CHAPTER II
Geology, Soils and Geomorphology

2.1 Introduction

The Archean terrain of south Indian shield happens to be one of the earliest to be studied by geologist of Mysore Geological Department has remained unchanged with time for its accuracy and wealth of geological information Fermor (1936) grouped the Archean province of India for the first time into charnoekitic (high grade) and non-charnoekitic (low grade) terrains. Subsequently, several workers made through investigations on this interesting terrain (Rama Rao, 1940, Pichamuthu, 1947 and 1967, Naqvi et al. 1974, Janardhan and Srikantappa, 1974, Ramakrishnan and Vaidyanadhan, 2008, Radhakrishna and Vasudev, 1977). The idea of Fermor (1936) has blossomed into the recognition of two types of terrains, namely: (a) high-grade granulitic terrain, and (b) Low-grade granite-greenstone terrain in the Archean shield of Indian Peninsula. The South Indian peninsular shield includes (1) High-grade associations (granulites of Tamilnadu and Kerala); (2) Granite greenstone associations (older supracrustals of Sargur type) and (3) craton-basin associations (Dharwar). No other part of the world has these three associations brought together in such a well-knit composite unit affording excellent opportunities for a close study and understanding of different stages in evolution of ancient crust (Radhakrishna, 1983). The study region under study fall in the granite-greenstone terrain (3500-2500 MY) of South Karnataka.

2.1.1 Geology of Karnataka

The State of Karnataka is geographically located from 11° 5' to 18° 5' N latitudes and 74° 0' to 78° 5' E longitude, It is bounded by Maharastra and Goa States in the north and northwest; by the Arabian Sea in the west; Kerala and Tamil Nadu in the south and the Andhra Pradesh in the east (Fig. 2.1). Karnataka extends to about 750 km from north to south and about 400 km from east to west. The highest point in Karnataka is the Mullayanagiri hill in Chikkamagalore district which has an altitude of 1,929 m (6,329 ft) above mean sea level.

The peninsular India shield, of which the Karnataka plateau constitutes an important part, is one of the main Precambrian shield areas of the world. Geologically,
Karnataka state is bounded on the west by the Arabian Sea with stretch of coastal sediments and on the east by the high grade granulitic terrain of Tamilnadu and Andrapradesh. In the north, it is truncated by the Godavari graben and covered by the sediments of late Proterozoic and Deccan traps of Cretaceous- Tertiary age. In south, the boundary is less well defined and is represented by Tamilnadu- Kerala granulitic terrain. There are four main types of geological formations in Karnataka viz

- **The Archean complex made up of Dharwad schists and granitic gneisses:** These cover around 60% of the area of the state and consist of gneisses, granites and charnoekites. Some of the economic and rocks minerals found in this region are dolomite, limestone, gabbro, quartzite, pyroxenite, manganese, iron ores and metabasalt.

- **The Proterozoic non-fossiliferous sedimentary formations of the Kaladgi and Bhima series:** The Kaladgi series has horizontal rocks that run for 160 km in the districts of Belgaum, Raichur, Dharwad and Bijapur districts. The Bhima series that is present on either side of the Bhima River consists of different rocks like sandstone, limestone and shale and these are present in the Gulbarga and Bijapur districts.

- **The Deccan trappean and intertrappean deposits:** This is a part of the Deccan traps which were formed by the accumulation of basaltic lava. This is made up of greyish to black augite-basalt.

- **The tertiary and recent laterites and alluvial deposits:** Laterite capping is found over the Deccan Traps and was formed after the cessation of volcanic activity in the early tertiary period. These are found in many districts in the Deccan plateau and also in the coast (Radhakrishna and Vaidyanadhan, 1997).
2.1.2 Lithology of South Karnataka

Southern part of Indian shield mainly consists of Archean and Proterozoic rocks which forms the Karnataka Craton / Dharwar Craton (Swaminath and Ramakrishnan, 1981), also called Karnataka- Andhra Pradesh Craton. Dharwar Craton is principally composed of peninsular gneisses and Supracrustal belts which are generally referred to as the schist belts / greenstone belts. In 1872, Bruce Foote coined the term “Dharwar
System” to those schistose formation, which occupy nearly 1, 28,000 sq kms in the state which are well exposed around Dharwar. Based on the lithological, stratigraphical, metamorphic grade and tectonic observation of greenstone belts, the regional Dharwar Craton are categorized in to four units (Radhakrishna, 1994). They are Younger Dharwar green stones, Older-gold bearing Kolar type, Supra crustal units and Ancient Sargur type. Primarily four types of Schist belt exist within the Karnataka State; they are Bababudan schist belt, Shimoga schist belt, Chitradurga – Gadag schist belt and Sandur schist belt. According to the hydro-geological classification, the lithological formation of South Indian Shield is reorganized into six types, such as 1) River alluvium, laterites and minor intrusive, 2) Deccan traps, 3) Puranas (Kaladgis and Bhimas), 4) Closepet granites and Ultrabasics, 5) Dharwars and 6) Peninsular gneisses.

The southern part of the state particularly to the south of 13°N latitude covers a large portion of the amphibolite’s to granulite facies transaction. The schistose rocks occur as supracrustal sequences in the form of their sub-parallel belts of high-grade rocks amidst later peninsular gneisses which have deformed and migmatised them. The supracrustal sequences are called as Sargur Group (Swaminath et al. 1981) are largely well developed around Sargur. The Sargur Schist complex as early as 1944 was first studied by Rama Rao. He inferred that the rocks of this region were highly metamorphosed and were older than Dharwars. The Gundlu river region forms the southernmost part of the Sargur supracrustals and extend into granite greenstone belt.

The present field investigation revealed that the occurrence of Islands of granites and granodiorites within the gneissic complex are common which are geomorphologically expressed as well defined hillocks and bouldry outcrops. There are also numerous acid and basic dykes belonging to different geological events occurring as intrusives in the study area.

2.2 Lithostratigraphy

Based on geological map (Fig. 2.2) of the south Kabini Basin carried out the present investigation and the available literature the following lithostratigraphic of Sargur and Gundlupet region have been comparatively studied and constructed stratigraphic column (Table 2.1).
The Gundlupet area investigated by the author is essentially a gneissic terrain. The lithology is constituted by a wide range of rock types from metasediments (quartzite-fuchsite bearing, ferruginous and manganiferous calc-silicates) with pelitic assemblages (Kyanite Sillimanite schists) to semipelites (biotite garnetiferous silimanite schists) basic rocks (hornblende granulites/amphibolites to ultramafics of orthopyroxenite hornblendite, pyroxenite gabbroic anorthosites). The mafic gneisses referred in this present work as Gundlupet gneisses which are in turn invaded by younger pink granites and cut by late basic dykes of dolerite and norite (Janardhan, 1984).

2.2.1 Petrography

The rock types of the study area consist of amphibolite, hornblendite, quartzite, banded magnetite quartzite, gneisses, Gundlupet gneisses, carbonates, pyroxenites, granitic gneisses, basic dykes, felsite dykes, pegmatite and kanker.

Amphibolite: Amphibolites form a significant litho unit in the study area and existing as an important marker horizon. Petrogenetically its evolution is of considerable importance in the terrain. It occurs both as thick bands of mappable dimension and as small enclaves or pods in the younger gneisses. The rock is medium to fine grained with mesocratic and consisting essentially of hornblende, along with few clino-pyroxene and plagioclase.

Hornblendite: Hornblendites are associated intimately with older amphibolites and recrystallised ultramafics in the area.

Quartzite: Quartzites occur as thin band but widely exposed bands in the area investigated rarely exceeding 50 m in width and are traced for a few kms in distance. They occupy the hill tops and intact control the topography of the area. The largest quartzite band is seen to the south of Kurubarahundi extending over 3 km in length from Kurubarahundi in the north up to Shivapura in the south. If extrapolated it can be traced upto Madahalli, NW of Gundlupet and this has an overall strike length of about 12kms. The bands of fuchsite bearing quartzite are also noticed in two localities: (1) two km SE of Kannegala and (2) 2-3 km south of Kundakere.
Fig. 2.2: Geological map of Kabhini basin
Table 2.1 Lithostratigraphic succession for South Gundal basin (after Srikantappa, 1979),

<table>
<thead>
<tr>
<th>Lithostratigraphic Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolerite dyke</td>
<td>Prominently present in the western and southern part of the area.</td>
</tr>
<tr>
<td>Pink granitic gneiss</td>
<td>Exposed as hillock near Kadihally.</td>
</tr>
<tr>
<td>Chornockite</td>
<td>Seen locally in Metikuppa, Hullabally and Gopalswamy betta.</td>
</tr>
<tr>
<td>Younger Basic Sill/Dyke</td>
<td>Emplaced across the fabric (N-S) of Gundlupet Gundlupet Gneiss</td>
</tr>
<tr>
<td>Hornblende – Biotite gneiss</td>
<td>Occur near Padguru village.</td>
</tr>
<tr>
<td>Ultramafic Rock</td>
<td>Mostly recrystallized and now occurring as ortho pyroxenite - pyroxenite Hornblendites.</td>
</tr>
<tr>
<td>Ferruginous horizon</td>
<td>Banded Magnetite Quartzite.</td>
</tr>
<tr>
<td>Carbonate and Manganiferous</td>
<td>Ferruginous Manganiferous horizons, crystalline limestone calc-silicates.</td>
</tr>
<tr>
<td>Horizon</td>
<td></td>
</tr>
<tr>
<td>Quartzite</td>
<td>Often fuchsite bearing.</td>
</tr>
<tr>
<td>Early Basic Rock</td>
<td>Amphibolites.</td>
</tr>
<tr>
<td>Kabini - Gneiss +</td>
<td>Quartz - feldspathic gneisses seen as enclaves.</td>
</tr>
<tr>
<td>Basic rock</td>
<td></td>
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</tbody>
</table>

Well cleaved fuchsite bearing quartzite bands, with an average modal percentage of fuchsite around 20% are seen near Hospura and Honkanpura. The fuchsite content in the quartzite seem to decrease, when they are traced to the south of the area, ie. towards Gundlupet. The rock is highly jointed and hence in the field occurs as small' blocks. Two km south of Terakanambi 125 m. thick band of quartzite is closely associated with carbonatic rocks and petites. The thickness of the band gradually thins out to little as one meter in the hillock, north of Silvantapura. At places development of garnet has also been noticed.

Quartzites comprising mainly quartz with sporadic distribution of fuchsite mica. Sutured borders between the quartz grains are common where many of the quartz with
strain shadows are noticed in the thin sections, indicative of high strain and stress during metamorphism. Marginal granulation of quartz grains are also observed in some thin sections suggesting high stress conditions during formation of the rock.

**Banded Magnetite Quartzites:** banded magnetite quartzites happens to be one of the salient characteristic rock types of the Sargur high grade schist belt serving as good marker horizons. In the Gundlu river watershed, BMQ are fairly represented as small bands and lenses trending N-S in the low lying areas particularly to the north and South west of Kurubarahundi and Baragi.

**Gneisses:** Are the most dominant rock types in the area. They are generally termed as ‘Peninsular gneiss’. Almost 70% of the area of Gundlu river watershed is dominated by gneissic rocks, with a general trend N 10 E - S 10 W: but occasionally maintain direct N-S trend dipping easterly from 60° to more than 80°. These rocks are weathered, fractured and – highly jointed. There are two types of gneisses viz hornblende gneisses and pegmatitic gneiss prominent outcrops of hornblende gneisses are existing in the eastern part of the area around Hanumantharayanagudi banded nature is marketed by alternate layers of quartz, feldspar with hornblende and other mafics.

The pegmatitic gneisses are widely outcropped in the Kodihalli Betta. They exhibit prominent orientation of quartz, feldspar and garnets parallel to the strike. Mafic minerals, mostly biotite and hornblende are altering to chlorite. The gneisses in the region seem to have been subjected to different tectonic episodes, and thus developed number of joints and crack both parallel and across the strike direction.

**Gundlupet Gneiss:** The gneisses well exposed in and around Gundlupet area, are termed as Gundlupet gneisses (Janardhan et al. 1984). They opined that the age of gneisses is about 2850 Ma. After a detailed field and petrographic studies the investigator recognized three distinct types in the Gundlupet gneisses namely (1) Medium grained and brownish quartzo-feldspathic gneiss (2) Fine to medium-grained grey gneiss, and (3) Coarse-grained white to pink colored feebly foliated pegmatoidal gneiss. Gneisses of the first two varieties are well foliated and the gneissosity is defined by biotite alignment.

The third verity of Gundlupet gneiss is leucocratic and pegmatoidal in nature and shows only feeble -foliation. The migmatitic structures that are commonly seen in gneisses are agmatitic structure, nebulitic structure and at places augen structure.
Agmatic structure appears in the first stage of migmatisation. Lit-par-lit" injection also took place in the early stages of migmatisation. The above features are best seen in the quarry openings near Kodihally and Bachhally. Dictyomitic and ptygmic are the other structures observed in the quarry cuttings. Mineralogically Gundlupet gneisses consist of quartz and biotite forming the major constituents with plagioclase, microcline as minor constituent. The structural fabric of N-S direction to present N 60° E, in Gundlupet gneiss is in corroborated with the fabric of peninsular gneiss.

**Carbonates:** Carbonates constitute a significant unit in the Sargur Supracrustals which exposed in a discontinuous band, in south western part of the Gundlu river watershed as calc-silicate rocks and marbles in the Mallaiyanapura hillock (3316 feet height, three km west of Gundlupet) and in the low lying areas, west of Raghavapura. It also outcropped north of Gundlupet as interbedded units with amphibolites, particularly north of Kurubarahundi. Marble bands are well seen in Mallaiyanapura hillock; generally form boundinaged, lenticular concordant beds with calc-silicates and basic rocks. The garnet rich and calcite, poor variety of calc-silicates occur adjacent to the pyroxenites in and around Kurubarahundi.

**Pyroxenites:** Pyroxenites are the best exposed ultramafic component of the area. These bodies occur as rafts, gently as large sized enclaves in gneisses. Individual bodies measure 20 to 100 m in thickness and extended for a length of 300 m. Excellent exposures are seen to the north of Kurubarahundi, one km south of Hosapura and near Alathur. All these outcrops are highly disturbed and deformed by subsequent magmatic invasion and thus occur as discontinuous patches and lenses. The pyroxinite patches generally trend parallel to N-S but when involved in folding near Honnegowdanahally, south west of Gundlupet trending N60° E - S60° W and E-W. The best outcrops of ultramafics seen, near Gundlupet and Terakanambi distinctly striking in E-W trend.

**Granitic Gneisses:** Coarse grained granitic gneisses with pink feldspar occur in the hillock, one km south of Kodihally. The rock happens to be highly jointed, weathered and mostly occur as boulders of different sizes. The mylonite zones are also recognized at the contact of granitic gneisses and gneisses near Kodihalli. This seems to be a clear indication that there was structural disturbance during the emplacement of the magma in ductile condition.
The granite is coarse to very coarse-grained with big grains of K-feldspar and quartz with minor proportion of plagioclase and hornblende. Hornblende appears to be calc-rich and is dark green in color, under the microscope hornblende shows strong pleochroism from yellowish green to dark green. K-feldspar is the most common salic mineral and happens to be microcline, since they exhibit good cross-hatched twinning. Sometimes often perthitic intergrowth could be observed, plagioclase is commonly oligoclase with highly weathered and saussuritised. The granite seems to be disturbed by structural disturbances as evidenced by the development of shears and fractures.

**Basic Dykes:** The basic dykes are represented by norites and dolerites. The magmatic activity of this type indicates the culmination stages of attainment of tectonic stability in the region. In the Gundlupet, the dykes dominantly trending N-S and E-W, the major fracture systems are also coinciding with the same trend. A noritic dyke is seen near Honkanapura with a width of about 100 mts. Two parallel dykes trending N 20° W - S20° E are outcropped discontinuously from northern part of Kurubarahundi to Bhimanabidu and another from Bhimanabidu upto Honshetihundi in the south, for a distance of approximately 1.5 kms. They are discordant bodies emplaced during the later stages of deformation. Thin section of dolerite shows, the ophitic and sub-ophitic texture.

**Felsite Dykes:** Dykes occur in this area vary in thickness from 0.5 to about 3 m and extend from few meters to over one km in length. A big felsite dyke is noticed at the bottom of the Kodihally betta, runs for about 1 km in length and a width of 8-10 m, cut across the gneisses. It strikes N 55° W - S 55° E and traversed by 3 prominent pegmatitic veins which are almost parallel to the strike of the dyke.

Felsite is light green colour, hard and compact, breaking with conchoidal fracture with splintery character. Wherever, weathering is prominent felsite has been decomposed and giving rise to Kaolin as weathered product. Kaolinization is rampant at many places due to the alteration of microcline and orthoclase feldspars.

**Pegmatite:** Generally pegmatite occurs as Veins and reefs in gneisses striking NE-SW dipping 65° towards south and they are highly weathered. The chief mineral constituents are coarse -grained and pink feldspar, whereas the minor components are biotite and muscovite mica pegmatites exhibit intergrowth texture between quartz and
feldspar. Due to metamorphism, long prismatic minerals have got themselves oriented parallel to the strike direction. In some pegmatites garnet is characteristically present.

**Kanker:** Kanker is found near Begur and it has been extended upto Gundalpet. It seems to be weathered product of carbonate rocks, ultra-basics and gneisses. Kankar is highly porous occasionally with concretion of calcium which on burnt give rises to quicklime.

The Kankary limestones are very well exposed, 2 kms NE from the foot hills of H.Gopalswamy hill happens to be the largest exposure in the watershed. The rock formations in the area under study exhibit different types of main structural features, like, foliation, lineation, folds, faults and joints. They are prominently developed in the gneisses, granites and in dykes. Lineation and foliations are distinctly present in gneisses and amphibolites. They have been described in the following paragraphs.

**Foliation:** Foliation is the common planar structure noticed in all litho-units of the area. Different types of foliation commonly observed in the rocks are compositional layering, preferred orientation of platy or lenticular minerals and or a combination of both. Compositional layering is the common type of foliation, best noticed in banded gneisses exhibiting alternate layers of salic and mafic minerals. Banded gneisses possess biotite hornblende rich layers alternating with quartz + feldspar rich layers, where the thickness of the individual layers varies from 1 cm to less than 5 cm. Even thin sections banded nature could be observed by orientation of mineral grains.

**Lineation:** Lineation is the result of the parallelism of some direction property of minerals in the rock. For example in the hornblende gneisses long axes of hornblende crystals are essentially parallel to the strike direction and is said to possess lineation.

Some of the granites in the area possess a primary lineation due to the orientation of long prismatic hornblende in the direction flow of the magma. However, lineation in gneiss may be inherited from the original rock which probably developed during metamorphism.

**Folds:** Folds represent deformational waves in the earth's crust. They generally form under very varied conditions but their presence certainly indicates some form of ductile deformation in the region. It is often found that a particular deformation can generate folds with different styles and orientation, depending on the competency of the
rock type. In the Gundlu river watershed the granitic gneiss exhibiting number of folds has been exposed east of Hanumantharayana Gudi, near Hirikere village. Here an easterly plunging anticline is very well displayed in granitic gneiss. In between Begur and Kotekere villages, the exposures of granitic gneisses are very hard and compact, showing number of minor folds. The fold axis strikes N-S with steep plunge towards east. The hornblende-gneiss exposed near Kaligoudanahalli, a double plunging syncline on a minor scale has been observed at the top of Hanumantharayana hill.

**Faults:** Faults represent deformational ruptures in rocks along which the opposite blocks have moved past each other. Faults of both minor and major scale are noticed in the Gundlu river watershed. They mainly strike N-S and E-W. Displacement of mappable scale are noticed only in the region, two km south of Terakanambi, length of running in between Gundlupet and Hongahalli, the length of the fault is two kms trending E-W. The third fault which occurs in between Deshipur and Chammallipura villages, the length of the fault is 2.5 km running in the N-S direction. Minor faults on small scale are observed where they are seen to displace the compositional layering of the rock.

**Joints:** Joints are the divisional planes or smooth fracture surfaces that divide rocks, along which there is no visible movement parallel to the plane are surface. Joints may have any attitude; some are vertical, horizontal and inclined at various angles. Joints are common in almost all the rock types in the Gundlu river watershed. Granitic gneisses in the southern part of the area, joints are closely spaced. A fairly high ridge, on Sulthan bathery road, 3 km west of Gundlupet, in weathered grey granitic-gneisses rectangular joints are prominently developed. Well defined joints are observed, trending E-W and N-S direction. Economically the joints are often filled by quartz veins. Normally the degree of weathering is comparatively more along the joint planes than on the other part of the rock body.

**2.3 Geological setting of the watersheds**

The Mulehole, Maddur and Terakanambi watersheds are located in the southwestern part of the West Dharwar craton close to the Moyar shear zone. The craton is composed of several types of rocks. In the study area, the peninsular gneisses (Tonalite Trondhjemite Granodiorite suite) are by far the most common rocks that are intermingled
with mafic rocks from the Sargur series (Greenstone belt). Geological information was gathered in the abundant literature regarding the Dharwar craton. The bedrock composition influences directly both regolith and water geochemistry (litho-dependence) while the depth and fractures of the protolith may have a direct effect on the fluid pathways.

2.3.1 Quantification of the geological units

It is important to understand the geometry of the geological units in the watershed, because it is important to understand the geological units, weathered zone thickness, depth of the bed rock and also its role in infiltration. Normally remote sensing and Arial photographs are the appropriate tools to identify large structures and lithological units. Due to the thickness of forest cover it was difficult to use the Imageries for geological studies at Mulehole and Maddur. The existing geological map (from geological survey of India) was in 1: 2,50,000, the resolution was inappropriate for this study.

Mulehole watershed:

Geological transect study was conducted for Mulehole, Maddur and Terakanambi watersheds, the result showed that the most common rock of the watershed is gneiss, intermingled with amphibolites and some quartz dykes (Fig. 2.3). Paragneiss is dominant and consist mainly of quartz, feldspar (plagioclase and potassic) with a low quantity of biotite.

The geological structure (Fig. 2.3) in Mulehole presents a general east/west orientation. Rocks are highly foliated and observations at outcrops show that the foliation ranges from a dip angle of 75° to the vertical. The average strike direction is N80°E, but two main trends can be noticed following the streams orientation. In the northern part of the watershed, strikes are mainly N70°E, while they are N100° E in the south, in accordance with the stream direction.

Maddur watershed:

A geological survey confirms that the Maddur watershed is mainly located in gneiss (black mafic and white acidic). Black gneiss has been observed in the north part of the watershed, in the forested area. Strikes and dips survey showed an isotropic formation and no preferential orientation for the watershed (Fig. 2.4).
Terakanambi watershed:

Terakanambi watershed is composed with gneissic rock and few traces of doleritic dykes, quartizite and amphibolites with a general trend N10°E - S 10°W (Fig. 2.5), but occasionally maintain direct N-S trend dipping easterly from 60° to more than 80°. Lineaments of the watershed show that rocks are weathered, fractured and highly jointed.

2.3.2 Protolith mineralogical and geochemical composition

Peninsular gneiss: The major minerals are quartz, albite, K-feldspar and rare amphibole crystals. The accessory minerals, quite scarce, are tiny crystals of sulfides (Zn, Fe) and zircon. On average, the gneiss samples have a trondhjemitic composition (Figure 2.6).

Amphibolite: The major minerals are green hornblende (Si-Al-Mg-Ca-Fe), clinopyroxene and plagioclase (abundant Si-Al-Na-Ca and less abundant Si-Al-Na-Ca). Hydrothermal alteration of CPX and plagioclase gives epidote (light green). The accessory minerals are apatite (+ 100 m) included in hornblende crystals, sulfides Fe-Ni-Cu (often weathered into Fe-oxides; FeS₂ crystals of about 10 m), Cr-Mn-Fe oxides, zircon grains (-20 m) a titanite (+15-20 m). The amphibolite has a basalt composition.

Other rocks: Green schist facies rocks (origin Ultra Basite) containing acicular amphibole crystals (tremolite? Mg) and phyllosilicates (talc? Mg, chlorite) with hydrothermal alteration features.
Fig. 2.3. Geological map of Mulehole watershed.
Fig 2.4 Geological and structural map of Maddur watershed
Fig 2.5 Geological and structural map of Terakanambi watershed
Fig. 2.6 An-Ab-Or CIPW normative composition of the mafic and acidic rocks of the silicate protolith of the Mulehole, Maddur and Terakanambi watersheds belonging to Dharwar craton

2.4 Characterization of soil system

Methods and actions

Soil cover in Mulehole, Maddur and Terakanambi watersheds are characterized by two types of Red soil and Black soil system (Alfisol, Entisol, Vertic Inceptisol and Vertisol), due to the thickness of forest cover, satellite pictures are unable to discriminate the soil system at an appropriate scale.

Geophysical survey is the useful method to study of soil system. It is carried out Preliminary geophysical electrical resistivity test on outcrops. The test shows that the black soils are more conductive than the red soils. Consequently Electromagnetic (EM) method are used to map the watersheds, because EM is sensitive to conductive material (black soils), doesn’t require any contact with the ground (induction) and allows covering large surfaces in a limited survey time using GPS location. After Comparing the efficiency of two devices EM31 (Fig.2.9) and EM34 (Fig. 2.10), EM31 was found to be the best to investigate the first 5 meters of the subsurface. On Maddur and Mulehole watersheds are made profiles of every 100 meters, with a sampling interval of 5 meters
(Fig. 2.11). A statistical analysis was performed on the data and 2 electrical conductivity maps were drawn. In a second step, a modeling was performed on simulated soils distribution and enabled to translate the conductivity map into a soil distribution map with a good degree of confidence for Mulehole and Maddur watersheds. Soil map for Terakanambi watershed has been prepared by using Remote sensing data with visual interpretation.

2.4.1 Method of Electromagnetic conductivity meters

Geometry and principle of functioning

Electromagnetic methods are based on the electromagnetic theory and both electric and magnetic fields are concerned. The electromagnetic conductivity meters are all made of two coplanar electric coils, one Transmitter coil (Tx) and one Receiver coil (Rx), separated by a spacing S.

When the transmitter coil Tx is energized with an alternating current at a given frequency, it emits a time-varying magnetic field, which induces very small eddy currents in the ground. These induced currents generate a secondary magnetic field, $H_s$, which is recorded together with the primary magnetic field, $H_p$, by the receiver coil Rx (McNeill, 1980), (Fig. 2.9).

The ratio of the secondary magnetic field to the primary magnetic field is a complicated function of the intercoil spacing S, the operating frequency $f$, and the ground conductivity $\sigma$. Under certain geometrical and electronic constraints, technically defined as “operation at low values of induction number”, this ratio becomes linearly proportional to the ground conductivity. Its mathematical expression is shown to be:

$$\left( \frac{H_s}{H_p} \right) = \frac{i \omega \mu_0 \sigma S^2}{4}$$

Where

- $H_s$ = secondary magnetic field at the receiver coil
- $H_p$ = primary magnetic field at the receiver coil
- $\omega = 2\pi f$
- $f$ = frequency (Hz)
- $\mu_0 = $ magnetic permeability of free space ($4.\pi.10^{-7} \text{ H/m}$)
\[ \sigma = \text{ground conductivity (S/m)} \]
\[ S = \text{intercoil spacing (m)} \]
\[ i = \sqrt{-1} \]

The conductivity meters are built in such a way that they fill the conditions of “operation at low values of induction numbers”. The devices measure the ratio of the secondary magnetic field to the primary magnetic field which allows the direct-reading of the ground conductivity in MilliSiemens per meter (mS/m).

The conductivity meters actually measure an apparent conductivity, which would be the true conductivity only in the case of a homogeneous earth. If the ground is not homogeneous the conductivity presents a spatial variability, depending on the water content, the geological formations, the soil layering. The apparent conductivity read on the screen is an integration of the true conductivity values in the ground within the investigation depth. This integration takes into account the vertical as well as the horizontal variability of the ground conductivity. But conventionally, the “apparent conductivity” is presented directly as “conductivity” when drawing the profiles and the maps. The investigation depth of the conductivity meters at low induction number fundamentally depends on the intercoil spacing \( S \). Longer the intercoil spacing, deeper the investigation depth.

**Horizontal coplanar (HCP) and vertical coplanar (VCP) Modes**

As mentioned above, the Tx and Rx coils must be coplanar for the conductivity meter to give good results. The conductivity meter can be used in two different modes depending on the position of the coils with respect to the ground.

In the horizontal coplanar mode (HCP), the Tx and Rx coils are both located in the same horizontal plane (Fig. 2.10). “Horizontal” is actually not an exact description as the coils must in fact be located in the same plane parallel to the topographical surface. This mode is also called the Vertical Dipole mode, as the dipole symbolizing the primary magnetic field is vertical if the coils are horizontal (the dipole is perpendicular to the plane formed by the loops of the transmitter coil).
In the vertical coplanar mode (VCP), the Tx and Rx coils are both located in the same vertical plane. The VCP mode is also known as the Horizontal Dipole mode, as the dipole symbolizing the primary magnetic field is horizontal if the coils are vertical.

The different Geonics devices

EM38 (Fig. 2.7) is the smallest conductivity meter of the set. The Tx and Rx coils are included in the body of the device, which guarantees that there is absolutely no changes in the geometry of the instrument the intercoil spacing “S” and the coplanarity are fixed. With an intercoil spacing of 1 m, the EM38 can investigate a 1 m thick layer of ground in the VCP configuration. Using the HCP mode, the exploration depth is increased to about 1.5 m. This equipment has been used to carry out a rough soil conductivity mapping in Mulehole.

EM-31

This conductivity meter is built with an intercoil spacing of 3.66 m which yields an investigation depth of about 4 to 6 m, using respectively the VCP or the HCP configuration. It is made of three parts that can be taken apart when the device is not in use. As for the EM38 the Tx and Rx coils are included in a common body.

EM34

This conductivity meter is the biggest one of the set (Fig. 2.8), its Tx and Rx coils are much bigger (respectively 1 m and 0.63 m diameter) and are linked together with an electric cable. At least two people are required to carry out the survey. This device allows an interesting flexibility in the choice of the intercoil spacing, which can be 10, 20 or 40 m. However, as the coils can be moved independently a particular care is required to keep them coplanar during the measuring.

Choice of the device and sampling strategy

Some direct modeling was carried out before the survey in order to test the instrumental response range for both EM34 and EM31. The EM34 response range was tested in both the VCP and HCP configurations, for two intercoil spacings, 20 and 40 meters. The 40 m intercoil spacing was too long to be used under the forest cover. Given the visibility in the forest, the two operators would have had too many difficulties to see each other’s and to respect the coplanarity. This was resulting in instability in the
readings (few mS/m of deviation) which was unacceptable regarding the resolution required. The HCP configuration with an intercoil spacing of 20 m was given up after a test on one transect for the same reason: the coplanarity was too difficult to implement, due to the vegetation and the changes in topography.

The watersheds were divided in transects spaced at hundred meters, along which measurement points were taken and stored automatically by a data logger every 5 seconds. This resulted in a conductivity measurement every 5-10 meters depending on the speed of the walk. A Global Positioning System (GPS) was monitoring the position of the equipment every 5 seconds. The internal clock of EM31 was adjusted to the GPS clock. At the end of each day the GPS locations of the conductivity measurements points were extracted by comparing the GPS and EM31 files.

Kriging was used as interpolation method for the construction of the conductivity map. The duplicates had to be removed because the kriging process, when interpolating a value, gives more weight to the nearby located measurement points. The experimental variograms were fitted with theoretical models which were later introduced in the interpolation process.

<table>
<thead>
<tr>
<th>Intercoil spacing (meters)</th>
<th>Investigation depth (meters)</th>
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<tr>
<td></td>
<td>Vertical Coplanar</td>
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<td>10</td>
<td>10</td>
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<td>20</td>
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<td>40</td>
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Table 2.1.1 Investigation depth for EM34 at various intercoil spacing
Fig. 2.7 Electro Magnetic conductivity meter (EM-38)

Fig. 2.8 Electromagnetic instrument EM-34
Fig. 2.9. Functioning of a conductivity meter (EM-31. Geonics)

Fig. 2.10. Geonics EM34 conductivity meter in Vertical Coplanar (left) and in Horizontal Coplanar (right) configurations
2.5 Result of the study

Fig. 2.12 depicts the results of the statistical analysis and the conductivity maps of Mulehole and Maddur.

The 1D forward EM modeling of 33 typical soil organizations in Mulehole enabled to identify five conductivity ranges corresponding to five typical soil systems (Barbiero L., et al. 2010). Then it was possible to prepare a soil map from the geophysical
maps. The output soil distribution map enables to calculate the proportions of the total area occupied by each of the typical soil systems

- from 0.14 to 0.7 mS/m: outcrops or thin alterite layer above fresh rock (< 1 m) which is 0.2 % of the total surface area of the watershed
- from 0.7 to 3 mS/m: thicker alterite layer above fresh rock – 14.8 % of the total surface area of the watershed.
- from 3 to 5 mS/m: thin red soils (0.5 to 1.5 m thick) above alterite or fresh rock – 39 % of the total surface area of the watershed.
- from 5 to 9 mS/m: thick red soils (> 1.5 m) above alterite or fresh rock – 30 % of the total surface area of the watershed.
- from 9 to 50 mS/m: thick black soils (> 1 m) above alterite or other very conductive soils (with carbonates) – 16 % of the total surface area of the watershed. A clear relation was identified between the organization of the soil system and the distribution of the main erosion zones (Barbiero L, et al. 2007). This is a major result that will guide further studies.

Conductivity distribution

- The conductivity values range from 0.1 to 50 mS/m in Mulehole against from 0.1 to 110 mS/m in Maddur.
- The conductivity classes are more homogeneously distributed and the transitions between the classes are more consistent and distinct in Maddur than in Mulehole. The most important conductivity classes in each watershed are: the 2 to 5 mS/m conductivity class in Mulehole (50 % of the watershed), the 5 to 10 mS/m conductivity class in Maddur (26 % of the watershed).
- As a general rule the conductivity values are correlated with the topography, and consequently with the streams in Maddur. Crests and high points of the watershed present the lowest conductivity values whereas the gullies and the low parts of the watershed are rather conductive areas. This relation between topography and conductivity values is much stronger in Maddur than in Mulehole, where the organization of the subsurface conductivity is more independent of the drainage network.
• A preferential direction was found in the conductivity distribution in Mulehole during the variogram analysis whereas the conductivity distribution in Maddur does not present any anisotropy. This preferential direction of N70° found in Mulehole is consistent with the structural anisotropy evidenced during the geological survey.

• The variogram analysis showed that the sampling strategy was well chosen and the sampling dense enough to bring valuable information.

Terakanambi watershed

There are mainly three in types of soil system classification are distributed in Terakanambi watershed which is red soil, gravely moderate erosion and very low amount of clay content and secondly very deep, well drained clay soils and slight erosion and shallow red soils mixed with gravel and moderately eroded and the other soil type is deep clay/black soils mainly in valley region and slightly salinity in patches.

2.6 Geomorphology of the watershed’s

The topography of Mulehole and Maddur watersheds has low to moderate undulated terrain and no hills exist. Mulehole and Madur watershed has rocky out crops and one residual hill at the ridge followed by minor pediments in the forest part.

Normally recharge takes place majoritily all along the streams and also vertical and lateral flow exist in red soils. The ridge line and the black soil area remain runoff zones in Mulehole and Maddur watersheds.

The Terakanambi watershed as reasonably greater area and five categories (Fig. 2.16) has been identified which are mainly by valley fill shallow weathered, pediplain shallow weathered, pediplain moderately weathered, pediment and structural hill.
Fig. 2.12. The results of the statistical analysis and the conductivity maps of Mulehole (a and c) and Maddur (b and d) watersheds.

Fig. 2.13. Spatial discrimination of the soil distribution and repartition of the soils types in Mulehole.
Valley fill shallow weathered

Valley fills are deeply weathered pediplains, a number of lineaments exist within this zone. The lineaments follow the stream courses and intersecting lineaments are considered as good potential zones of groundwater targeting, as they reflect high porosity and hydraulic conductivity of the underlying materials banded gneiss and ultramafic enclaves are the prominent litho-units of the structural valley. The landform of valley fills
shallow formed by the deposition of alluvial and colluvial material of various grades along the nalla course. This consists of sand, gravel, silt and clay and facilitates channel bed infiltration. It is a highly permeable zone helping the partial bank recharge and subsurface flow of groundwater occurs under semi-confined to perched water table conditions with shallow water levels. Groundwater prospect in valley fill shallow weathered are good.

**Shallow weathered pediplain**

The shallow weathered pediplain develops from the continuous process of pedimentation. It has a gently sloping or almost plain surface with a shallow overburden of soil / weathered zone that extends up to a depth of about 5m. Groundwater prospects are moderate to poor in view of elevated ground surface compare to moderately weathered pediplain, the occasional occurrence of intersected lineaments and virtually dry environment. However, gentle slopes adjacent to the stream courses / tanks have moderate potential zones. The area covered by this geo-morphological unit can be used for development of groundwater resources in terms of shallow wells.

**Moderately weathered pediplain**

Moderately weathered pediplain is a flat surface located in middle and southern part of the study area, this unit occupies the topographically low-lying areas and associated mostly with lineaments. Groundwater prospects in the moderately weathered pediplain are considered as good to moderate. However, higher yield may be expected from this geomorphological units associated with lineaments intersection zones. Groundwater can be withdrawn from this unit through development of shallow and deep wells, because of moderately high thickness weathered zone (5 to 20m).

**Pediment**

Pediments are isolated, gently sloping smooth surface of inclined residual hills with being remnants weathering; denudation and erosion surface carved out on the bed rock and is developed at the foot of hills. From the groundwater point of view this unit is treated as neither contains nor transmits groundwater (i.e. aquifuge in nature). At some places there is a possibility of yield of groundwater, where the intersection of lineaments exists.
Structural hills

Structural hills are the linear hills exhibiting definite trend lines. The structural hills of the watershed area are structurally controlled with complex folding, faulting and criss-crossed by numerous joints / fractures, which facilitates some infiltration and mostly act as run off zones. These hills are located in the South South-East part of the watershed.

Figure 2.15 Geomorphology of Mulehole and Maddur watersheds
Figure 2.16 Geomorphology of Terakanambi watershed