One of the objectives of the study was to look at the various soil factors in the study area that affect the extent of groundwater pollution.

3.1 Contaminant Migration

With the growing extent of groundwater contamination in many regions, it can no longer be considered as pure water. Contaminants in the form of dissolved elements and suspended particles, bacteria, viruses and gases may also be present. The type and concentration of dissolved elements depend on the sources of groundwater contamination, chemical and mineralogical composition of the rock formations in which groundwater flow occurs and travel time of water in these rocks, hydro geological and geo-environmental conditions.

Groundwater particularly in the shallow zone aquifer is an easily available source of fresh water that serves various needs of people around it. Due to rapid growth in the industrial sector, the shallow ground water regime becomes vulnerable to industrial toxicity and human activity. However in the study area, shallow aquifers have gone dry due to over exploitation and the impact of industrialization has reached the deeper aquifers.

Groundwater in hard rock aquifers are known to be vulnerable to quality problems as rocks are often carbonate deficient and give rise to poorly buffered groundwater (Smedley et al., 1995). The mechanism of groundwater pollution is quite different from that of surface water and is more complicated. Surface water pollution is rapid and
becomes widespread in comparatively short times from perceptible changes in colour, taste, odour and at times by dead aquatic life. The process of groundwater pollution is comparatively much slow and the time lag between pollution discharge on land and it reaching ground water may be several years. This mechanism of pollutant migration, depends on the soil type and sub-surface rocks

The hydrogeology of fractured rocks is presented in Table 3.1

**Table 3.1 Hydrogeology of fractured rocks**

<table>
<thead>
<tr>
<th>Aquifer Characteristics</th>
<th>Aquifer Type-Fractured Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective porosity</td>
<td>Through joints and fractures</td>
</tr>
<tr>
<td>Isotropy</td>
<td>Mostly anisotropic</td>
</tr>
<tr>
<td>Flow</td>
<td>Rapid and turbulent</td>
</tr>
<tr>
<td>Temporal water chemistry variation</td>
<td>Greater variation</td>
</tr>
</tbody>
</table>

In areas underlain by hard crystalline rocks-granite, gneiss, schist etc. occurrence of groundwater in the fractured system has been identified down to a depth of 60m and even 200m locally with a bore well yield of 15-80 m³/h (UNESCO, 1984a).

The depth of the bore wells in the study area ranged between 133m to 242m. The map showing depth of the bore wells is presented in Plate 3.1.
Plate 3.1 Source and depth at which water samples were drawn

Pollutant that is added to the soil may adhere to the soil matrix and become available to plant roots and thus be taken up into the plant structure from where it can enter the food chain. Other pollutants can slowly permeate through the top soil structure to the sub strata and eventually into the aquifer below. An example is nitrate in drinking water which arises from the intensive use of nitrate fertilisers which have now been washed through the soil and to the aquifer. This may or may not be the case for heavy metals in soils as their mobility within the soil matrix is dependent upon several factors.
3.2 Factors affecting the solubility of trace elements (heavy metals)

3.2.1 Total trace element content

Clearly, soluble trace element concentrations in soils are likely to be influenced to some extent by the total concentrations of trace elements present in the soil. In the case of contaminated soils, solution trace element concentrations are also likely to increase with the total contaminant loading. However, the source of the contaminant trace elements may also be important. For example, trace elements added to the soil as simple metal salts may initially be much more soluble than those applied in materials such as sewage sludge. The maximum total metal concentration in soils of the study area was 234 mg kg\(^{-1}\) lead (dumpsite), 5.9 mg kg\(^{-1}\) Cd, 56.8 mg kg\(^{-1}\) of Cr, 0.196 mg kg\(^{-1}\) of Hg, 118.01 mg kg\(^{-1}\) of Zn (Dumpsite) 115.4 mg kg\(^{-1}\) of Mn, 36.3 mg kg\(^{-1}\) of Ni, 7.9 mg kg\(^{-1}\) of As, 49.6 mg kg\(^{-1}\) of Cu and 42.9 mg kg\(^{-1}\) of Fe.

3.2.2 Soil composition

Sorption/desorption reactions at the surfaces of soil colloids can play a substantial role in controlling the solution concentrations of many trace elements. The presence in the soil of those colloids able to sorb trace elements will therefore have a major influence in controlling trace element availability to plants. Soil organic matter in particular has a large capacity to sorb or complex trace elements, and in many studies this has been observed to be a dominant soil constituent affecting sorption, e.g., Cu (McLaren and Crawford, 1973b), Cd (Gray et al., 1998) and Hg (Yin et al., 1996).

Trace elements may also be sorbed by clay minerals and oxides of Fe, Al, and Mn. However, the results of many studies suggest that, in the short-term at least, these
constituents play a relatively minor role in maintaining solution trace element concentrations compared to the overriding dominance of soil organic matter. The soil organic matter showed a maximum of 2.65%. The high values (OC > 0.75%) at several locations may be responsible for adsorption of trace metals in the soil matrix thereby controlling the leaching of these metals into the groundwater regime.

3.2.3 Soil pH

Soil pH is recognized as having a major influence on the availability of trace elements. The influence of soil pH on trace element availability is mainly due to its effect on the reactions controlling trace element concentrations in the soil solution. Under acid conditions, sorption of trace element cations by soil colloids is at a minimum, and thus solution concentrations are relatively high. In addition, the solubilities of Fe and Mn oxides are high under low pH conditions. As soil pH rises, sorption of trace element cations increases and the solubility of oxides decreases. The sorption of those elements that occur in anionic forms decreases with increasing pH, and hence solution concentrations and availability increases.

A complicating factor with certain trace element cations (e.g., Cu and Pb) is that, as soil pH increases, metal solubility reaches a minimum between pH 6 and 7 and then rises again at even higher pH values (Mcbride and Blasiak, 1979; Bruemmer, et al., 1986). This is mainly due to increased solubility of organic matter at high pH, causing the retention of trace elements in solution in the form of soluble organic complexes. The soil pH ranged between 6.74 and 8.72. The presence of lead (1.82 mg L$^{-1}$) and copper (0.31 mg L$^{-1}$) in the groundwater of the study area can be attributed to the increased
solubility at higher pH as indicated by the study of Mcbride and Blasiak (1979) and Bruemmer et al. (1986).

3.2.4 Soil redox conditions

The trace elements Fe and Mn can occur in more than one oxidation state. In freely drained aerobic soils they occur predominantly in their higher oxidation states as various Fe and Mn oxide minerals. Such minerals are relatively insoluble and hence the availability of Fe and Mn to plants is at a minimum. As soils become anaerobic due to water logging, the redox potential decreases and transformation to the more soluble reduced forms of these elements ($\text{Fe}^{2+}$ and $\text{Mn}^{2+}$) takes place. This effectively results in the dissolution of oxide materials and substantial increase in solution concentrations and bioavailability of Fe and Mn. In addition, since substantial concentrations of many other trace elements are often sorbed or occluded by Fe and Mn oxides in soils (e.g., Le Riche and Weir, 1963; Taylor and McKenzie, 1966), solubilization of the oxides also releases these other elements into solution.

3.2.5 Trace element leaching through soil

The realization that trace elements do leach from soils under some circumstances has led to a demand for predictive models of trace element leaching, particularly in relation to toxic elements such as As, Cr, Cd etc. A limited number of attempts have indeed been made to model trace element transport in soil, ranging from simple to extremely complex models. However, it would be fair to say that most, if not all, attempts to model trace element leaching have not progressed beyond experimental studies carried out with soil columns in the laboratory.
3.2.6 Soil Characteristics

Soil texture refers to the type of soil based on particle size—the proportion of sand, silt and clay in a soil. If the sand proportion is high it is coarse textured and if the clay proportion is high it is fine textured.

The characteristics of soil based on texture is shown in Table 3.2

Table 3.2 Soil characteristics based on soil texture

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Coarse Textured</th>
<th>Fine Textured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration rate</td>
<td>Very rapid</td>
<td>Slow</td>
</tr>
<tr>
<td>Percolation rate</td>
<td>Very rapid</td>
<td>Very low</td>
</tr>
<tr>
<td>Water holding capacity</td>
<td>low</td>
<td>High</td>
</tr>
<tr>
<td>Drainage</td>
<td>Well drained</td>
<td>Poorly drained</td>
</tr>
</tbody>
</table>

The characteristics of soil based on texture in the study area is given in Table 3.3

Table 3.3 Soil characteristics based on soil texture

<table>
<thead>
<tr>
<th>S.No</th>
<th>Textural class</th>
<th>Soil texture</th>
<th>Percolation rate min/inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandy clay loam</td>
<td>Moderately fine textured</td>
<td>&gt;45</td>
</tr>
<tr>
<td>2</td>
<td>Sandy loam</td>
<td>Moderately coarse textured</td>
<td>3-30</td>
</tr>
<tr>
<td>3</td>
<td>Sandy clay</td>
<td>Fine textured</td>
<td>&gt;60</td>
</tr>
</tbody>
</table>

Percolation rate T is the time in minutes for a 25mm drop in water level. Clayey soils have got a low percolation rate while sandy soils have got a higher percolation rate. Percolating water goes deep into the soil until it meets the free water table. As it is the
only source of groundwater recharge it becomes the carrier of pollutants from the surface to the aquifers below. Percolation depends on

a) **Climate** - If the rainfall is greater than the evaporation then there will be appreciable amount of percolation.

b) **Nature of soil** - Sandy soils allow more percolation as these occupy larger volume of macropores. The macropores serve as the main channels of the groundwater flow. However clayey soils permit less water to percolate. Red soils, formed by the weathering of igneous and metamorphic rocks comprising gneisses and schists have low water holding capacity and hence are well drained.

c) **Type of rock** - fracture pattern and weathering

    As the study area comprises of red soils which are well drained, this may also be an important factor for contaminant transport into the groundwater. Accelerated infiltration processes, high mass influx and shallow groundwater table are factors conducive for easy access of heavy metals to the phreatic aquifers.

3.3 **Transport Mechanisms**

There are different modes through which groundwater contaminants move such as -

**Advection**

    The movement of contaminants along with flowing groundwater at seepage velocity in porous media.
Diffusion

Molecular mass-transport process in which solutes move from areas of high concentration to areas of lower concentration.

Dispersion

Mixing process caused by velocity variations in the porous media.

Adsorption

Adhesion of a species onto the surfaces of particles or the accumulation of particles on the surface of a medium.

The purpose of discussing transport mechanisms is to understand the processes that most strongly influence the migration of dissolved contaminants in saturated flow in granular aquifers. The most prevalent human activities that cause groundwater contamination are waste disposal, storage and transport of commercial materials and agricultural activities etc. (Candela et al., 1995)

3.4 Contaminant Transport Modelling Approaches

Transport problems cover a wide range of applications in real environment areas. These problems include variety of contamination, pollution and health risk problems associated with different sources of pollution such as landfills, waste disposal, wastewater injection, irrigation practices, seawater intrusion, surface impoundments, accidental spills, leakage, seepage etc. Important considerations in contaminant transport modelling includes source term characterization incorporating both hydro geological and
hydro geochemical, dispersion and attenuation characteristics of porous media in prevailing geo environment, simulating the effects of natural and/or engineered barriers, and understanding the unsaturated zone. A groundwater contamination plume generally contains numerous contaminants. Each contaminant within the plume may migrate differently and some may react with each other. In transport predictions, one normally concentrates on the contaminant that is considered to be the most significant for the investigation in the study area. However it may be one or a set of chemical species. Therefore, contaminant transport modelling also depends upon the nature of chemical species considered for investigation and may require many other models for simulating the subsurface environments.

A number of modelling approaches exist. These approaches vary in their complexity, solution techniques and applicability to deal with real life groundwater contamination problems. These modelling approaches can be classified as:

*Conceptual Models

*Analytical Models

*Semi analytical Models

*Lumped Models

*Numerical Models

*GIS based Models

*RS and GIS based Models

*Integrated Models
Among these modelling approaches, numerical models are the most commonly used models. However, analytical models are of much relevance for testing the numerical models and getting a quick understanding about the groundwater system. Integrated models involving numerical and remote sensing and GIS techniques are now emerging.

3.4.1 Application of GIS in creation of spatial distribution of pollutants

It was envisaged to assess the rate of migration of pollutants in the study area. Pollutant migration is assessed by using mathematical modelling. Different types of hydro geological and geophysical studies like Electrical Resistivity Tomography (ERT) to produce high resolution image of the sub-surface and to determine the groundwater flow needs to be carried out. This is highly difficult to record and beyond the scope of this study. In addition, the resultant output obtained from running the software on the rate of migration will not be realistic in the field as the study area comes under hard-rock terrain (granitic gneisses) and is highly heterogeneous.

However, the migration of pollutants from season to season is brought out in the spatial distribution maps obtained using GIS, for the visual interpretation of contaminated areas. This would substantially increase the communication capabilities of those involved in urban management-industrialists, policy makers and local administration. In the present study, the lateral migration of heavy metals in the study area, for the pre-monsoon, monsoon and post-monsoon seasons have been determined.

Heavy metal pollution is a condition which represents the presence of these elements in sufficient concentration which is toxic to living organisms. Heavy metals are major sources of environmental pollution which are added to the soil through several
agencies. The most problematic metal toxicity issues to manage and solve are soil, water, plant, etc in which metals accumulate as such at sites due to application of sewage sludge, compost, fertilizers, pesticides and other municipal and industrial effluents.

The content of heavy metals in the groundwater, surface soils and dumpsites is presented in Tables 4.18, 4.20 to 4.24, 4.41 to 4.43. The average contents of lead, cadmium, chromium, mercury, zinc, arsenic, nickel, manganese and copper in the surface soil of the industrial area were 45.74, 3.58, 34.91, 0.16, 85.87, 4.81, 28.3, 97 and 35.7 mg kg\(^{-1}\) and that of the dumpsites were 78.32, 0.95, 23.56, 0.11, 53.62, 5.76, 23.98, 7.83 and 22.07 mg kg\(^{-1}\) respectively, where as the maximum content of heavy metals in the groundwater was 1.82 mg kg\(^{-1}\) of lead, 0.2 mg kg\(^{-1}\) of Cd, 16.2 mg kg\(^{-1}\) of chromium 0.86 mg kg\(^{-1}\) of Ni, 0.31 mg kg\(^{-1}\) of copper and 2.5 mg kg\(^{-1}\) of iron.

Groundwater samples collected from the study area recorded concentrations of mercury, arsenic, zinc and manganese below desired levels indicating that soils act as a filter in controlling the seepage of metals and preventing entry into ground water. The environmental/public health concern from the metal contamination of soil relates to its potential influence on contamination of ground waters and metal uptake by plants and their transmission to human food chain. Arable soils of industrialized areas are strongly affected by heavy metal pollution through long distance transport of contaminants.

Soil is a dynamic and complex system with intrinsic chemical properties of pH, cation and anion exchange and others. Further the structural properties of texture and porosity determine the movement of elements. Years of dumping industry wastes and effluent seepage largely influence the migration and concentration of metals into the
lower strata as indicated in the results. Urban communities tend to have distinct patterns in the heavy metal content of their soils.

The age of community, population, industrialization and several other factors continue to markedly alter the heavy metal concentration of soils, especially in urban areas. The heavy metals in soils may be prone to downward movement in soil profiles either slowly by diffusion or much more rapidly because of preferential flow in voids of soil. Based on GIS information and the distribution of heavy metals it was inferred that the concentration of Pb, Cd, Cr, Ni, Cu and Fe in the groundwater samples recorded values greater than their desired limits indicating their migration to lower depths.
REFERENCES


