



**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH
TECHNOLOGY**

**Hydrochemical Facies, Groundwater Pattern in 'Red Beds and Basaltic Aquifers',
Origin of Brackish Waters And Salt Encrustation, Khanapur Plateau, Western
Ghats, Maharashtra, India.**

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Abstract

An integrated Hydrochemical, geochemistry and mineralogy of the salts encrustation on the 'red beds' on the Khanapur plateau, along the eastern side of the Western Ghats (Hills) of India region of the Indian peninsula. This area receives low precipitation (638 mm/year) as compared to the western side (4000 to 6000mm/year).

Over a greater of the Deccan Volcanic Province of India, the basaltic aquifers contain fresh water with TDS<1000ppm. However, brackish waters (TDS>1000ppm and <10.000ppm) have been recorded in the alluviated aquifers in the region. The present study deals for the first time with an occurrence of brackish waters in the 'red beds' area on the Khanapur Plateau.

The data collected for groundwater samples and salt encrustation, suggesting the origin of salinity imposed to the groundwater system in the area. It is evident that the waters are saline during the pre-monsoon period. The semi-arid climate conditions prevailing in the area during the Quaternary period and chemistry and mineralogy of the 'red beds', might have played an important role in imparting salinity to both soil and groundwaters.

There are significant variations in the chemistry/quality of groundwaters in different seasons and aquifers. The groundwaters show changes in their chemical characteristics during monsoon season and waters from the shallow basaltic and 'red beds' aquifers exhibit shift in their Hydrochemical facies from Cl+SO₄, HCO₃ to HCO₃, Cl+SO₄. The post-monsoon season shows the dominance of groundwaters with Cl+SO₄, HCO₃ anion Hydrochemical facies with shift in the cation Hydrochemical facies from Na+K, Ca+Mg to Ca+Mg, Na+K. The calculated SAR values indicated that the water is saline and do not suitable for irrigation. The salt samples subjected to chemical and mineralogical analysis to understand their origin and genesis. IR data shows the dominant of the carbonate minerals as, magnesite, calcite and dolomite associated with clay as montmorillonite, illite, huntite, kaolinite, nontronite and other iron oxides; hematite, siderite, , goethite, with quartz and gypsum.

Keywords: 'red beds', Deccan Volcanic Province, Hydrochemical facies, water quality, brackish water, salt encrustation.

Introduction

The Deccan Volcanic Province represents a most spectacular volcanic episode, covering an area of about 500.000km², in peninsular India, out of this gigantic extent, an approximately 240.000km² area in Maharashtra is occupied by horizontally deposited basaltic flows (**Nasrolla and Thigale, 1991**).

The region of Western Ghats in the Deccan Volcanic Province of India is characterized by an erosional landscape. The upland region of the Western Ghats shows the absence of Sedimentological records for the stratigraphic period from post- Eocene to pre-Pleistocene, except laterite, which is extensively developed over the region (**Patil, 1991; Elzien, 1992**).

In the region of Khanapur Plateau, rain water constitutes the only source to the recharge of

groundwaters. During the process of seepage of waters into the soil, the meteoric water undergoes a number of physico-chemical changes by various reactions. This continues till the water acquires a steady state condition with respect to its dissolved minerals/salts content (**Elzien, 1992**). The changes in the chemistry of waters are generally, governed by such factors as the climatic conditions, nature of vegetation cover, chemistry and mineralogy of the host rocks, topography, time, and human activity, which usually, have a very complex inter-relationships (**Elzien, 1992**). The changes in chemical equilibrium lead to the precipitation of certain salts that may eventually develop into a distinct lithotype.

In 'red beds' areas of the Khanapur Plateau, surficial accumulation of evaporate minerals as well as extensive deposits of secondary precipitates, chiefly of calcareous and siliceous materials within the 'red beds' sediments.

Groundwaters composition as well as seepage is determined by weathering processes. The weathering of different types of basalts creates water with relatively high concentrations of total dissolved solids (TDS), and weathering of laterites and related duricrust results in waters with low TDS (Elzien, 1992). The water chemistry may change as water passes from one geological environment to another, many Hydrochemical evolution of major ion composition of groundwaters and seepage are based on spatial variation (Gibbs, 1970; Allen, 1995). Water chemistry data collected in different parts of catchment area, are used to model the possible relationship between geology and chemical composition of water samples. These models are based on equilibria among secondary minerals and salts formed by weathering and may predict the chemistry of the sources rock involved. Water- rock interaction described and discussed in terms of water and salts chemistry genesis and effects of discharge on intra-annual variations of ion concentrations (Elzien, 1992).

In Dry Land Rivers, however, fluctuations of discharge may have enormous effects on the hydrochemistry of the rivers (Allen, 1995; Davies et al., 1996). Equilibria of the secondary minerals will be greatly affected by evaporation and dilution and may result in high dynamic water chemistry. In general, concentrations of major ions are negatively related to discharge, due to dilution and precipitation effects (Gibbs, 1970; Allen, 1995). However, because of differences in solubility not all ions are equally affected by these processes (Drever, 1997). 'Rinse-out effects', caused by the dissolution of precipitated salts at the onset of the rainy season, may cause temporary strong increases of major ion concentrations (House and Warwick, 1998; Keith et al., 2001). Geochemical modeling on time series of field data that include both data on chemical composition of waters and salts encrustation would be highly desirable.

The Area of Investigation

The area under present investigation forms a part of the Western Ghats of India, which runs in an approximately north-south direction parallel to the coastline for a distance of over 1500km from Tapi River in the north to Kanyakumari in the south. The western Ghats are characterized by conspicuous escarpment running parallel to their crests, the

western side of these being marked low-lying coastal plain and the eastern side by a high lands referred to as the Deccan Plateau. The Plateau is dissected by a number of east flowing rivers. This upland region itself is constituted of a number of Plateaux and one of the prominent Plateaux is the Khanapur Plateau.

The Khanapur Plateau has been considered to be denudational surface and referred to as the Khanapur surface (Kale and Gupte, 1986). The Khanapur Plateau (580km²) extends in approximately northwest-southeast direction for a distance of about 42km. It has an average width of about 29km. It is located at 110kms to the east of the Great Escarpment of the Western Ghats (Fig1). The region of the Khanapur Plateau is included within the Survey of India topographic sheet No. 47 K/11, 47 K/12, 47 K/15 and 47 K/16 and is bounded by latitudes 17° 04'06"N – 17°19'27"N, and longitudes 74° 33'35"E – 74°55'00"E.

Physiography of the Area

The area, experiences a tropical wet-dry climate with alternate wet and dry spells. The area falls within the rain shadow zone of the Western Ghats, therefore, receives very low precipitation during the monsoon period especially from June to October, the mean annual rainfall 638mm. The mean annual temperatures vary between 34.8 °C and raise up to 40.6 °C during summer and fall down to 10 °C during winter. The plateau exhibits semi-arid to sub-humid climatic conditions with extremely low precipitation and high evaporation.

Scanty vegetation confined mainly to the alluviated valley floors and colluviums slopes and the plain areas along the banks of Agran River and its important tributaries are under cultivation. The plateau with an average elevation of about 870m above MSL is marked by steep escarpment from all sides. The plateau constitutes part of the water – divide between the Krishna and Bhima rivers, and exhibits a radial drainage pattern (Fig 2). Within the plateau area an overall exhibits dendritic to sub-dendritic drainage pattern.

The plateau presents an extensive flat surface that is characterized by a flat featureless undulating topography, with level to gentle slopes (0° to 5°) (Young, 1972). However, a few isolated hillocks e.g. Renavi (869m), Landgewadi (820m), Palshi (840m), Bhawani Khadi Donger (918m), Jarandi (822m) and Kundlapur (888m) dot the surface. These residual hillocks dotting the Khanapur surface are marked by moderate to moderately steep slopes (5° to 18°). Along the periphery of the plateau specially in the northern side, a typical badland topography is developed in the 'red beds' sediments,

where, the streams have cut more than 37m deep narrow steep sided saw-cut valleys in the 'red beds'.

Methodology

In order to understand the chemical characters of groundwaters from the basaltic and 'red beds' aquifers, water samples were collected from the dug-wells tapping deeper basaltic aquifers. Few dug-wells, bore-wells and springs water samples from the 'red beds' area (**Fig 3**) were collected for chemical analysis. The water samples were collected during monsoon, pre-monsoon and post-monsoon seasons in an attempt to record the seasonal variations and to study the origin of the salts encrustation which developed on the surface of the sediments.

In order to obtain information on the variability of the major ion composition, water samples have to be collected at a regular season intervals, during an entire year. The water samples were collected during the pre-monsoon, monsoon and post-monsoon season in the year 1990 to 1991. Data on water chemistry and salts encrustation have been compiled for the area of study, in an attempt to record the seasonal variations.

The chemical analysis of the groundwaters was carried out by following the standard procedures (APHA, AWWA AND WPCF, 1975). The physico-chemical parameters, the pH, EC, alkalinity, and temperature of the water were determined in the field. The pH water was determined with the help of an Elico LI-120 digital pH meter, while, Elico CM-ISO Electrical conductivity meter was used to estimate electrical conductivity (EC), Na⁺ and K⁺ estimation was done with the help of Corning 400 Flame Photo meter and titration method was used in the determination of Ca²⁺ and Mg²⁺. Samples for major ion analysis were collected in HDPE bottles filled to overflowing and stored at -5 ° C until analysis, following filtration carried out in the field after sampling (0.45µm cellulose membrane filter); Si⁴⁺ was analyzed mainly with UV Spectrophotometer. The samples from the salt encrustation were taken systematic and analyzed chemically using AAS, Flame photometer, UV – Colorimeter and mineralogically with the help of Infrared Spectroscopy (IR) and X-Ray Diffractometer (XRD).

Geology

Khanapur Plateau is a part of the Deccan Volcanic Province, cover its greater parts exposes largely horizontally disposed basaltic lava flows which are unconformably overlain by a thick sequence of reddish-brown coloured sediments (red beds) of Paleocene (?) age. Alluvio – colluvial sediments of Quaternary age have been observed

along the courses of the major streams and, at the base of hill slopes and escarpments. All these lithological units show the development of soils in their upper sections. In addition to this, extensive development of calcrete has been observed in the Khanapur Plateau area (Elzien, 1992). It occurs in a variety of forms including powder, nodular, honeycomb, laminar, platy, and tabular and hardpan types (Patil and Surana, 1992). A hardpan calcrete with 1.5m thick exposed in a stream - cut near Adsadwadi village contains fresh – water gastropod fossils, *Melania Sp.* and *Melanoides Sp.*

A thick deposit of waterfall tufa composed chiefly of calcium carbonate has been observed at Sukh Deo Temple.

Chemistry of Groundwaters

It is evident from the chemical data (**Table 1**) that the groundwater from the 'red beds' aquifers (spring waters), in general is saline (TDS >1000ppm) and that from deeper basaltic aquifers is non-saline (TDS <1000ppm) (Todd, 1970). The water from shallow basaltic aquifers close to the 'red beds' areas also has higher salinity (TDS >1000ppm) on account of the mixing effects. The effect of dilution is observed during the monsoon season and for this reason, the groundwaters from all three aquifers mentioned (deeper basaltic, shallow and 'red beds' aquifers) have TDS values <1000ppm, thereby, indicating their non-saline nature. During the post-monsoon groundwaters from the three aquifers show little or no variation in their TDS values and shows effect of dilution. On the contrary, maximum salinity of the groundwaters is recorded during the pre-monsoon period.

The parameters including Electrical Conductivity (EC), Total Alkalinity (TA), Total Hardness (TH), and anion like Chloride (Cl⁻), Sulphate (SO₄²⁻), and cation like Ca²⁺, Mg²⁺, K⁺ and Na⁺ show wide seasonal variation in their concentrations. The pre-monsoon period shows maximum EC values (9750), while, Total Hardness of water is highest during the post-monsoon period (6173.45). The groundwaters from the basaltic aquifers do not show such variation in cationic and anionic concentrations (Cl⁻, Ca²⁺, Mg²⁺, K⁺, Na⁺, SO₄²⁻, and Si⁴⁺). The shallow basaltic and 'red beds' aquifers show wide seasonal variations in the concentration of (Cl⁻, Ca²⁺, Mg²⁺, K⁺, Na⁺, SO₄²⁻, and Si⁴⁺) (**Table 1**).

Hydrochemical Facies

The chemical data (**Table 1**) obtained from the 'red beds' aquifer (**Fig 3**), were further, processed in terms of Hydrochemical facies. The concept of

Hydrochemical facies formulated by **Back (1960)**, to denote the diagnostic chemical characteristics of groundwaters. The concept was further developed (**Back, 1961; Morgan and Winner, 1962; Seaber, 1962; Back 1966**). The Hydrochemical facies reflect the effect of chemical reactions between the rocks and minerals and the groundwaters (**Pawar, 1986**), **Piper (1953)** developed a trilinear diagram to classify the groundwaters. The chemical data for the three seasons (**Table 1**), were plotted on Pipers' trilinear diagram (**Fig 4**). It is seen that the groundwaters in the 'red beds' areas show the dominance of Na + K, Ca + Mg cation and Cl + SO₄, HCO₃ anion Hydrochemical facies. The groundwaters show change in their chemical characteristics during monsoon season and the waters especially from the shallow basaltic and 'red beds' aquifers, exhibit shift in their Hydrochemical facies from Cl+SO₄, HCO₃ to HCO₃, Cl+SO₄. The post-monsoon season, shows the dominance of groundwaters with Cl+SO₄, HCO₃ anion with a shift in the cation hydrochemical facies, from Na+K, Ca+Mg, to Ca+Mg, Na+K.

Rock – Water Interaction

The changes of hydrochemical facies have been shown to be controlled by such factors as the mineral composition of parent material, physiography of the area, climatic conditions, nature of groundwater circulation and vegetation cover (Pawar, 1986). The Khanapur Plateau is constituted chiefly of basalts which are considered to be highly susceptible to chemical weathering. The Khanapur Plateau shows the presence of 'red beds' that are rich in both ferric (Fe³⁺) ion and bases (Ca²⁺, Mg²⁺, Na⁺, and K⁺).

The pyroxenes and plagioclases – the chief constituent of basalt minerals- when come in contact with water, undergo chemical alteration involving a variety of chemical reactions. The rain water charged with CO₂, when infiltrates down into the rock mass through joints, cracks, fractures and other voids, comes into contact with the mineral matter. The initial pH of meteoric water is generally of acidic nature due to incorporation of atmospheric CO₂ and organic matter. At this pH, the minerals of the parent rock, breakdown and base cations (Ca²⁺, Mg²⁺, Na⁺, and K⁺), being highly soluble in water, are taken into solution (**Birkeland, 1984**). This leads to the changes in the pH of percolating waters that becomes alkaline and eventually facilitates the mobilization of Si⁴⁺. The chemistry of percolating waters, changes to a considerable extent during their passage through the rock mass.

The crystal size of the minerals, rock structure, porosity, regional structures, degree of jointing, length of previous exposure, time and other

environmental factors such as faunal and floral activity to a great extent, influence the composition of groundwater (**Hem, 1970**). The changes in hydrochemical characters of water have also been shown to be governed by alkali and alkaline earth elements. **Matthess and Harvey (1982)** have shown that Cl⁻ and SO₄²⁻ are very mobile; Ca²⁺, Mg²⁺ and Na⁺ are moderately mobile; Si⁴⁺, P⁵⁺ and K⁺ are mobile and Fe²⁺ and Al³⁺ are slightly mobile or inert substances of igneous rocks. If this taken into consideration Ca²⁺, Mg²⁺ and Na⁺ cations K⁺ and Si⁴⁺ dominate the river and groundwaters, Ca²⁺ constitutes the most dominant ions in the river water, while, Na⁺, Mg²⁺, CO₃²⁻, SO₄²⁻, Cl⁻ occur in decreasing amounts (**Mason and Moore, 1982**).

Gibbs (1970) has pointed out that the chemistry of water is generally, controlled by the rate of evaporation, chemistry of rocks and rain water. To evaluate the sources of various ions, the chemical data of waters from the area of study (**Table 1**) were plotted on Gibbs diagram. The plots of the total dissolved solids (TDS) versus Cl/Cl+HCO₃ (**Fig 5a**) suggest that the ions are chiefly derived from the basalts and 'red beds' and their concentration in groundwaters is mostly due to evaporation. Similar results have been obtained when TDS plotted against Na+K/Na+K+Ca (**Fig 5b**). Precipitation, indicating contribution from the rain water, however, has not played any role in the concentration of ions in the waters from the area of study.

Salinity of Groundwaters

The Khanapur Plateau experiences semi-arid climate which is characterized by excessive evapotranspiration over a total annual precipitation resulted in inequilibrium with respect to soil moisture budget. During the dry season, the rain does not provide any excess waters required for the leaching of highly soluble cations like Ca²⁺, Mg²⁺ Na⁺ and K⁺. These cations remain in the system and eventually contribute to salinisation of both the surface and groundwaters.

In order to evaluate the nature of water with respect to salinity and related parameters for the groundwaters from the area, the chemical data were processed, the equilibrium of groundwaters with respect to CaCO₃ can be established in a simpler way with the help of Langelier Index (LI) which is nothing but the difference between the measured pH of the water and the hypothetical pH of the water, if waters were in equilibrium with CaCO₃

When the water is in equilibrium with CaCO₃, LI commonly is zero. Positive values of LI indicate oversaturation of waters with CaCO₃, while undersaturated conditions are defined by the negative

values of LI. The values from the waters from the 'red beds' are collected during pre-monsoon, monsoon and post-monsoon seasons (**Table 2**) indicate that the groundwaters remain saturated with CaCO_3 which evidenced by positive LI values. The water becomes diluted during the post-monsoon season due to addition of more water during the rainy period, show negative or lower LI values (**Table 2**).

The partial pressure of CO_2 plays a vital role in the precipitation of CaCO_3 from the groundwaters. From the pCO_2 values (**Table 2**), obtained from the Freeque programs, LI values are positives when pCO_2 values are low. It is pointed out by **Matthess and Harvey (1982)** that the mechanism of precipitation and dissolution of CaCO_3 is governed by the chemistry of $\text{CO}_2\text{:H}_2\text{O:CaCO}_3$ system. The four variables, temperature, common ions, pCO_2 and pH control the solubility of CaCO_3 . The solubility product (Ca^{2+}), (HCO_3^-) decreases with increasing temperature and pH, rising in partial pressure of CO_2 and increasing concentration of salts and common ions like Mg^{2+} .

During the pre-monsoon period temperature of water is relatively high. This leads to the evaporation of water causing decrease of partial pressure CO_2 and increase in the pH of solution ultimately resulting in the rapid precipitation of CaCO_3 . From the data on temperatures, pH values, concentration of Mg^{2+} (**Table 1**) and pCO_2 (**Table 2**), it is concluded that the waters are saline during the pre-monsoon and monsoon seasons and always remained oversaturated with respect to CaCO_3 .

Table 5.3 presents various ionic ratios for the groundwaters from the 'red beds' area on the Khanapur Plateau. The molar ratio Cl/HCO_3^- which is one of the important indicators of the origin of salinity with values <1.0 for the resident deeper water in basalt; (**Table 3**) is suggestive of the occurrence of non-saline waters in the deeper basaltic aquifers. The groundwaters in the 'red beds' area aquifers show higher values for Cl/HCO_3^- ratio (>1.0) on account of intense water-rock interaction and dissolution of soluble salts in the highly saline sediments. The mixing of waters from 'red beds' at the shallow depth is indicated by higher Cl/HCO_3^- values especially from the shallow basaltic aquifers (**Table 3**). It is observed that the molar ratios such as Ca/Mg , Cl/SO_4 , $\text{Na}/(\text{Ca} + \text{Mg})$, etc. show increase in their values from post-monsoon to pre-monsoon seasons (**Table 3**). This suggests that Ca^{2+} , Na^+ and Cl^- are concentrating in the groundwaters due to evaporation. Na/Cl and Na/Ca ratios decrease from post-monsoon to pre-monsoon season indicating relative rise in Cl^- and Ca^{2+} concentration in comparison with Na^+ . The increase in Ca/Mg ratio from the post-monsoon to pre-monsoon season reflects the removal of Mg^{2+}

from the solution. Similarly, SO_4^- is also removed in large quantity from the aqueous solution, thereby, causing rapid rise in the values of Cl/SO_4 ratios (**Table 3**). The Ca^{2+} and Na^+ are concentrating in the waters; the $\text{Na}^+ / (\text{Ca} + \text{Mg})$ ratio is depicting an increasing trend. It is evident from the plots of EC (Electrical Conductivity) against SAR (Sodium Absorption Ratio) that the waters are highly to very highly saline (**Fig 6**). The high salinity conditions have, resulted in the precipitation of mineral salts (evaporate minerals), that occur as salt encrustations in the ephemeral stream beds. The precipitation of salts from waters may take place rapidly with evaporation and degassing of water (**Eugster and Jones, 1979**) and decrease in partial pressure of CO_2 in the near surface environment.

Evaporite Sedimentation

The field studies revealed that the ephemeral streams draining the 'red beds' areas as well as the springs emerging out of the 'red beds' areas locally showed secondary chemical precipitates in their vicinity. The local inhabitants of Menganwadi area used to extract common salt (NaCl) out of the surface encrustations occurring along the stream beds from the peripheral region of Menganwadi 'red beds'. In local language this salt is known as "Mengan meeth" i.e. salt from Menganwadi. The salt deposits either form thin layers on the soil surface (**Photo 1**) or aggregates of radiating tiny crystals having spheroidal or botryoidal form (**Photo 2**). The initial white colour of the precipitates with ageing becomes dark red to reddish-brown on exposure to atmosphere. Most of these deposits have ephemeral character and they generally, develop during the dry season when moisture from the near surface saline soils evaporated rapidly. The amount of salts precipitated is very small. Moreover, the salts get readily redissolved during rainy spells, which destroy the surface salt-crust (**Watson, 1983**). To evaluate the nature of these deposits, the salt samples were collected from the encrustations along the beds of ephemeral streams emerging out of the 'red beds' area, were analyzed in the laboratories and the results were processed.

The term "evaporates" is restricted to the rocks precipitated from a concentrated watery solution i.e. hydrochemical precipitate from the solutions concentrated and formed either with or without biogenic influence (**Sonnenfeld, 1984**). Evaporites include chlorides and sulphates of Na, K, Ca and Mg; carbonates of Na and Mg either with or without Ca and nitrates of Na and K (**Sonnenfeld, 1984**). A variety of salts of iodine, boron and iron have been recorded in association with the common

evaporite minerals. All these chemical admixtures in a terrestrial environment constitute important indicators of their environment of formation. In the present case, both the semi-arid climatic conditions, chemical and mineralogical composition of the 'red beds' played a vital role in the development of these salts deposits.

Mineralogy of Salts

The representative salt samples from the Menganwadi 'red beds' area (Fig 3) were subjected to infrared spectroscopic (IR) and X-ray diffractographic analyses in an attempt to ascertain their evaporite mineral assemblage. From the XRD (Fig 7) and IR (Fig 8), the material dominated by carbonate minerals including magnesite (2.5081, 2.3441, 2.1560, 1.4407 ° A) and calcite (4.0583, 3.8171, 3.0178, 2.2703 ° A), other minerals like montmorillonite (5.1257, 3.6187, 3.948, 2.2869 ° A), illite (5.1852, 2.9214, 1.9852 ° A), huntite (4.9279, 2.840, 1.6104 ° A), dolomite (4.0583, 2.805, 1.8768 ° A), kaolinite (4.3959, 2.5565, 2.4747, 1.4881 ° A), hematite (2.6749, 2.5149, 1.4881 ° A), siderite (3.5339, 2.1080, 1.768, 1.3645 ° A), nontronite (4.5753, 1.5234 ° A), goethite (4.1329, 2.2220, 1.7217 ° A) and gypsum (2.0713, 1.9852, 1.898 ° A) (JCPDS, 1974a, b).

The XRD supplemented by the IR spectroscopic studies. The IR spectra of the representative salt samples (Fig 8) have indicated the dominance of hydromagnesite (3650, 589, 535, 480cm⁻¹), magnesite (1485, 1445, 885, 744cm⁻¹), hematite (1180, 1030, 888, 600, 552cm⁻¹), calcite (1435, 1420, 875cm⁻¹), dolomite (1430, 885, 735, 470cm⁻¹), and siderite (1800, 859, 740, 735cm⁻¹). The evaporite minerals occur in association with a variety of clay and related minerals including kaolinite (3700, 3650, 3600, 705, 477, 467cm⁻¹), attapulgite (3620, 3540, 700cm⁻¹), sepiolite (3620, 1200, 1025, 478, 467cm⁻¹), nontronite (3560, 1020, 675cm⁻¹), quartz (780, 555, 488cm⁻¹) and tridymite (1095cm⁻¹), illite (3622, 1022, 525, 475cm⁻¹), montmorillonite (3624, 1027, 467cm⁻¹) and imogolite (987. 578cm⁻¹) (Nakamoto, 1963; Van der Marel and Beutelspacher, 1976; Russel, 1987).

Chemistry of Salts

Chemical analysis of the representative salt samples from the Menganwadi 'red beds' area (Table 4) has shown that the salts are dominated by CaO (17.68% to 56.58%) appreciable amounts of MgO (0.46% to 18.93%), FeO (2.44% to 12.49%), Al₂O₃ (5.27% to 18.15%), SiO₂ (3.31% to 24.15%) and K₂O (0.11% to 0.84%). The Cl⁻ content of the evaporites ranges between 0.07% to 3.05%, while SO₄²⁻ content varies from 0.019% to 0.40% (Table

4). The chemical analysis of the salt samples is very well in agreement with the mineralogical data.

Conclusion

The groundwaters from the Khanapur Plateau 'red beds' area have exhibited characteristics of brackish water and the ephemeral stream draining the 'red beds' areas and the springs emerging out of the 'red beds' areas have shown salt encrustation in and along the beds. From the chemical data for both the groundwaters and salt encrustations from the Menganwadi 'red beds' area on the Khanapur Plateau, it is evident that the waters are saline during the pre-monsoon period. The semi-arid climatic conditions prevailing in the area under study during the Quaternary period might have played an important role in imparting salinity to the groundwaters. The low rainfall received by the region during the monsoon season appears to be insufficient to leach out the soil system off the soluble salts. As the result, the salts of bases (Ca, Mg, Na and K) have remained in the system, and eventually got concentrated in the subsoil into and developed evaporite minerals deposits. It appears that the mineralogical and chemical composition of the 'red beds' (Elzien, 1992) have equally played a vital role in imparting salinity to the groundwaters as the 'red beds' are rich in alkali and alkali earth elements. It is thus, concluded that the salinisation of soils and groundwaters from the Khanapur Plateau has been resulted due to semi-arid climate and base elements of both basalts 'red beds' sediments.

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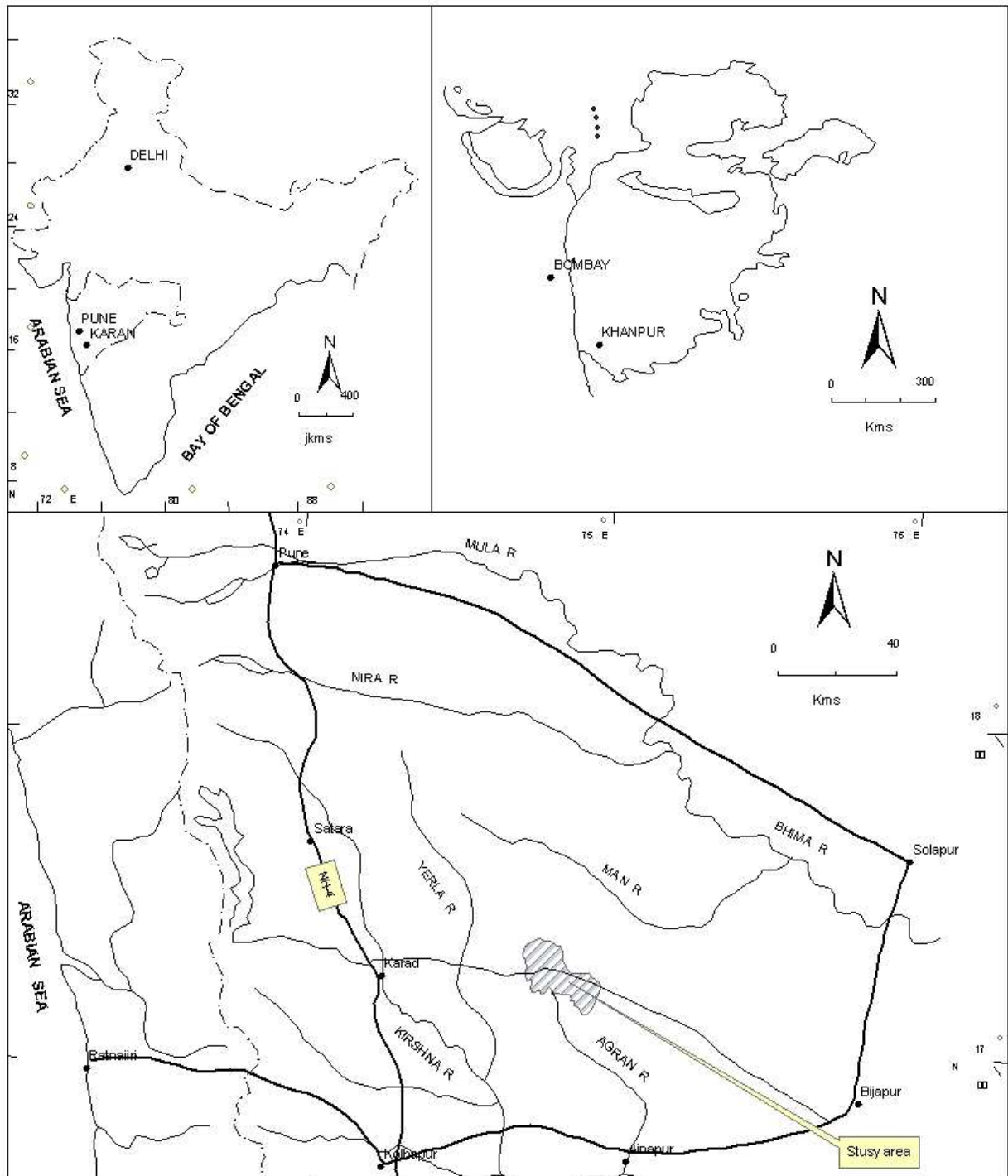


Fig (1) location map of the Khanapur Plateau

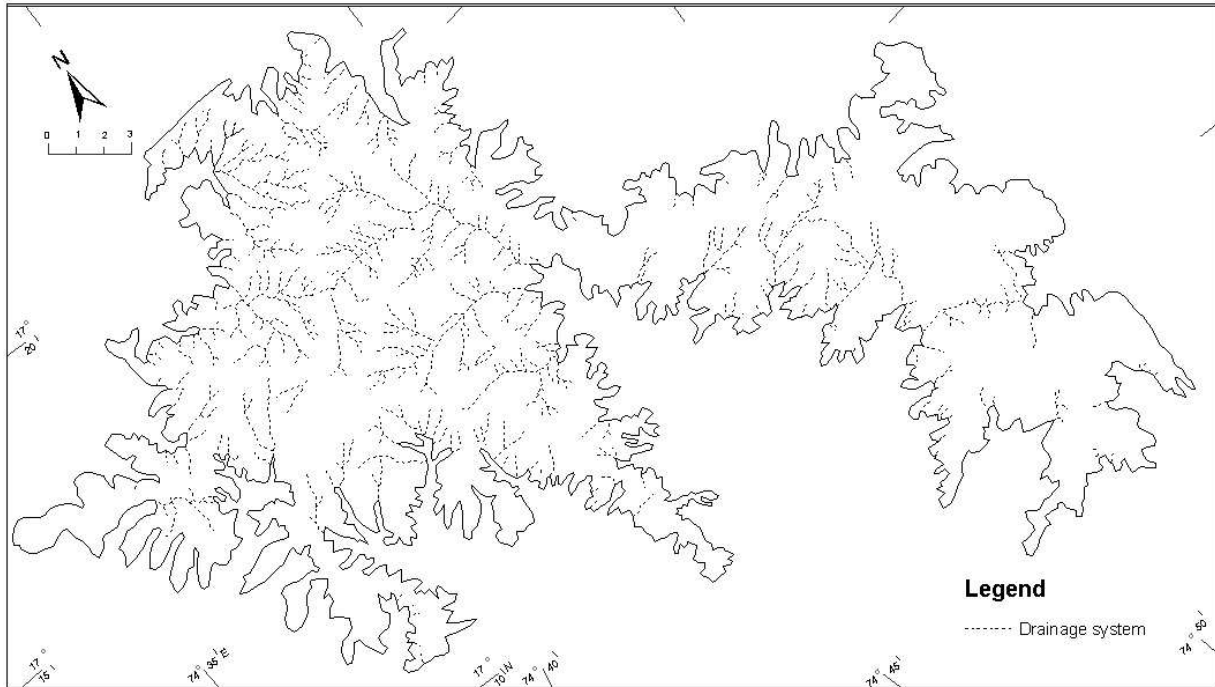


Fig. (2): Drainage map of the Khanapur Plateau

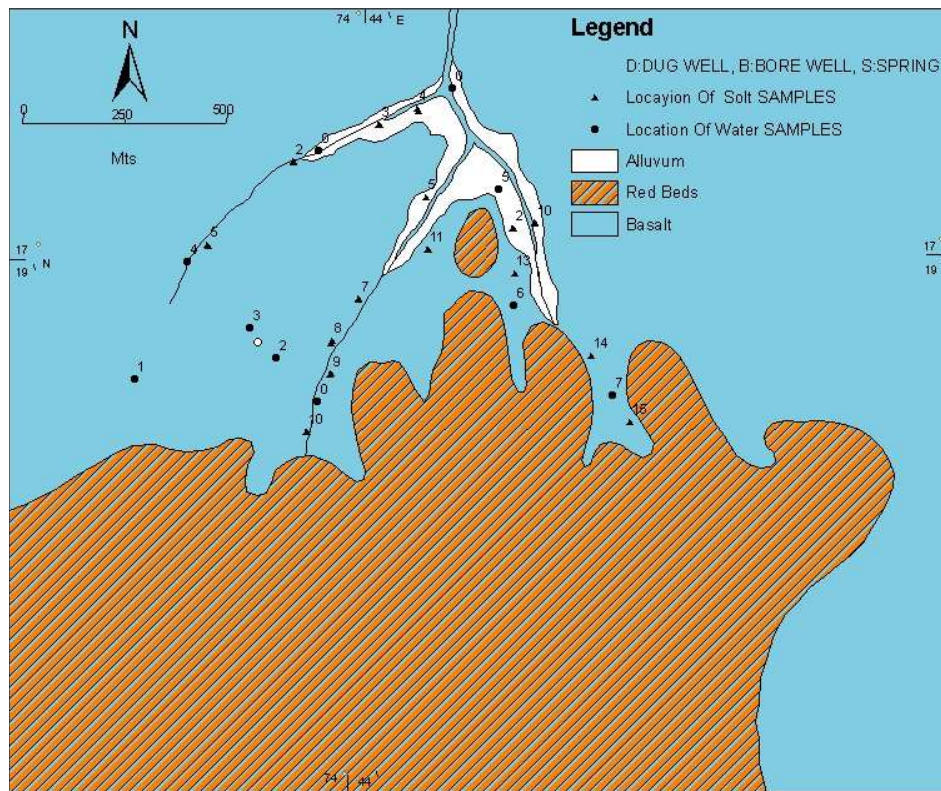


Fig. (3): Location map of ground water and evaporate samples

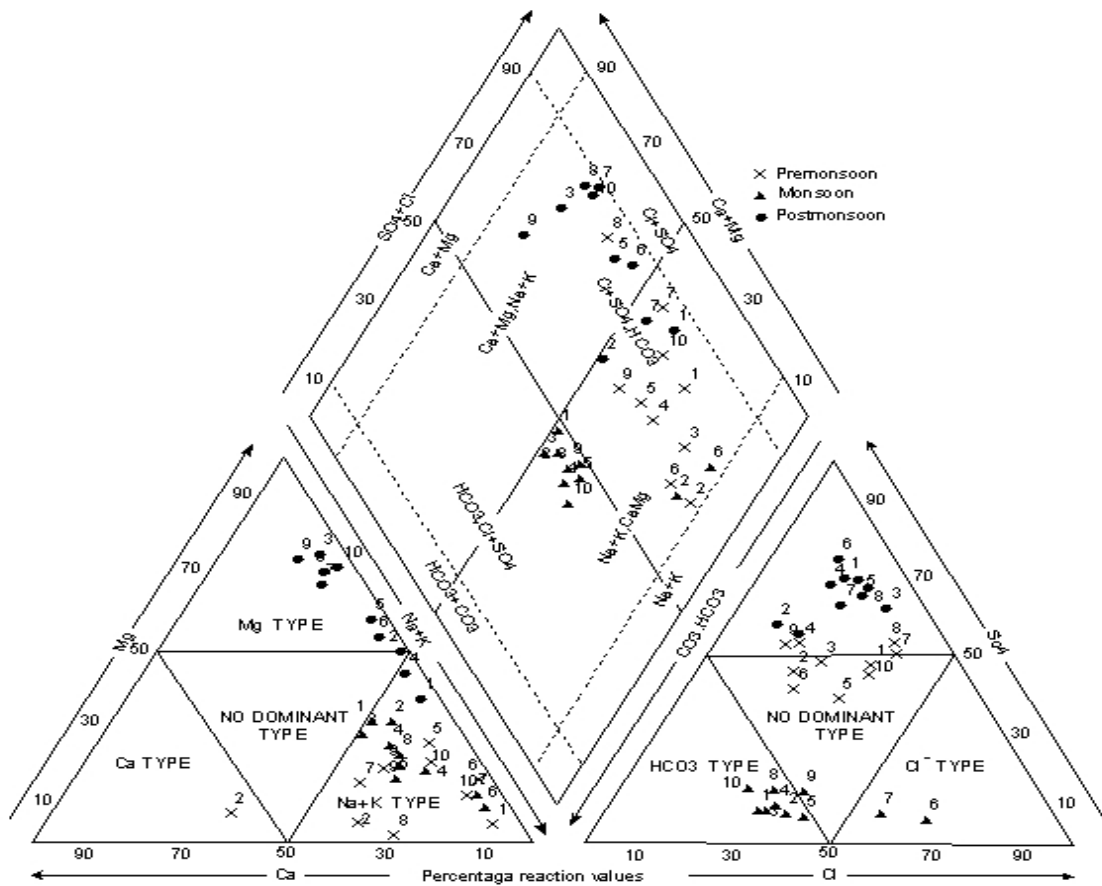


Fig.(4): Trilinear diagram showing hydrochemical facies of ground water from Menganwadi area (after piper, 1953)

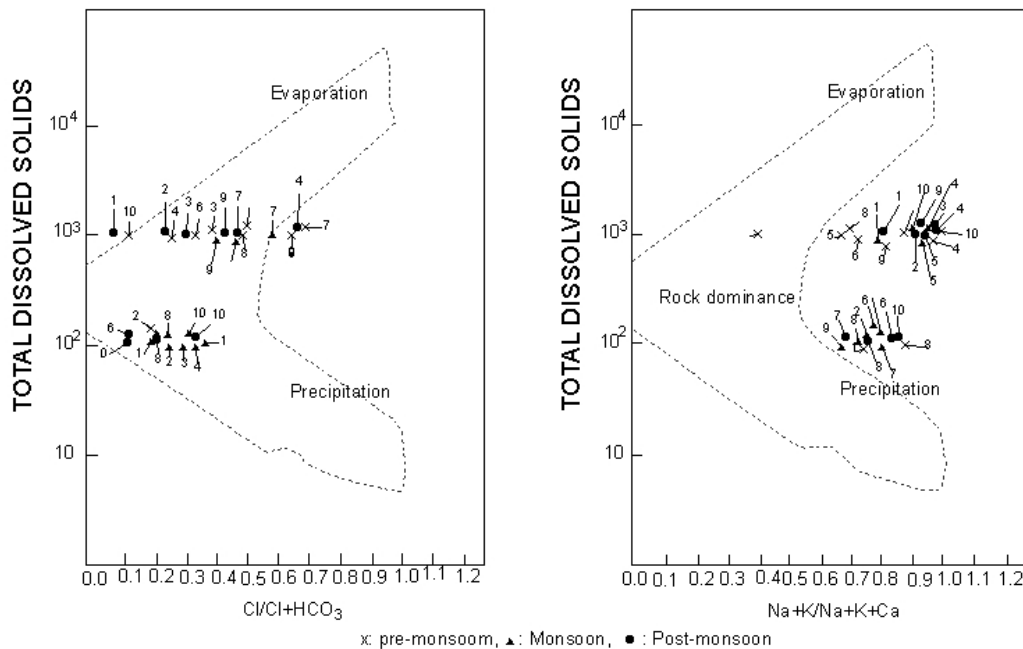


Fig (5): Gibbs diagram for the ground water from the Menganwadi area

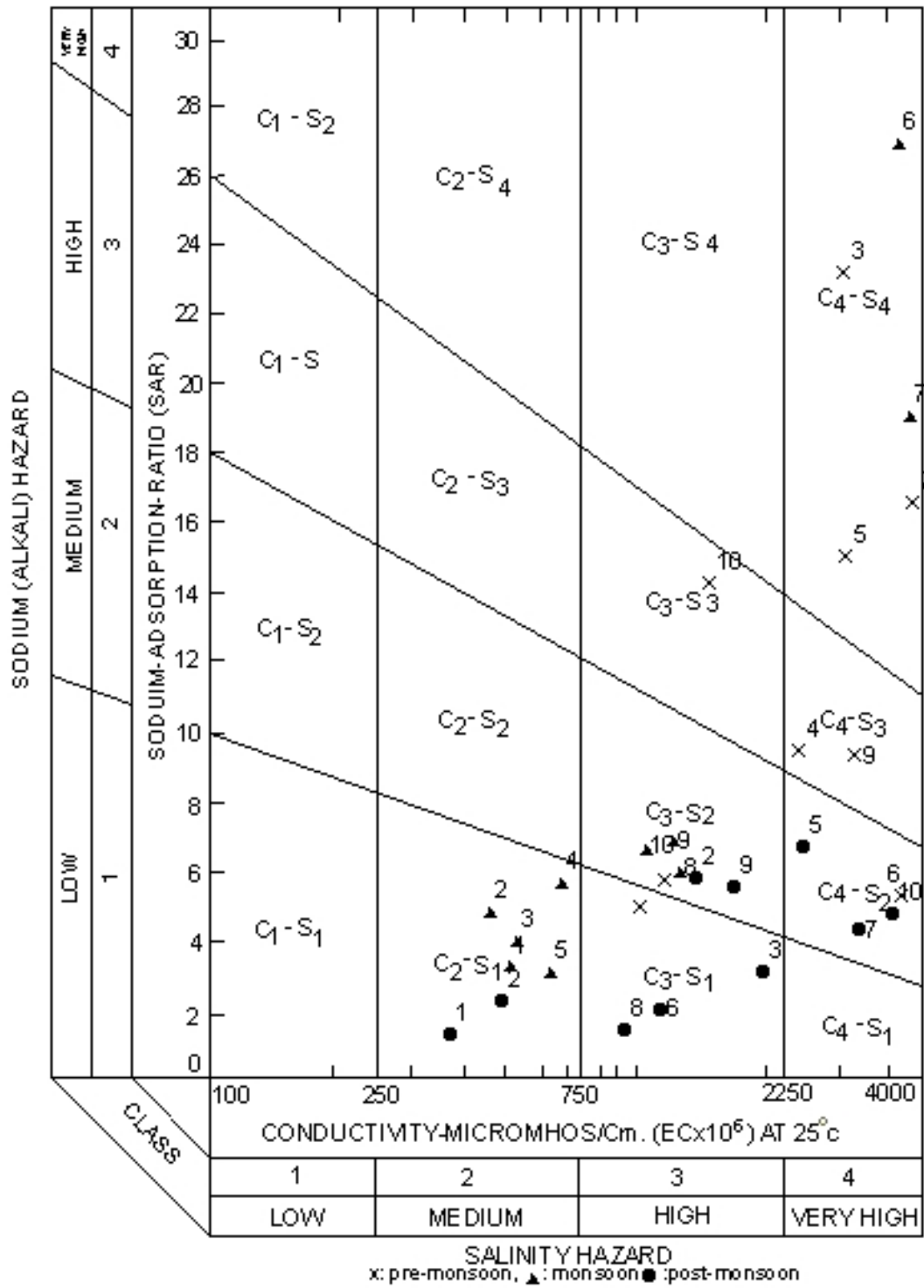


Fig (6): Relationship between SAR & EC for the ground water

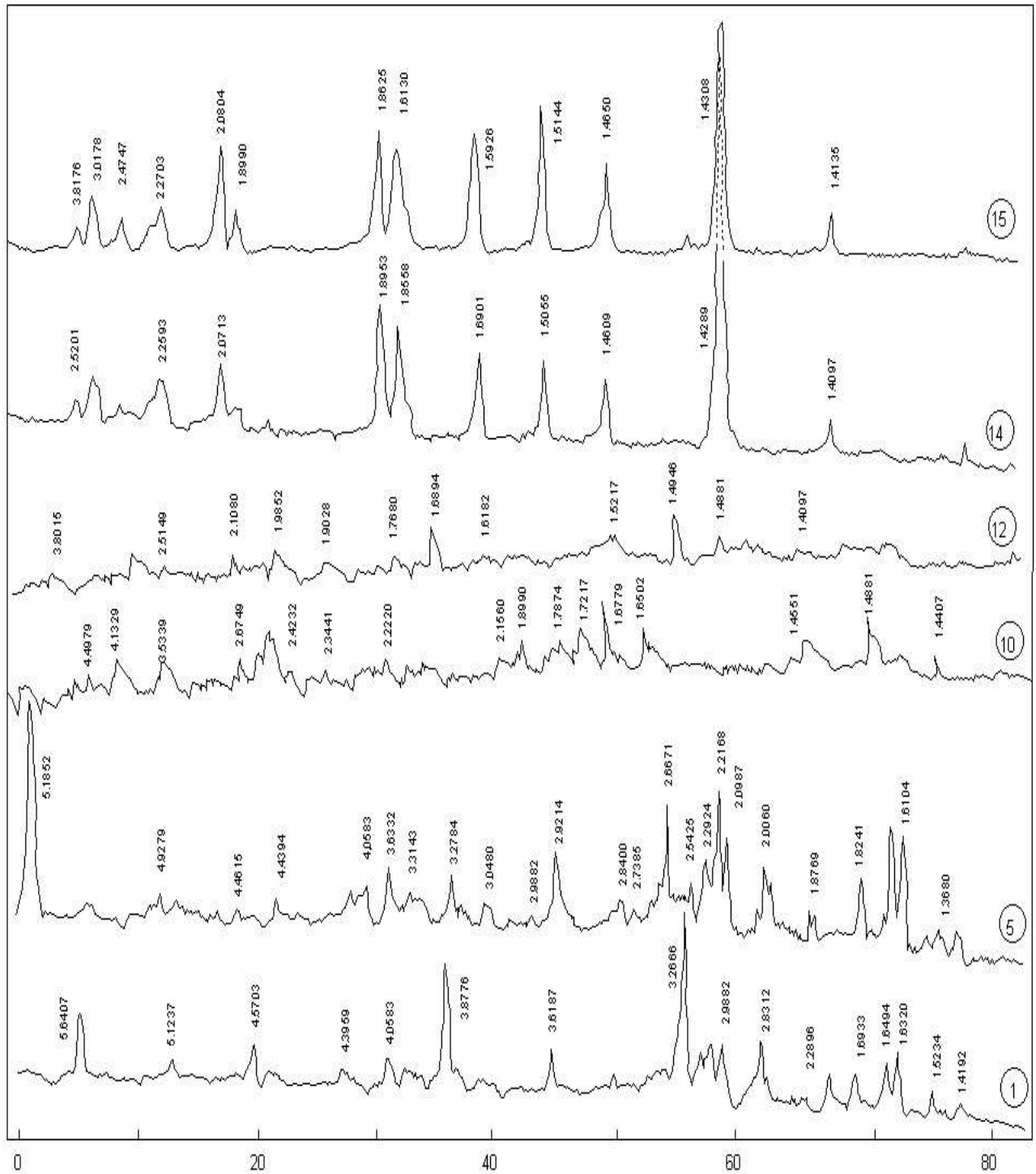


Fig (7); X-ray diffractograms for the salt (evaporate) samples from the Menganwadi area

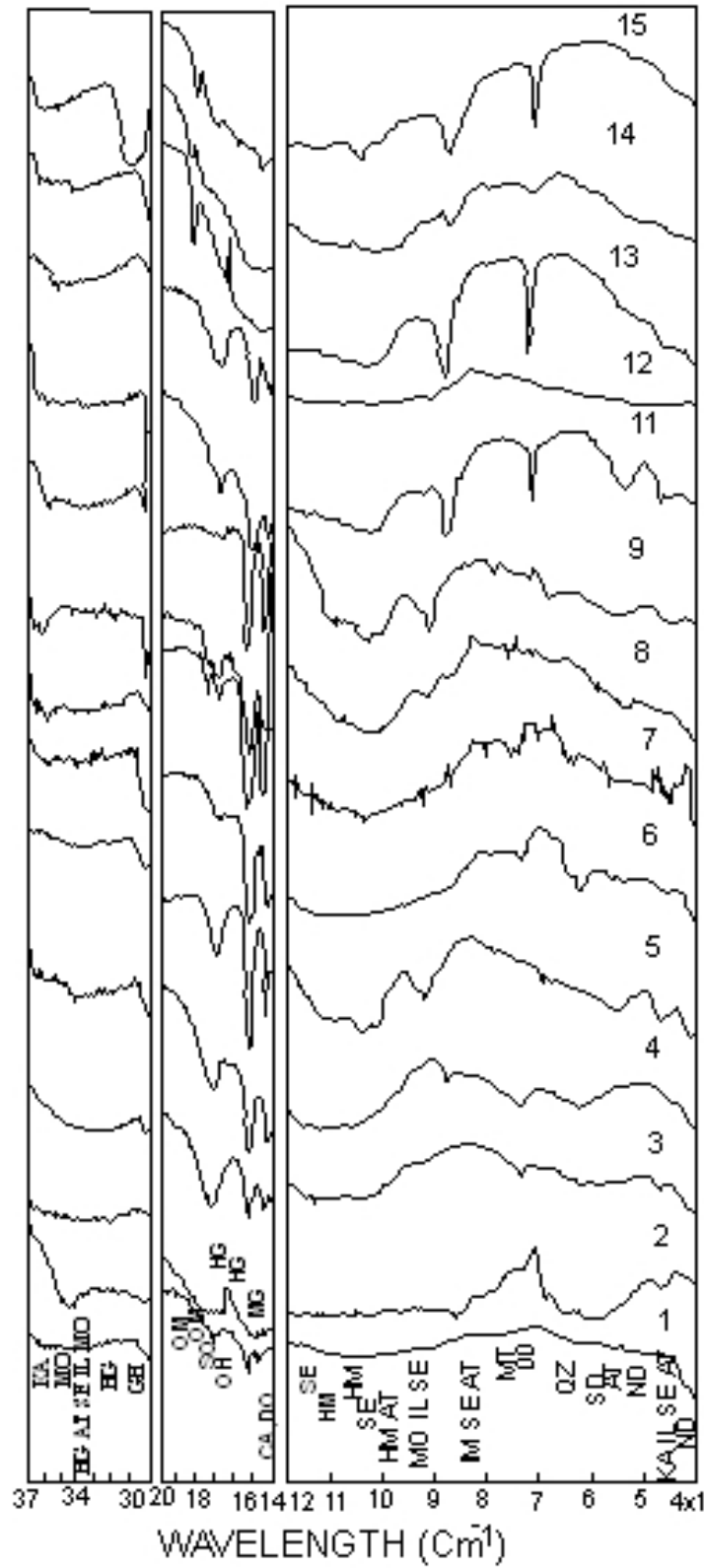


Fig (8) IR spectra for the salt (evaporate) samples from Menganwadi area

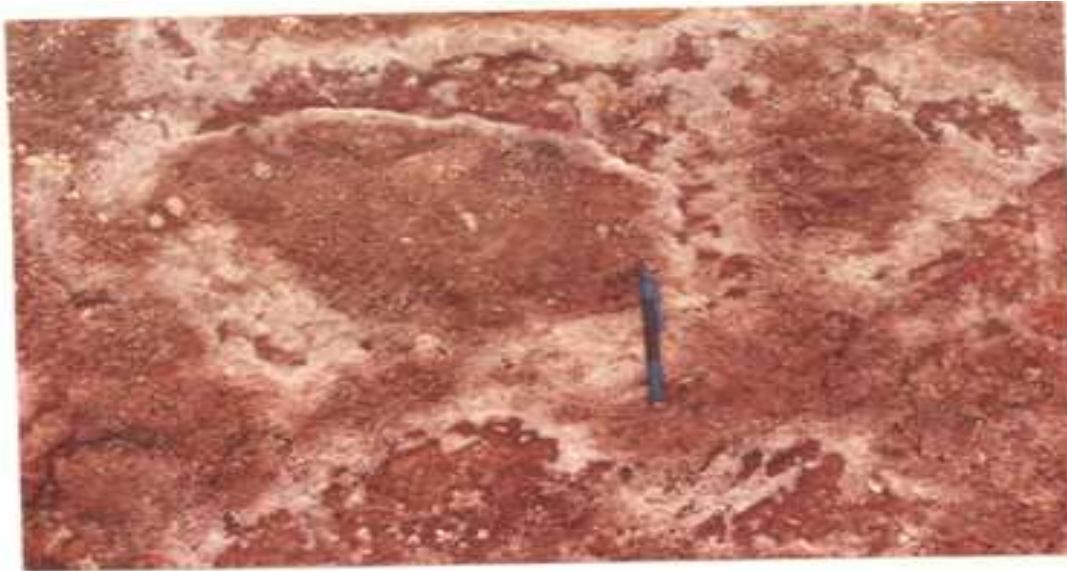


Photo 1: Thin layer of salt encrustation, Menganwadi village.

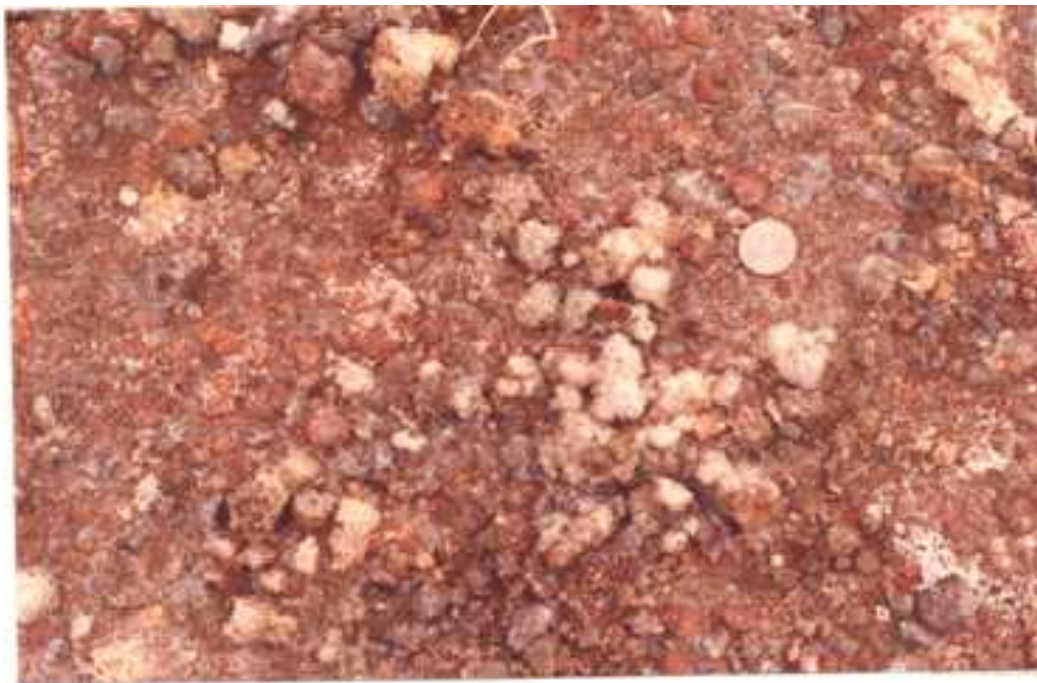


Photo 2: Accumulation of salts on soil surface, showing spheroidal form, Menganwadi village.

Table 1: Geochemical Characteristics of the Groundwaters from the pre-monsoon (Figures in bold), monsoon Figures in parenthesis) and post-monsoon seasons from the Menganwadi 'red beds' area, Khanapur Plateau.

Sr.No	pH	TC	EC	TA	TH	Cl-	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	SO ₄ ²⁻	Si ⁴⁺	TDS
B-1	8	30	3000	785	231	274	35	35	2	800	770	48	1950
	-8	-24	-520	-550	-355	-265	-55	-53	-1	-165	-50	-42	-338
	6	23	1550	715	881	54	10	208	1	400	1029	9	1008
B-2	8	29	1550	410	265	214	34	44	7	525	525	52	1008

	-8	-23	-520	-530	-294	-230	-79	-24	-1	-165	-50	-66	-338
	7	21	1200	450	2058	225	37	478	8	220	1450	7	780
D-1	8	29	5000	780	1159	824	453	7	6	1300	1475	29	3250
	-8	-24	-560	-600	-347	-201	-60	-48	-1	-170	-50	-60	-364
	6	21	1770	400	1078	180	38	239	4	750	1813	9	1105
D-2	8	35	9750	495	2004	1078	484	193	2	1200	1930	34	6338
	-8	-22	-470	-519	-253	-201	-42	-36	0	-172	-50	-60	-306
	6	24	5000	600	2025	1274	204	1375	2	880	5000	8	3250
D-3	8	31	6250	335	2117	692	749	60	1	525	1360	46	4063
	-7	-22	-690	-650	-304	-305	-71	-31	-1	-235	-25	-62	-449
	7	25	4250	650	6173	761	172	1315	2	740	4300	11	2763
D-4	8	31	8000	795	1538	826	523	56	10	1150	1450	28	5200
	-9	-21	-7300	-1282	-415	-1861	-91	-46	0	-1249	-160	-42	-475
	7	23	3500	600	1893	601	35	1200	7	730	4250	9	2275
D-5	7	30	2500	600	321	84	87	25	2	400	515	32	1625
	-9	-22	-5300	-1232	-397	-1171	-75	-51	-1	-904	-205	-42	-3445
	7	22	500	560	3623	66	49	126	1	150	300	11	325
S-1	8	30	4000	600	549	199	79	86	2	575	850	43	2600
	-8	-23	-1390	-898	-513	-312	-95	-67	0	-340	-156	-62	-904
	6	22	1850	520	1556	170	21	365	8	800	1870	10	1203
S-2	8	29	3250	520	616	338	47	121	2	500	515	63	2113
	-8	-23	-1380	-789	-453	-341	-96	-52	0	-312	-156	-60	-897
	7	21	1700	485	1935	400	24	455	1	550	2250	10	1105
S-3	8	30	3125	625	311	224	12	68	14	600	555	33	2203
	-8	-24	-1440	-822	-398	-227	-84	-46	0	-322	-150	-50	-936
	6	24	2500	580	311	223	29	474	3	729	3400	10	1625

Note: TDS: TOTAL DISSOLVED SOLIDS; EC: ELECTRICAL CONDUCTIVITY IN $\mu\text{mhos}/\text{cm}^{-1}$, TA: TOTAL ALKALINITY; TH: TOTAL HARDNESS

Table 2: Langelir Index (LI) and pCO_2 values of the groundwaters for the pre-monsoon (figures in bold), monsoon (figures in parenthesis) and post-monsoon seasons, from the Menganwadi 'red beds' area, Khanapur plateau.

Sample No.	LI values	pCO_2
B-1	0.3901	-1.7760
	(0.5622)	(-1.9602)
	-1.4877	-0.5589
B-2	0.4809	-2.4016
	0.8880	(-2.1732)
	-0.8549	-1.0886
D-1	1.3607	-1.8158
	(0.5703)	(-1.8548)
	0.0024	-2.0851
D-2	1.4634	-2.2689
	(0.6058)	(-2.1973)
	-0.5210	-0.7315
D-3	1.2289	-2.1458
	(0.3054)	(-1.4800)

	-0.1353	-1.0953
D-4	1.6296	-2.0054
	(1.7276)	(-2.5893)
	-1.0512	-0.9167
D-5	0.4420	-1.5670
	1.9882	(-3.1058)
	-0.1325	-1.2481
S-1	0.6066	-1.8903
	(1.5350)	(-2.0303)
	-0.8549	-1.0886
S-2	0.4421	-2.0266
	(1.2670)	(-2.2442)
	-1.0866	-1.0588
S-3	-0.0842	-1.9105
	(1.4764)	(-2.4775)
	-1.5116	-0.4841

Table 3: Molar ratios of the groundwater for the pre-monsoon (Figures in bold), monsoon (Figures in parenthesis) and post-monsoon seasons from the Menganwadi red beds area, Khanapur plateau.

Sample No.	Na/(Ca+Mg)	Ca/Mg	Na/Cl	Ca/Ca	Cl/HCO ₃	Cl/SO ₄	Mg/Cl	SAR
B-1	7.459	0.618	4.502	19.773	0.601	0.482	0.369	22.93
	(1.013)	(0.62)	(0.98)	(2.64)	(0.82)	(7.05)	(0.60)	(3.81)
	0.990	0.028	11.45	36.25	0.13	0.07	11.26	5.87
B-2	4.318	0.465	3.788	13.595	0.897	0.552	0.599	14.04
	(1.223)	(2.01)	(1.20)	(1.83)	(0.69)	(5.68)	(0.33)	(4.19)
	0.233	0.047	1.51	5.20	0.86	0.21	6.19	2.11
D-1	2.442	40.357	2.434	2.502	1.818	0.757	0.024	16.62
	(1.066)	(0.77)	(1.30)	(2.45)	(0.58)	(5.45)	(0.69)	(3.97)
	0.096	0.096	6.41	17.36	0.78	0.14	3.86	9.96
D-2	1.304	1.522	1.717	2.161	3.749	0.757	0.522	11.67
	(1.481)	(0.70)	(1.32)	(3.60)	(0.67)	(5.46)	(0.52)	(4.71)
	0.310	0.090	1.07	3.75	3.66	0.35	3.15	4.87
D-3	0.540	7.578	1.171	0.611	3.554	0.689	0.253	4.97
	(0.540)	(7.578)	(1.171)	(0.611)	(3.554)	(0.689)	(0.253)	(4.97)
	0.276	0.800	1.50	3.74	2.02	0.24	5.04	4.21
D-4	1.628	5.666	2.147	1.916	1.788	0.772	0.198	12.76
	(6.562)	(1.21)	(1.04)	(11.99)	(2.50)	(15.76)	(0.07)	(26.69)
	0.320	0.018	1.88	18.05	1.72	0.19	5.83	4.48
D-5	2.719	2.127	7.373	3.991	0.240	0.220	0.864	9.72
	(4.965)	(0.90)	(1.19)	(10.49)	(1.64)	(7.74)	(0.13)	(19.75)
	0.510	0.235	3.51	2.67	0.20	0.30	5.58	2.58
S-1	2.674	0.556	4.458	6.380	0.571	0.317	1.257	10.68
	(1.444)	(0.86)	(1.68)	(3.13)	(0.61)	(2.71)	(0.63)	(6.52)
	1.120	0.035	7.25	33.46	0.56	0.12	6.26	8.83
S-2	1.768	0.237	2.282	9.216	1.119	0.889	1.043	8.77
	(1.101)	(1.12)	(1.41)	(2.85)	(0.74)	(2.96)	(0.45)	(6.38)
	0.620	0.032	2.12	19.94	1.42	0.24	3.32	5.44
S-3	4.203	0.107	4.136	43.500	0.616	0.546	0.889	14.81
	(1.765)	(1.12)	(2.19)	(3.34)	(0.48)	(2.06)	(0.59)	(7.03)
	0.784	0.037	5.04	22.02	0.66	0.09	6.21	7.05

Note: B1 & B2: deeper basaltic aquifer, D1 to D5: shallow basaltic aquifer, S1 to S3 'red beds' aquifer.

Table 4: Chemical data (weight percentage) for salt encrustations from Menganwadi area, Khanapur plateau

OXIDES	1	2	3	4	5	6	7	8	9	11	12	13	14	15
SiO ₂	5.70	11.37	4.18	7.59	3.31	9.14	8.42	24.15	11.49	17.17	17.17	6.99	9.31	5.72
Al ₂ O ₃	6.77	7.51	7.81	6.59	5.27	9.48	10.89	10.23	11.59	10.96	13.18	14.82	13.94	18.15
Fe ₂ O ₃	0.66	1.79	0.62	0.57	0.41	0.36	0.85	1.32	1.26	0.50	1.27	0.60	0.77	0.59
TiO ₂	0.37	3.23	2.38	2.14	2.12	3.61	1.61	1.59	2.11	1.50	3.98	1.71	1.63	2.08
FeO	7.38	8.37	10.44	9.89	12.49	5.58	7.19	8.49	7.43	2.44	7.30	7.25	8.69	5.80
MgO	2.77	5.39	0.46	8.59	4.13	13.74	14.30	14.15	16.35	5.76	18.39	15.66	8.27	3.06
CaO	42.01	43.88	45.20	43.09	30.73	38.20	50.21	32.81	31.54	39.37	17.68	46.57	44.36	56.58
Na ₂ O	0.01	0.03	0.02	0.02	0.01	0.33	0.03	0.02	0.03	0.36	0.03	0.55	0.52	0.70
K ₂ O	0.28	0.54	0.22	0.34	0.11	0.84	0.60	0.54	0.76	0.22	0.74	0.35	0.22	0.30
P ₂ O ₅	0.005	0.82	0.028	0.008	0.004	0.005	0.07	0.08	0.018	0.005	0.027	0.008	0.007	0.01
MnO ₂	0.06	0.19	0.054	0.09	0.045	0.11	0.20	0.31	0.24	0.65	0.23	0.18	0.12	0.54
Cl	2.76	2.014	0.67	0.77	0.56	3.05	0.31	0.10	0.80	0.075	1.54	0.18	0.07	0.08
SO ₄	0.31	0.17	0.071	0.33	0.40	0.23	0.34	0.017	0.019	0.007	0.12	0.05	0.004	0.01
NO ₃	0.001	0.001	0.001	0.001	ND	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.005	0.01
H ₂ O*	30.92	16.48	27.60	28.97	40.74	15.30	4.77	6.19	17.08	20.98	17.80	5.08	11.96	8.39
Total	100.01	101.80	99.75	100.00	100.33	99.98	99.90	99.99	99.99	99.99	99.99	99.99	100.2	100.01

Note: Sample No's 1 to 14: salt encrustations, Sample No 15: calcrete.