zone is more than the permissible limits prescribed by BIS (1991). The groundwater at Dhandari Khurd, Oswal Mill and Focal Point Phase V in industrial zone; New Simla Puri, Janta Nagar, ViII. Mangli Nichi, Saleem Tabri and Badi Haibowal in mixed-use zone and Model Town and Urban Estate Phase-I in residential zone has the highest values of total hardness than the desirable limits prescribed by BIS (1991). The calcium content in the groundwater of Oswal Woolen Mill, Focal Point Phase V and Chambal Ghatti in industrial zone and New Simla Puri, ViII. Mangli Nichi and Saleem Tabri in mixed-use zone is higher than the desirable limits. The groundwater near Gobind Rubber Unit II, Oswal Woolen Mill, Focal Point V, and Focal Point Phase VII in industrial zone, Guru Nanak Nagar and Saleem Tabri in mixed-use zone and Model Town, Khasi Kalan and Hambran Village in residential zone has value lower than the desirable limits of magnesium content as per BIS (1991).

The lead content of groundwater at all the localities of industrial zone is higher than the desirable limits. In mixed-use zone only one locality (Mohalla Atal Nagar) has the lead content within the desirable limits while in residential zone the two localities (Model Town and Hambran Bus Stand) are free from lead hazard. Only one locality (Oswal Woolen Mill) of industrial zone, five localities Mangli Nichi, Bhamian Kalan, Saleem Tabri, Badi Haibowal

Table- 5 : Health related geochemical parameters of industrial zone

Sample No.	Location	Source of Sample	Depth (in feet)	TH aa $CaCO_3$ mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Pb µg/l	Cu µg/l	Zn µg/l	Cr µg/l	Cd µg/l	Mn µg/l	Ni µg/l	Co µg/l	As µg/l
LGWH-1	Dhandari Khurd	HP	55	324	42.48	51.11	76	10	460	67	240	ND	ND	170	ND	200	ND
LGWH-2	Gobind Rubber Unit-II	HP	50	224	41.68	27.23	10	12	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-3	Dhandari Kalan	TW	127	216	29.65	37.59	6	7	290	59	ND	96	10	10	900	30	ND
LGWH-13	Dholewal Chowk	HP	80	186	20.84	32.64	68	7	560	110	3470	690	30	160	600	150	60
LGWH-14	Sherpur Chowk	HP	75	250	44.08	34.11	40	8	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-15	Oswal Woolen Mill	HP	75	462	161.92	14.13	76	12	380	14	860	1550	20	ND	ND	90	ND
LGWH-16	Focal Point	HP	80	270	53.70	33.13	68	9	450	80	110	120	10	100	200	80	40
LGWH-17	Focal Pt Phase V	HP	90	306	76.15	28.26	68	9	260	180	580	86	20	40	400	40	20
LGWH-18	Focal Pt Phase VII	HP	65	174	32.86	22.41	64	6	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-21	Chambal Ghatti	HP	45	210	120.94	33.26	74	12	NP	NP	NP	NP	NP	NP	NP	NP	NP
Average				262.20	62.43	31.38	55	9.20	400	85	876.66	423.66	15	80	350	98.33	20
BIS (1991) Limits		Desirable		300	75	30	-	-	50	50	5000	50	10	-	-	-	-
		Permissible		600	200	100	-	-	-	1500	15000	-	-	-	-	-	-
% age of samples exceeding BIS (1991) Limits		Desirable		30	30	60	-	-	100	83.33	None	83.33	50	-	-	-	-
		Permissible		None	None	None	-	-	-	-	None	-	-	-	-	-	-
WHO (1996) Guideline Values				-	-	-	-	-	10	2000	3000	50	3	500	20	2000	10
% age of samples exceeding WHO (1996) Guideline Values				-	-	-	-	-	100	-	16.66	83.33	83.33	None	66	None	50

HP- Handpump; TW- Tubewell; NP- Not performed; Nd- Not detected

Table- 6 : Health related geochemical parameters of mixed – use zone/trace elements.

Sample No.	Location	Source of Sample	Depth (in feet)	TH as CaCO3 mg/l	Ca mg/l	Mg mg/l	Na Mg/l	K mg/l	Pb µg/l	Cu µg/l	Zn µg/l	Cr µg/l	Cd µg/l	Mn µg/l	Ni µg/l	Co µg/l	As µg/l
LGWH-4	New Azad Nagar	HP	80	236	32.06	38	120	8	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-5	Guru Nanak Nagar	HP	80	208	40.08	26.31	**14**	8	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-6	New Simla Puri	HP	80	406	96.99	37.95	24	10	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-7	New Simla Puri	HP	80	382	72.94	**48.72**	52	12	230	53	**170**	ND	20	70	340	**10**	ND
LGWH-8	Janta Nagar	HP	80	336	54.50	**48.72**	72	14	340	280	4170	**42**	30	40	170	80	60
LGWH-9	Dashmesh Nagar	HP	80	210	**11.22**	44.34	52	10	430	**360**	830	130	**10**	40	ND	30	10
LGWH-19	Mangli Nichi	TW	120	196	24.04	33.13	34	15	120	47	ND	ND	**50**	**20**	**40**	20	ND
LGWH-20	Mangli Nichi	HP	65	**520**	153.10	33.62	100	9	390	170	3320	92	20	90	200	20	ND
LGWH-24	Bhamian Kalan	HP	65	210	16.83	40.93	32	6	**70**	43	810	ND	ND	180	1000	40	**10**
LGWH-25	Saleem Tabri	HP	35	352	102.60	**23.39**	70	20	360	40	2230	**860**	30	70	200	**170**	**70**
LGWH-26	Kundan Puri	HP	30	**180**	20.04	31.67	108	28	**660**	52	**4900**	390	40	**870**	**1200**	110	50
LGWH-27	New Chander Nagar	HP	40	230	**11.22**	49.21	78	18	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-28	Badi Haibowal	HP	55	320	30.46	59.44	104	19	510	50	570	170	30	600	300	80	ND
LGWH-29	Chhoti Haibowal	HP	60	282	**55.31**	35.08	**160**	**115**	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-30	Gopal Nagar	HP	40	270	46.49	37.52	136	22	120	**30**	850	90	30	130	480	50	ND
LGWH-31	Dairy Complex	HP	50	216	16.03	42.88	36	27	240	52	690	180	20	150	130	20	ND
LGWH-36	Atal Nagar	HP	120	212	24.04	37.03	76	9	ND	220	3400	ND	10	140	90	90	ND
Average				**284.62**	**48.99**	**39.43**	**74.58**	**21.31**	**289.16**	**116.41**	**1828.33**	**162.83**	**24.16**	**200**	**345.83**	**60**	**16.66**
BIS (1991) Limits		Desirable		300	75	30	-	-	50	50	5000	50	10	-	-	-	-
		Permissible		600	200	100	-	-	-	1500	15000	-	-	-	-	-	-
% age of samples exceeding BIS (1991) Limits		Desirable		35.29	17.64	88.23	-	-	91.66	58.33	None	58.33	75	-	-	-	-
		Permissible		None	None	None	-	-	-	None	None	-	-	-	-	-	-
WHO (1996) Guideline Values				-	-	-	-	-	10	2000	3000	50	3	500	20	2000	10
% age of samples exceeding WHO (1996) Values				-	-	-	-	-	91.66	-	33.33	58.33	91.66	16.66	91.66	None	25

HP- Handpump; TW- Tubewell; NP- Not performed; ND- Not detected

Table- 7 : Health related geochemical parameters of residential zones/trace elements.

Sample No.	Location	Source of Sample	Depth (in feet)	TH as $CaCO_3$ mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Pb µg/l	Cu µg/l	Zn µg/l	Cr µg/l	Cd µg/l	Mn µg/l	Ni µg/l	Co µg/l	As µg/l
LGWH-10	Model Town	TW	150	158	33.66	18.02	8	7	ND	62	ND	ND	20	20	100	20	ND
LGWH-11	Model Town	HP	95	322	59.31	42.39	60	9	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-12	Urban Estate Phase I	HP	90	330	10.42	74.06	124	104	160	67	130	28	10	20	ND	30	ND
LGWH-22	Dhanan Sau	HP	60	174	15.23	33.13	32	19	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-23	Khasi Kalan	TW	80	166	33.66	19.97	30	10	90	43	ND	ND	ND	340	1200	20	10
LGWH-32	Avali Khurd	HP	60	230	6.41	52.14	38	4	NP	NP	NP	NP	NP	NP	NP	NP	NP
LGWH-33	Malakpur Bet	HP	65	274	58.51	31.18	72	48	140	69	260	76	10	40	20	70	ND
LGWH-34	Hambran	TW	140	162	25.65	23.87	16	4	120	57	ND	40	10	60	20	10	40
LGWH-35	Hambran Bus stand	HP	120	210	9.61	45.31	104	2	ND	64	190	20	30	70	70	10	30
Average				225.11	28.05	37.78	53.77	23	85	60.33	96.66	27.33	13.33	91.66	235	26.66	13.33
BIS (1991) Limits		Desirable		300	75	30	-	-	50	50	5000	50	10	-	-	-	-
		Permissible		600	200	100	-	-	-	1500	15000	-	-	-	-	-	-
% age of samples exceeding BIS (1991) Limits		Desirable		22.22	None	66.66	-	-	66.66	83.33	None	16.66	33	-	-	-	-
		Permissible		None	None	None	-	-	-	None	None	-	-	-	-	-	-
WHO (1996) Guideline Values				-	-	-	-	-	10	2000	3000	50	3	500	20	2000	10
% age of samples exceeding WHO (1996) Guideline Values				-	-	-	-	-	66.66	-	None	16.66	83.33	None	50	None	33.33

HP- Handpump; TW- Tubewell; NP- Not performed; ND- Not detected

and Gopal Nagar) of mixed-use zone and one locality (Khasi Kalan) of residential zone has concentration of copper in the groundwater within the desirable limits. The concentration of zinc in the groundwater of the research area is within the desirable limits of BIS, 1991. Chromium content of Dhandari Khurd in industrial zone and of New Simla Puri, Janta Nagar, Mangli Nichi, Bhamian Kalan and Atal Nagar of mixed-use zone is within the desirable limits of BIS (1991). Only one locality of the residential zone (Malakpur Bet) has higher content of chromium in groundwater than the desirable limit. Three localities each of industrial zone (Dhandari Khurd, Dhandari Kalan and Focal Point) and mixed-use zone (Dashmesh Nagar, Bhamian Kalan and Mohalla Atal Nagar) and four localities of residential zone (Urban Estate Phase I, Khasi Kalan, Malkpur Bet and Hambran Village have concentration of cadmium in the groundwater within the desirable limits. Only two localities (Kundan Puri and Badi Haibowal) of mixed-use zone have higher values of manganese content in groundwater than the guideline values proposed by WHO (1996). Rest of the water of the research area is free from manganese contamination. The groundwater of Dhandari Khurd and Oswal Woolen Mill in industrial zone, Dashmesh Nagar in mixed-use zone and Urban Estate Phase I, Malakpur Bet and Hambran Village in residential zone has safe limits of nickel concentration as per the guideline values of WHO, 1996. The groundwater of research area does not contain cobalt beyond the guideline value of WHO, 1996. Three localities each of industrial zone (Dholewal Chowk, Focal Point and Focal Point, Phase V) and mixed-use zone (Janta Nagar, Saleem Tabri and Kundan Puri) and two localities of residential zone (Hambran village and Hambran Bus stand) contain arsenic in the groundwater higher than the guideline values of WHO, 1996.

In totality the groundwater of research area in all the three zones has an average value of pH, magnesium, lead, copper, cadmium, nickel and arsenic higher than the prescribed desirable limits of BIS, 1991 or guideline value of WHO (1996). The TDS, iron and chromium has higher values than the prescribed limits in the groundwater of only industrial zone and mixed-use zone. Rest of the parameters in the groundwater of all the three zones are within the safe limits.

SOILS

The soils of the research area from 13 different locations where soil profiles were manually exposed up to about half metre, were subjected to complete geochemical analysis. A total of 43 samples collected from the selected profiles were subjected to laboratory investigations to work out the geochemical characteristics of soils grouped as pedochemical parameters, major elemental composition and trace elements.

A critical review of distribution of various elements in the soils profiles indicates that Si content in the soil ptofiles generally increases with increase in depth except in case of LSPH-2 (near Octrai Post, G. T. road), LSPH-8 (near Dairy Complex, Hambran road), LSPH-IO (Mohalla Ishar Nagar, Gill road) and LSPH- 13 (village Govindgarh, G. T. road). There is corresponding decrease in the aluminum content in some of the soil profiles. The average Si content of the soils of the research area corresponds more or less equal to the standard values of Si in shale as well sandstone. On the other hand, the average aluminum content is more near to that of shales rather than sandstone as is the case for average values for phosphorus and titanium. The organic matter in the soils is present in small amounts, the average value being 0.34%. Most of the organic matter is concentrated in the top soil horizons. The average CEC value of various profiles vary within a large limit from 3.92 meq/100g to 15.19 meq/l00g. The average CEC of soils of research area is 8.02 meq/lOOg. The CEC values generally increase in the deeper horizon except in the case of LSPH-9 (near Zainpur village. Hambran road) and LSPH-ll (village

Lahara. Gill road). The soils of research area are poor in calcium content with an average content 9101.27 μg/g. The average content of magnesium is very close to the standard value of the element in sandstones. The value of 8878.48 μg/g for average sodium content of the soils is more near to the standard value given by Turekian and Wedepohl (1961) for shale. The average value of 16392.50 μg/g of iron content in the soils is very low as compared to the values given for shale (47,200 μg/g). However. the average amount of iron is somewhat closer to the standard values for sandstone.

The distribution of trace elements in the soils depends largely upon the nature of parent rock on which the soils are formed. Therefore the contents vary widely in the soils than in rocks and in some cases the soil contents of trace elements are much higher than those of the parent rocks. Apart from this the content and distribution of these metals depends upon the soil forming processes, in which various climatic, biological. mineralogical and textural factors play their roles. In the soils of the polluted area the trace element concentrations are affected by unnatural addition from domestic effluents and sewage. industrial wastes and discharges. agricultural runoff and aerial emissions.

The average lead content of the soils of LSPH-3 (near Rattan Haumer, Chandigarh road) LSPH-4 (near Balvindra Paper Mill. Tajpur road) and LSPH-6 (near Tony Dyeing, Tajpur road) is higher than the range given by Bowen, 1966. The distribution of .lead content in various horizons of the soil profile doesn't have any uniform trend. It increases with depth in LSPH-1 (opposite Oswal Mill, G. T. road) LSPH-6 (~ear Tony Dying, Tajpur road), LSPH-8 (near Dairy Complex, Hambran road) and LSPH-10 (Mohalla Ishar Nagar, Gill roaq). The average copper content of LSPH-4 is more than the standard range proposed by Bowen, 1966 and the maximum permitted value under ECR Wild, 1996. Most of the copper in this profile is concentrated in the top soil upto 6 cm of depth and it decreases in the lower horizons. This profile also contains a large amount of zinc which is more than standard range of Bowen, 1966 as well as the maximum permitted concentration under ECR (Wild, 1996). This metal is also largely restricted to the top horizon and its content decreases in the lower horizon. The average content of cadmium is maximum in LSPH-8 (near Dairy Complex, Hambran road), where its values are more than 25 times high than the permitted concentration under ECR (Wild, 1996). The average cadmium content of all the soils is 38.57 μg/g, which is again many-fold higher than the standard range and permitted concentration. The nickel content of the soil profiles LSPH-1 (opposite Oswal Mill, G. T. road), LSPH-6 (near Tony Dyeing, Tajpur road), LSPH-IO (Mohalla Ishar Nagar, Gill road) is higher than the permitted concentration under ECR (Wild, 1996).

The concentration of trace elements in various horizons of soil profiles exhibits a close relationship with amount of organic matter and clay fraction. Such relationship between the concentration of other trace elements with amount of organic matter and the texture of the soil is depicted in Fig. 19 to 27.

CONCLUSION

In general the groundwater of mixed-use zone is slightly more polluted than the industrial zone. The water of residential zone is least polluted among the three demarcated regions. The extent of pollution of groundwater as depicted from the distribution of hazardous concentration of various chemical parameters and heavy metals in various localities, is more threatening in Saleem Tabri, Kundan Puri, Dholewal chowk, Near Oswal Woolen mill, Hambran bus stand, Chambal Ghatti and the area covered by different phases of Focal points. The groundwater of localities such as Model Town, Guru Nanak Nagar, New Chander Nagar, Dhandari Kalan, Gopal Nagar, New Azad Nagar and Chhoti Haibowal also has alarming

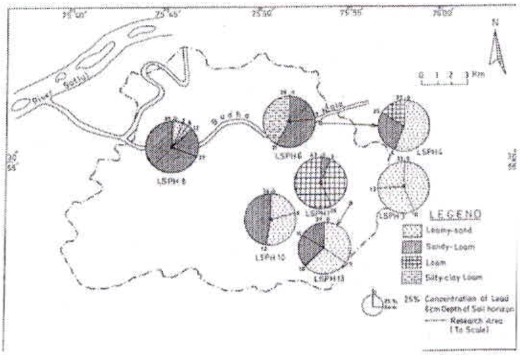

Fig. 19 : Depth wise relative lead content (%) w.r.t. texture of soil at different locations in research area.

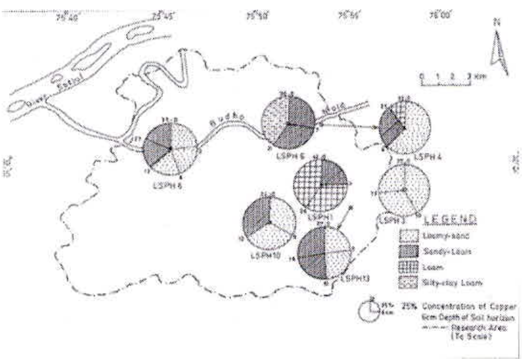

Fig. 20 : Depth wise relative copper content (%) w.r.t. texture of soil at different locations in research area.

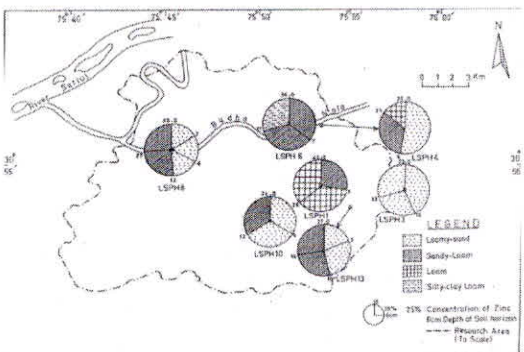

Fig. 21 : Depth wise relative zinc content (%) w.r.t. texture of soil at different locations in research area.

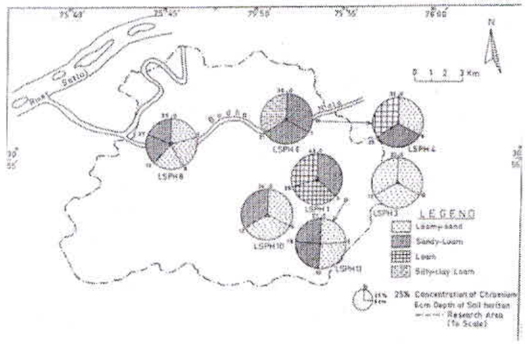

Fig. 22 : Depth wise relative chromium content (%) w.r.t. texture of soil at different locations in research area.

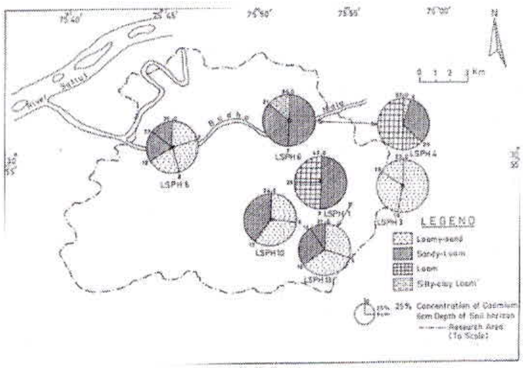

Fig. 23 : Depth wise relative cadmium content (%) w.r.t. texture of soil at different locations in research area.

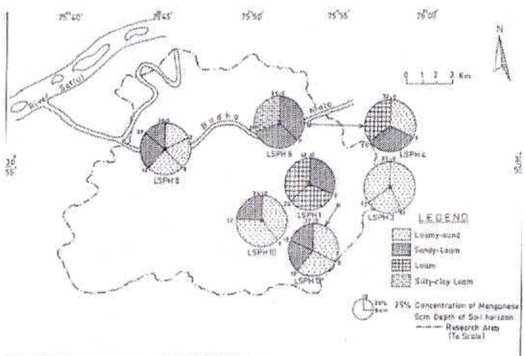

Fig. 24 : Depth wise relative manganese content (%) w.r.t. texture of soil at different locations in research area.

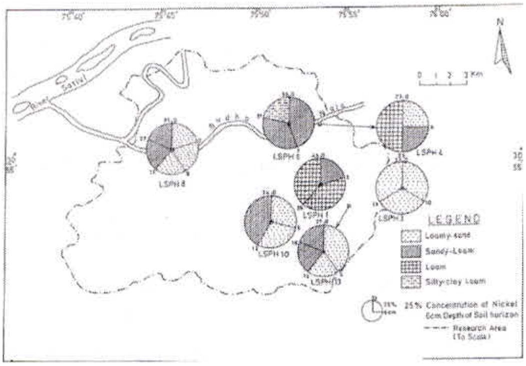

Fig. 25 : Depth wise relative nickel content (%) w.r.t. texture of soil at different locations in research area.

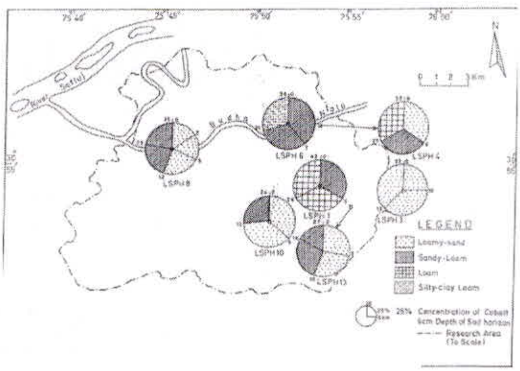

Fig. 26 : Depth wise relative cobalt content (%) w.r.t. texture of soil at different locations in research area.

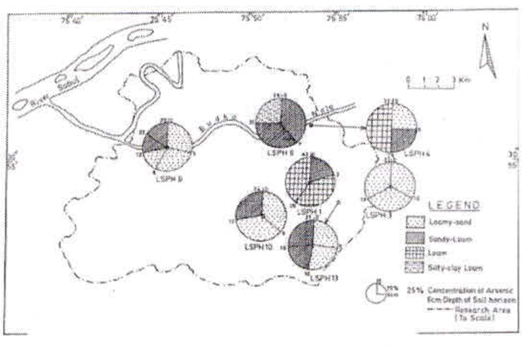

Fig. 27 : Depth wise relative arsenic content (%) w.r.t. texture of soil at different locations in research area.

content of some of the chemical parameters specially chromium, cadmium and nickel.

The concentration of nickel, chromium and lead and cadmium in the groundwater of research area has reached critical levels in the groundwater of larger number of localities in research area as compared to other parameters (Fig. 28). The distribution of major pollutants in the groundwater of various localities demarcates three zones of groundwater quality. The area adjoining some part of Budha Nala and some portion of eastern region is demarcated as most polluted zone (Fig. 29). Some part of research area to the northeast,

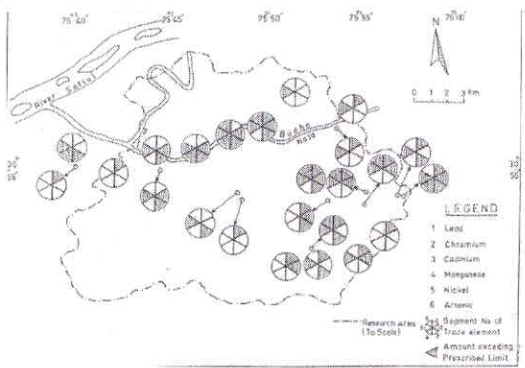

Fig. 28 : Distribution of pollutants in contaminated groundwater

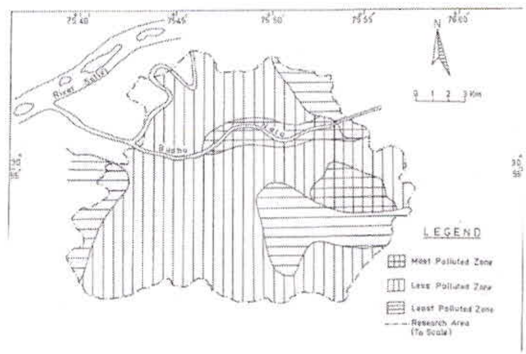

Fig. 29 : Groundwater quality zones in research area

southwest and southeast is least polluted zone while rest of the region has less polluted groundwater. Similarly the distribution of aquifers, conditions of groundwater. (such as water table and flow directions), the nature of soil zone (as to its texture, organic matter, cation exchange capacity and mineralogy help in drafting the contamination risk zones for the groundwater of research area (Fig. 30). Most of the part of northwest territory particularly along Budha Nala and a major part of southeast portion of the area under consideration are a 'high risk' zone. A small strip of area in the southwest region and most of the East part of research area have a 'low risk' of contamination. Rest of the area running northeast-southwest as a narrow strip passing through the central part, fall in 'medium risk' category. The 'high risk' zone in some part of research area

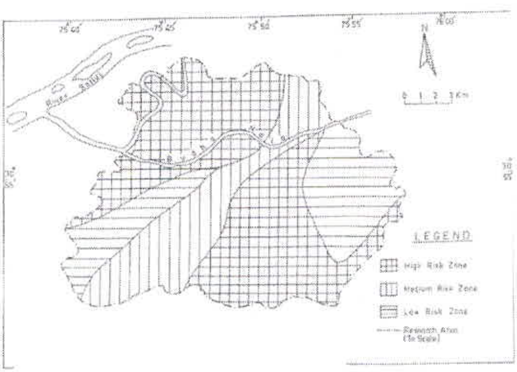

Fig. 30 : Contamination risk zones for groundwater

contradictory coincides with least polluted quality of the groundwater and similarly at some places the 'low risk' zone lies in the most polluted area. Such contrasts are explained due to the flow of miscible contaminants with subsurface flow of groundwater. Merritts *et al.* (1998) also remarked that the solutes slowly migrate from the source of contamination and the pollutants occur in far greater concentration away from the point of injection.

REFERENCES

Adams, W.A. (1973). The effect of organic matter on the bulk and true densities of some uncultivated podzolic soils. Jour. Soil Sci. 79,59-69.

Alexander, E.B. (1980). Bulk densities of California soils in realtion to other soil properties.Soil Sci.Soc.Amer.Jour. 44,689-692.

Desai, M.V.M and Ganguley, A.K. (1979). Exchange and non exchange behavior of cationic species in the interaction of metal ions with fumic acid and fluvial acid. Jour Ind. Chem. Soc., 56, 1167-1172.

Doner, H.E.,(1978).Chloride as a factor in mobiles of Ni,Cu and Cd in soil. Soil Sci. Soc. Amer. Jour., 42, 882-885

Fuller, W.H., (1977). Movement of selected metals, asbestos and cyanide in soil-Application to waste disposal problems. EPA 600/2-77-020.

Gill, G.S. and Arora, H.(1997) A victim of rapid industrialization, Ludhiana city, Punjab, India. Env. Poll. Contr. Jour. 1(1), 26-28

Gjems, O. (1963).A swelling dioctahedral mixed layer clay minerals in the weathering horizons of pedozols. Clay Miner. Bull., 5, 183.

Sekhon, G.S. and Arora, H.S.(1967). Moisture retention characteristics of some Punjab soils and their relationship with physic-chemical properties. Jour.Res.Pun.Argic.Univ. 4(3), 330-337

Singh, K.P. (11998). Groundwater pollution and risks in developing new groundwater supplies in Ludhiana Area, Punjab, India. In special volume of British Hydrological Society (Hydrology in a changing environment. II, 89-95

Singh, K.P. and Parwana, H.K. (1999). Pollutants in sediments and groundwater in Ludhiana area, Punjab, India. In: National Seminar on Geological Aspects of Environment, Centre of Advanced Study in Geology, Panjab University, Chandigarh. p10

Sinha, M.K., Dhillon, S.K., K.S. and Dyanand, S.(1978). Solubility relationships of iron manganese, copper and zinc in alkaline and calcareous soils. Aust. Jour. Soil Res. 16, 19-26

Sposito,G.K.M.,Holtz,C. and Baha, J.(1976). Analytical properties of the soluble, metal complexing fractions in sludge soil mixture, comparative structural chemistry of fulvic acid. Soil Sci. Soc. Amer. Jour. 40, 691-697.

Mehta and Marwaha(1999). Groundwater pollution in the Ludhiana city, Punjab, India .In; National Seminar on Geological Aspects of Environment, Centre Of Advanced Study in Geology, Panjab University, Chandigarh. p3

Wolverton, B.C., Mcdonald, R.C. and Duffer, W.R.(1983). Microorganisms and higher plants for waste water treatment. Jour. Envir. Qual. 12, 236-242.

Bowen, H.J.M. (1966). Trace elements in Biochemistry. Academic Press, New York.

Bureau of Indian Standards (1991). Indian standard specification for drinking water IS: 10500, Indian Standard Institute, New Delhi.

Wedepohl, K.H. (1969). Handbook of Geochemistry , Vol.3.Springer-Verlag.Berlin.

Merritts, D.J., De Wet, A. and Menking, K. (1998). Environmental Geology, an Earth System Science Approach. W.H. Freeman and Company, New York, 452p.

Wilcox, L.V. (1955). Classification and use of irrigation waters. U.S.Deptt. Of Agric.Circ.

Wild,A.(1996). Soils and the Environment-An Introduction. Cambridge University Press.

Bondietti, E.A., Perhac, R.M., Sweeton, F.H. and Tamura, T. (1973). Toxic metals in lake and river sediments. In Ecology and analysis of trade contaminations .Progress Report, ORNL-NSF-EATC-1; Oak rigde Natn. lab., Oak ridge. 161-195

Central Groundwater Board (1998). Hydrogeology of Ludhiana city with special reference to groundwater pollution. Unpublished report CGWB, Chandigarh.

Leeper, G.W. (1972). Reaction of heavy metals with soils with special regard to their application inn sewage wastes. Deptt of Army Corps of Engineering, Washington D.C.

Page, A.L. (1974). Fate and effect of trace elements in sewage sludge, when applied to agricultural lands. National Environmental Research Centre, Cincinnati, Ohio.

Saini, D.S. and Kakar, Y.P. (1980). Interim report on the urban hydrogeology and environment effects on groundwater regime in and around Ludhiana city, Punjab. Unpublished Report of Central Groundwater Board.

World Health Organisation (1996). Guidelines for Drinking Water. (2ND ED).Vol 1 and 2 WHO, Geneva.