INTRODUCTION

'Water underground is more precious than even precious metals and minerals and requires to be systematically explored. Water is a 'crop', a resource to be cultivated, nurtured, stored and harvested over long periods of time.

Water is fundamental to all life and is one of the most valuable resources for mankind. Man has long depended on it for many purposes such as drinking, transportation, sanitation, defence, irrigation, industrial processes and generation of electricity. In recent years new uses of water have been recognized. They include ecological, recreational, low and high temperature geothermal energy etc. etc., and it is slated to play an increasing and important role in all the regions around the world.

The continuing growth and concentration of population and industry in urban and suburban areas in recent years has caused many problems. The concentration of large number of people results in increased demand for water which sometimes exceed locally available quantum. Many industries/factories and bulk consumers who normally depended upon municipal supplies are now resorting to manage their requirements from alternate sources. They have come to rely on groundwater which they can independently tap.
The availability of groundwater is dependent on climate, geomorphology and geological conditions of a region. For example, the alluvial formations of Ganga-Brahmaputra rivers in Northern India yield large quantity of water because of their high porosity and permeability. In the hard rock terrains of South India, the availability of groundwater is low. This is because of their hard and compact nature and the availability of groundwater is mainly due to their secondary porosity.

The quality of water is an important criterion to be considered for different uses. It is controlled by the natural environment as well as man made factors. Normally the river water and groundwater are pure. But man made factors such as discharging of inadequately treated waste water into a stream, lake or reservoir can add pollutants rendering the surface water as well as groundwater unusable. Contamination of groundwater also can occur in urban areas where wells are close to the ill-maintained sanitary systems. Water underground also becomes contaminated if a well is carelessly built or the casing has corroded (Chow, 1964). Thus, both quantity and quality are the basic considerations of water resources and their supply mechanisms.

Keeping these views in mind, the author has selected a typical municipal area viz; Hubli-Dharwad Municipal Corporation (HDMC) area, Dharwad District, Karnataka State, India, for the present study.
1. STUDY AREA

Hubli-Dharwad cities were originated in the 10th Century A.D. The HDMC began functioning in the year 1962. The present HDMC area lies between 15° 18' 25" - 15° 30' 47" North latitudes and 74° 57' 37" - 75° 11' 0" East longitudes included in Survey of India toposheet nos. 48 M/3 and 48 1/15 (Fig.1). The areal extent of the area is about 180 Square Kilometers. Next to Bangalore, the HDMC is the second largest municipal corporation in Karnataka State. This includes two urban areas viz; Hubli and Dharwad, which are situated 20 Kilometers apart. These two urban areas are surrounded by Suburbs/Villages. The total population is 6,47,780 (1991 Census). The National High Way No. 4 passing through this corporation connects Poona-Bangalore cities. The South Central Railway line links it with Bangalore on one side, Miraj and Vasco on otherside. The area is well connected with surrounding Suburbs/Villages by all season motorable roads. All basic needs like post, telegraph, radio and television services are available.

Presently, because of rapid urbanization the area is experiencing scarcity of potable water. Till 1957 Dharwad was receiving water supply from Keligeri tank at the rate of 6 gallons per capita per day (gpcd) while Hubli from Unkal tank at the rate of 8 gpcd. These two surface water bodies are within the corporation area.
With the fast growth of Hubli and Dharwad, these two sources were found to be inadequate to cope up with the demand. In the year 1955, the water supply from Neerasagar (20 Kms from the study area) was started and in the year 1983, the water supply from Malaprabha reservoir (50 Kms from the study area) was started. At present the municipal water supply is from Neerasagar (9 million gallons per day) and from Malaprabha reservoir (7.5 million gallons per day). This water supply is on alternate days. The per capita consumption accounts for 25 gpcd. Apart from surface water supply, the public is provided water from 569 hand pump borewells and 83 power pump wells (data till July 1991) which are also managed by Corporation authorities. Nevertheless, Corporation authorities are unable to meet the actual demand.

The author's spot interviews conducted during the field work with aged people has revealed that there was no scarcity of water during 1950s and 1960s and the groundwater quality was fairly good.

2. SCOPE OF THE PRESENT WORK

Hubli-Dharwad region has been studied earlier by a limited number of workers. Gokhale (1954), Gundu Rao (1954), Tatte (1960) and Gokhale et al (1980) have studied the geology. Karennavar (1967) and Mudbidri (1980) have described the history and development of
Hubli-Dharwad Municipal Corporation area. There is very little information about the hydrogeological conditions. Wodeyar et al (1985) have described the hydrochemistry around Yettinagudda and Narendra. The hydrogeological works carried out by Department of Mines and Geology and Public Health Engineering Department, Dharwad are not published in the form of reports or interpreted to know the hydrogeological conditions.

The rapid urbanization and inflation in population from 2,87,000 (1961 Census) to 6,47,780 (1991 Census) has increased the demand of potable water. This has given rise to private and public bore wells. The groundwater quality in a few open and bore wells is poor or unpotable. Such poor quality groundwater is also being used, due to the scarcity of good quality water.

Based on the above observations, the author has made an attempt to study the groundwater conditions of occurrence, distribution and quality in the study area.

The general features of the study area are studied by its topography, soil, vegetation, geomorphology, geology and hydro-meteorological conditions. The hydrogeological conditions are understood by well inventory, analysis of borewell data, estimation of aquifer parameters, groundwater exploration and groundwater recharge estimation studies. The quality of groundwaters is evaluated.
to know their suitability for various uses and to understand the factors controlling their chemistry. An attempt has been made to find a relation between land use pattern and quality of ground-water in the study area. The results of the work are discussed and some suggestions are made in the last chapter for future planning/management and proper supply of potable water.

In the next sections of this chapter the author describes the topography, soils, vegetation, geomorphology, geology and hydrometeorological characters of the study area.

3. TOPOGRAPHY, SOIL AND VEGETATION

The study area has an undulating topography (Fig.2) with a highest elevation of 740 meters (MSL) and a lowest of 600 meters (MSL). It experiences semi-arid climate with hot summers and cold winters. The average annual rainfall is 760 mm, most of which is from South-West monsoon between June and September.

There are mainly two types of soils viz; red soil and black soil. Their distribution pattern is studied with the help of both satellite imagery and field survey and is presented in Fig.3. The vertical section of red soil (Fig.4) shows about 2.0 meters thick reddish-brown sandy soil occupied on soft weathered shale. The vertical section of black soil (Fig.5) shows about one meter
thick black soil at the top underlain by a reddish yellow kankary shale. The thickness of both red soil and black soil, however, varies from place to place.

The vegetation in the study area are of two types viz; natural and afforested. The uplands are afforested by eucaliptus, acacia and mixed species. The foothills and the areas of low gradient are covered by neem, mango, gauva, tamarind, pongam etc. Coconut trees are commonly found in the residential areas (Fig.6).

4. GEOMORPHOLOGY AND GEOLOGY

The study area forms a contact zone between Western Ghat hillocks (Fig.7) and the eastern plains (Fig.8). The western and north-western parts of the study area are covered by erosional type hillocks. The foot hills are covered by a thick layer of soil which is a pediment zone. The northern and north-eastern parts are covered by comparatively a thick layer of soil, which is a pediplain area. The pediplain extends for a vast area towards north and north east.

Three landform/topographic profiles (AB and CD parallel to each other in NW-SE direction, and EF in nearly EW direction)
are drawn (Fig.2). The profiles are shown in Fig.9. The profile AB indicates small hillock/mounds in north western and south eastern parts. The profile CD shows a gentle slope which correspond to pediplain. The profile EF shows undulating pattern indicating the presence of hills, pediment and pediplain from west to east.

The study area does not form any drainage basin, rather forms almost a water divide, especially in the north western part (Fig.2). The streams on the west join the westerly flowing rivers and the streams on the east and north east join the easterly flowing rivers. This can be clearly seen on the Satellite imagery (Fig.10). The only stream "Bedti" originates near Tadasinkop village (West of Dharwad city) in the study area and flows towards Hubli, in SE direction. It forms a third order stream and ephemeral in nature. After passing through Hubli city the stream takes a diversion and flows towards west.

Geologically, the study area forms a small part of Shimoga basin belonging to the Younger Greenstones (Dharwars), (Fig.11) of Pre-Cambrian age (Radhakrishna, 1982). The Shimoga greenstone belt has been studied by numerous workers. The geology of Hubli-Dharwad region has been studied by a few workers viz; Gokhale (1954), Gundu Rao (1954), Tatte (1960) and Gokhale et al (1980).

Gokhale (1954) has studied the geology of Dharwad district, in

In the present investigations, the author has carried out a detailed geological mapping to know the general and structural characters of the rocks. The structural characters play a significant role in the occurrence, conditions and distribution of groundwater. The different rock types encountered are viz; shales and argillites, phyllites, banded iron formations, basic dykes and numerous acidic veins (Fig.12).

Shales and Argillites:

These rocks are exposed extensively throughout the study area and could be studied in details along railway and road cuttings. They display different colours viz; shades of yellow, red, pink and purple and some varieties are white. The shales and argillites are not mapped separately. The distinction can be made on the basis of their physical characters. The shales are soft, silty, slightly micaceous, fissile and tend to break along the bedding planes. The argillites are hard, non laminated and break with conchooidal fractures (Fig.13 and 14). It is difficult
to identify the mineral constituents of these rocks in hand specimen. The texture of these rocks can be best defined as shaly. The thin section study of these reveal the presence of quartz, feldspar as common minerals and zircon, epidote, tourmaline, biotite, hematite, magnetite, ilmenite and pyrite as accessory minerals.

Phyllites:

Small occurrences of phyllites are exposed in the eastern part of the study area viz; near Someshwar temple and Mansur village. At both the places extensive quarrying is being carried out exposing the lithounits. These rocks are darker in shades and have lustrous shine and very good cleavage. They are well jointed (Fig.15) and break into thin slabs and therefore extensively used in road metalling. Tatte (1960) has called these phyllites as slatty phyllites. Because of fine grained nature of these rocks, no minerals could be identified in hand specimen. Thin section study of these phyllites reveal the presence of quartz, feldspar, chlorite, calcite as common minerals and zircon, biotite, epidote, apatite, sphene, muscovite, sericite, pyrite and iron ores as accessory constituents.

Banded iron formations:

These rocks are conspicuous by their occurrence in the form
of longitudinal ridges occupying the elevated portions of the study area (Fig.16). The rocks occur in the form of bands, the widths of which vary from about 3 meters to 300 meters. The individual rock exposures exhibit alternate bands of silica and iron minerals. These bands vary in width, from a few centimeters to several centimeters (Fig.17). They run parallel to each other and quite often merge into one another. These rocks are steel gray, brown or sometimes black in colour; hard and compact in nature, break with irregular fractures. The study of these rocks under microscope shows the presence of quartz and hematite minerals.

Basic Intrusions :

There are three basic dykes cutting across the phyllite at Someshwar, near Dharwad. Gokhale et al (1980) have described these basic dykes as olivine dolerite, dolerite and vitrophyric basalt dykes.

Quartz veins :

All the rock types in the area are cut across by numerous quartz veins. Hard and resistant quartz veins remained after reaching of ferruginous material is clearly seen in shales. Thin and thick veins of quartz crossing in different directions are observed in phyllites (Fig.18).
Structural Characters:

All the principle three rock types viz; shales/agrillites, phyllites and banded iron formations trend in NNW-SSE direction with moderate to high angle easterly dip. This is general attitude of Dharwarian rocks. These rocks have undergone repeated structural deformation producing folds, refolded folds, fractures, joints and fissures in them. Several traverses taken by the author in the dip direction reveal the repetition of shales and banded iron formations. This repetition of beds and unidirectional dip indicates the presence of folded structure. Such a folded structure can be interpreted as isoclinal fold. The general axis of the folds trend NNW-SSE direction. The limbs of the folds have been refolded exhibiting different types of folds. In this process of primary folding, secondary folding and refolding, the limbs of folds have resulted in numerous major and minor faults, various sets of joints and different types of folds (Fig.19 and 20).

5. HYDROMETEOROLOGY

Hydrometeorology deals with all phases of water on earth and is an important subject for agriculture, flood control, irrigation, drainage, river navigation, hydropower generation, management of water resources and linking of river basins. The hydrometeorological parameters include precipitation, temperature, relative
humidity, wind velocity and evapotranspiration.

The temperature, relative humidity, wind velocity and evaporation data of 10 years (1981 - 1990) have been obtained from the Regional Research Station, U.A.S. campus, Dharwad. The rainfall data of 32 years (1959 - 1990) for 4 rain gauge stations of the study area has been collected from District Statistical Office, Dharwad, for the present study.

Temperature:

The main source of atmospheric temperature is sun and the general level of temperature is determined from the radiation balance. The temperature varies from place to place, mainly with geographical conditions. It is one of the factors which affect evaporation and transpiration. An increase in the temperature of the surrounding air will also increase the aqueous vapour pressure of both air and water.

In the study area, the temperature attains a maximum value of 37°C during April and a minimum value of 14°C during December (Table.1).

Relative humidity:

It is the percentage ratio of the actual vapour pressure to the saturation vapour pressure at the observed temperature.
The relative humidity affects precipitation and transpiration. When air humidity is low, the precipitation will naturally be low unless large moisture quantities are influxed.

The relative humidity in the study area ranges between 65% (April) and 89.3% (August) (Table.1).

Evaporation:

It is a process by which water precipitation on the earth's surface is returned to the atmosphere by vapourisation and is expressed as mm/day. The rate of evaporation depends upon several factors such as barometric pressure, air and water temperatures, sunshine, wind velocity, dryness of air and purity of water. The process by which water is evaporated from wet surfaces and transpired by plants is called evapotranspiration.

The evaporation value in the study area varies from 1.82 mm (August) to 8.04 mm (April) (Table.1).

Wind velocity:

The effects of wind velocity are many fold. Hydrometeorological point of view its effect on evaporation and transpiration is important. The effect of wind on evaporation may be more pronounced over large bodies of water than over small areas. Large water bodies may require high velocity and turbulent air
movement for water to evaporate at its maximum rate. The removal of water vapour next to the leaf surface by wind might increase transpiration.

The wind velocity in the study area varies from 6.88 Km/hr (February) to 16.22 Kms/hr (June). (Table 1).

Further the author has drawn a variation diagram (Fig.21) using 10 years (1981 - 1990) monthly average values of temperature (minimum and maximum), humidity, evaporation and wind velocity data to know the relation between them. The Fig. 21 shows a sympathetic relation between maximum temperature and evaporation i.e. when temperature is more evaporation is also more and temperature is less evaporation is also less. A sympathetic relation is found also between wind velocity and humidity. But humidity is antipathetically related with maximum temperature and evaporation. The relation of minimum temperature with other parameters is not significant.

Rainfall:

It is one of the most important meteorological factors. Its intensity and distribution are of great practical importance in groundwater studies, irrigation, agricultural engineering and other disciplines concerned with the use and regulation of water on land.
In the study area rainfall is measured by 5 rain gauges, located at U.A.S. Campus, Civil Hospital, Railway Station, Chitaguppi Hospital and Agricultural Research Station. The data of daily rainfall for 12 years (1979 - 1990) and monthly rainfall of 32 years (1959 - 1990) have been collected from District Statistical Office, Dharwad. The data from Agricultural Research Station is not available regularly and hence the data from this station is not considered for the present study. The data from the other rain gauge stations is analysed under the following heads:

Network design of raingauge
Seasonal variation of rainfall
Distribution of rainfall
Annual variation of rainfall
Average depth of rainfall

Network design of raingauge:

The establishment of raingauges at critical locations in an area gives a clear picture of rainfall distribution pattern. If the area is hilly a greater number of raingauges will have to be established both on rain shadow and opposite side at different altitudes to get the elevation-rainfall correlation. ISI (1968) has recommended the density of raingauge stations should be as follows;
Plain areas 1 for 520 Sq.Kms
Not too elevated areas 1 for 260-390 Sq.Kms
Hilly areas 1 for 130 Sq.Kms.

The optimum number of raingauges is obtained by the equation

\[ N = \left[ \frac{Cv}{P} \right]^2 \]

Where

- \( N \) = Optimum number of raingauges.
- \( Cv \) = Coefficient of variation of the rainfall values of existing raingauges.
- \( P \) = Desired degree of percentage error in the estimate of basin mean rainfall.

The average rainfall (12 years) of each raingauge stations is given below:

<table>
<thead>
<tr>
<th>Raingauge stations</th>
<th>Average rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.A.S. Campus</td>
<td>915.310 mm</td>
</tr>
<tr>
<td>Civil Hospital</td>
<td>845.750 mm</td>
</tr>
<tr>
<td>Railway Station</td>
<td>690.525 mm</td>
</tr>
<tr>
<td>Chitaguppi Hospital</td>
<td>690.700 mm</td>
</tr>
</tbody>
</table>

Average : 785.57 mm
Standard deviation : 113.26
Coefficient of variation \([Cv]\) : 14.41%

Using the above equation and considering the desired
degree of percentage as 10, the optimum number of raingauges is calculated and the N value obtained is 2.076. This means two raingauges are sufficient for the area under consideration. However there are 4 raingauges at present in the study area.

Seasonal variation of rainfall:
Anantha Krishnan and Rajagopalachari (1963) have divided the Calender year into four seasons viz; June to September (South-West monsoon), October to November (North-East monsoon), December to February (Winter) and March to May (Summer). The rainfall in different seasons for 32 years is given in Table 2. From the Table 2 it is seen that maximum rainfall (63.45%) occurs during South-West monsoon period and minimum rainfall (0.98%) occurs during winter. The amount of rainfall during North-East monsoon is 18.65% and during summer 16.91%.

Distribution of rainfall:
An arbitrary classification suggested by Sarma and Narayanaswamy (1982) has been adopted to study the distribution pattern of rainfall over the area under consideration. In this classification coefficient of variation (Cv) of daily rainfall is used and the different classes are as follows; (after Sarma and Narayanaswamy, 1982).
<table>
<thead>
<tr>
<th>Class</th>
<th>Range of Cv value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform distribution</td>
<td>&lt; 0.25</td>
</tr>
<tr>
<td>Normal distribution</td>
<td>0.25 - 0.50</td>
</tr>
<tr>
<td>Medium scatter</td>
<td>0.50 - 0.75</td>
</tr>
<tr>
<td>Heavy scatter</td>
<td>0.75 - 1.00</td>
</tr>
<tr>
<td>Very heavy scatter</td>
<td>&gt; 1.00</td>
</tr>
</tbody>
</table>

The coefficient of variation has been calculated for daily rainfall of 12 years (1979 - 1990) and is expressed in percentage. The Table 3 shows the frequency of each type of distribution. Only 6.54% of daily rainfall is uniformly distributed. Other distribution patterns viz; normal distribution (17.08%), medium scatter (17.65%) and heavy scatter (15.82%) are almost equal and 42.9% daily rainfall is very heavy scattered. The Table 3 also shows that very heavy scatter type distribution occurs throughout the year and the frequency of days showing all types of distribution is more during June to September i.e. during South-West monsoon period.

Annual variation of rainfall:

In order to know the annual variation in rainfall, yearly rainfall of 32 years (1959 - 1990) is considered. The variation diagram of number of years verses rainfall in mm (Fig.22) shows
that the total annual rainfall for 19 years is below normal and for 13 years it is above normal. The year 1979 shows the highest rainfall and the year 1989 shows the lowest rainfall recorded over the area. Coefficient of variation of rainfall calculated for these 32 years shows 21.98% variation, indicating a minimum/normal annual variation in the rainfall.

Average depth of rainfall over area:

The average depth of rainfall over the study area is calculated considering 12 years annual rainfall. The methods adopted are arithmetic mean and isohyetal methods.

\[
\text{Total volume of rainfall} = \text{Area} \times \text{Average rainfall of all the stations}
\]

Using the above equation, the total volume of rainfall is calculated and the value obtained is \(1.4139 \times 10^8 \text{ m}^3\).

The isohyetal map (Fig. 23) is prepared using the rainfall over four raingauge stations and the rainfall volume in each isohyetal area is calculated and summed up to obtain the total volume of the area. The value obtained by this method is \(1.4115 \times 10^8 \text{ m}^3\).

Thus, the rainfall volume calculated by the above two methods are almost equal and average depth of rainfall over study area is found to be \(1.41 \times 10^8 \text{ m}^3\).
6. CONCLUSIONS

The study area forms a part of hard rock terrains of South India. It experiences moderate climate, with an annual rainfall of 760 mm (av.). The soil types are black soil and red soil. The topography is undulating. The study area has a poor drainage pattern and forms almost a water divide.

Hard and compact shales and argillites belonging to Precambrain sequence are the major rock units, followed by minor exposures of phyllites and banded iron formations. All these formations trend in NNW - SSE direction with a moderate to high angle easterly dip. They exhibit various structures like folds, refolded folds, fractures, joints, fissures, etc.

The rainfall distribution varies from uniform type to heavy scatter type. Average depth of rainfall over the area is $1.4 \times 10^8$ m$^3$. 