DECIPHERING GROUNDWATER POTENTIAL ZONES IN SUBWATERSHEDS OF MEENACHIL RIVER BASIN USING GEOSPATIAL TECHNOLOGY

Objectives

1. To prepare various thematic layers such as drainage density, lineament density, slope, lithology, geomorphology and landuse/land cover using SOI topographical maps, remote sensing data and GIS.
2. To prioritize the weightages of individual themes and feature score depending upon their suitability to hold groundwater.
3. To prepare the integrated final groundwater potential map (GPM) using the ‘Raster Calculator’ option of spatial analyst.

6.1 Introduction

Groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both urban and rural environment. Hence it plays a fundamental role in human well-beings, as well as that of some aquatic and terrestrial ecosystems. At present, groundwater contributes around 34% of the total annual water supply and is an important fresh water resource. So, an assessment for this resource is extremely significant for the sustainable management of groundwater systems. GIS and remote sensing tools are widely used for the management of various natural resources (Dar et al., 2010; Krishna Kumar et al., 2011; Magesh et al., 2011a,b). Delineating the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data has made it easier to establish the base line information for groundwater potential zones (Tiwari and Rai, 1996; Das et al., 1997; Thomas et al., 1999; Harinarayana et al., 2000; Muralidhar et al., 2000; Chowdhury et al., 2010). Remote sensing not only provides a wide-range scale
of the space-time distribution of observations, but also saves time and money (Murthy, 2000; Leblanc et al., 2003; Tweed et al., 2007). In addition it is widely used to characterize the earth surface (such as lineaments, drainage patterns and lithology) as well as to examine the groundwater recharge zones (Sener et al., 2005).

In the study area, the groundwater forms the principal source of water for domestic and drinking purpose and most of the people depend on dug/tube well for their daily needs. Even though the study area receives high rainfall, the area experiences severe dry condition in the summer seasons. At that time, the people in the area depends on the rationed water supply of local administrative bodies. Besides this, rapid urbanization, developmental activities and the increased population have lead to the groundwater pollution and water table depletion. Therefore, the present study focuses on the identification of groundwater potential zones in selected subwatersheds of Meenachil River Basin (MRB) using the advanced technology of remote sensing and GIS for the planning, utilization, administration, and management of groundwater resources.

### 6.2 Review of literature

Groundwater is a valuable dynamic and renewable natural resource in present day and limited in extent. Groundwater resource assessment of a region involves a detailed study of the sub-surfacewater, including geology and hydrogeology, monitoring and record of well data. Exploitation and utilization of groundwater requires proper understanding of its origin, occurrence and movement, are directly or indirectly controlled by terrain characteristics (Khan and Moharana, 2002). Groundwater occurrence being subsurface phenomenon, its identification and location is based on indirect analysis of some directly observable terrain features. The interpretation of satellite data in conjunction with sufficient ground real information makes it possible to identify and outline various ground features such as geological structures, geomorphic features and their hydraulic characters (Srinivas Rao et al., 2000); and these may serve as direct or indirect indicators of the presence of groundwater (Ravindran and Jeyaram, 1997; Sree Devi et al., 2001; Gopinath and Saralathan, 2004).
Chapter 6 Assessing Groundwater Potentiality

Geophysical methods are conventionally employed for groundwater prospecting though there are several methodologies to locate and map the occurrence and distribution of groundwater.

The identification and location of groundwater resources using remote sensing data is based on an indirect analysis of some directly observable terrain features like geomorphology, geology, slope, landuse/land cover and hydrologic characteristics. With the capabilities of the remotely sensed data and GIS techniques, numerous databases can be integrated to produce conceptual model for delineation and evaluation of groundwater potential zones of an area (Chaterjee and Bhattacharya, 1995; Krishnamurthy and Srinivas, 1995; Srivasthava and Bhattacharya, 2000; Taylor and Howard, 2000; Sarkar et al., 2001; Prasad, et al., 2008).

The geographic information system (GIS) has emerged as an effective tool for handling spatial data and decision making in several areas including engineering, geology and environmental fields. Remotely sensed data are one of the main sources for providing information on land and water related subjects (Brunner et al., 2007; Jha et al., 2007). A review of GIS applications in hydrology and water management has been presented by several researchers during mid nineties and recently such as El-Kadi et al. (1994), Kamaraju et al. (1995), Krishnamurthy et al. (1996), Gogu et al. (2001), Sikdar et al. (2004), Dawoud et al. (2005), Vittala et al. (2005), Solomon and Quiel (2006), Leblanc et al. (2007), Münch and Conrad (2007), Vijith (2007), These reviews indicate that GIS applications in hydrology and water management are essentially in a modeling dominated context.

In the recent years digital technique is used to integrate various data to delineate not only groundwater potential zone but also solve other problems related to groundwater. These various data are prepared in the form of thematic map using geographical information system (GIS) software tool. These thematic maps are then integrated using “Spatial Analyst” tool. The “Spatial Analyst” tool with mathematical and Boolyan operators is then used to develop model depending on objective of problem at hand, such as delineation of groundwater potential zones.
In recent years, many workers such as Shahid and Nath (1999), Goyal et al. (1999), and Saraf and Choudhary (1998) have used the approach of remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. Jaiswal et al. (2003) have used the GIS technique for generation of groundwater prospect zones towards rural development. Murthy (2000), Obi et al. (2000), and Pratap et al. (2000) have used GIS to delineate groundwater potential zone. Srinivasa and Jugran (2003) have applied GIS for processing and interpretation of groundwater quality data. GIS has also been considered for multicriteria analysis in resource evaluation. Shahid et al. (2000), Boutt et al. (2001) and Jacob et al. (1999) have carried out groundwater modeling through the use of GIS. Mohammed et al. (2003) have carried out hydrogeomorphological mapping using remote sensing techniques for water resource management around palaeochannels. GIS has been applied to groundwater potential modeling by Rokade et al. (2007).

### 6.3 Materials and methods

In the present study, Survey of India (SOI) toposheets (58C/9, 58C/10, 58C/11, 58C/13 and 58C/14) of scale 1:50,000; geocoded IRS P6 LISS III images (P100/R67) acquired on 19th February 2004 and geocoded IRS - Linear Imaging Self Scanning Sensor (LISS-III) 2007 image with a resolution of 22.5 meter covering Kottayam area; geological map (1:2,50,000 scale), published by Geological Survey of India and field data were used for the preparation of desired themes. The thematic layers prepared include geomorphology, lithology, slope and landuse/land cover of the area. Geographic Information System (ArcGIS 9.3) was used for the preparation of thematic layers.
<table>
<thead>
<tr>
<th>Theme</th>
<th>Weightage (%)</th>
<th>Feature Class</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geomorphology</strong></td>
<td>20</td>
<td>Denudational Hills</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flood Plain</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower Plateau Lateritic</td>
<td>3</td>
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<tr>
<td></td>
<td></td>
<td>Piedmont</td>
<td>3</td>
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<tr>
<td></td>
<td></td>
<td>Residual Hills</td>
<td>2</td>
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<tr>
<td></td>
<td></td>
<td>Structural Valley</td>
<td>1</td>
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<tr>
<td></td>
<td></td>
<td>Structural Hills</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Valley</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Valley fill</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Valley flat</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pediment</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residual Hill Complex</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residual Mound</td>
<td>1</td>
</tr>
<tr>
<td><strong>Geology</strong></td>
<td>10</td>
<td>Biotite gneiss</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Charnockite</td>
<td>5</td>
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<tr>
<td></td>
<td></td>
<td>Dolerite</td>
<td>1</td>
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<tr>
<td></td>
<td></td>
<td>Granite</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pyroxene granulite</td>
<td>1</td>
</tr>
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<td></td>
<td></td>
<td>Quartzite</td>
<td>2</td>
</tr>
<tr>
<td><strong>Slope</strong></td>
<td>35</td>
<td>1-8°</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9-15°</td>
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<td>16-25°</td>
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<td>26-35°</td>
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<td>&gt;45°</td>
<td>1</td>
</tr>
<tr>
<td><strong>Landuse</strong></td>
<td>5</td>
<td>Grassland</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mixed vegetation</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paddy fields</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>River</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Barren Rock</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rubber plantation</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Settlement</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tea plantation</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Settlement with mixed crops</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fallow land</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Palm/coconut</td>
<td>2</td>
</tr>
</tbody>
</table>
The weightages of individual themes and feature score were fixed and added to each layers depending on their suitability to hold groundwater (Table 6.1). This process involves raster overlay analysis and is known as multi criteria evaluation techniques (MCE). Of several methods available for determining interclass/inter-map dependency, a probability weighted approach has been adopted that allows a linear combination of probability weights of each thematic map and different categories of derived thematic maps have been assigned scores, by assessing the importance of it in groundwater occurrence. The maximum value is given to the feature with highest groundwater potentiality and the minimum being to the lowest potential feature. The procedure of weighted linear combination dominates in raster based GIS software systems. After assigning the weightages and scores to the themes and features, all the themes were converted to raster format using ‘Spatial analyst’, extension of ArcInfo ArcGIS software. While converting to raster, the scores assigned to the individual features were taken in the value field. Then, the individual themes were normalized by dividing theme weightages by 100. The ‘Raster Calculator’ option of spatial analyst was used to prepare the integrated final groundwater potential map (GPM) of the area. The map algebra (ESRI 2007), used in the raster calculator is (Eq. 1),

\[ \text{GPM} = (\text{Slope}) \times 0.35 + (\text{Lineament density}) \times 0.25 + (\text{Geomorphology}) \times 0.20 + (\text{Geology}) \times 0.10 + (\text{Drainage density}) \times 0.05 + (\text{Landuse}) \times 0.05 \]  

(1)

The procedure of the groundwater recharge zoning is illustrated in Fig. 6.2.
A Watershed Approach for Sustainable Ecosystem Management of Meenachil River Basin with Emphasis on Remote Sensing and GIS
Fig. 6.2: Schematic sketch showing the interactive influence of factors concerning recharge property (modified from Shaban et al., 2006)
6.3.1 Interrelationships between the factors of the groundwater recharge potential

There might be interactions between the factors of groundwater recharge. This study used five factors of groundwater recharge potential, namely lithology, landuse/cover, lineaments, drainage, and slope. A plot of the interrelationship between these factors is shown in Fig. 6.2. Figure 6.2 illustrates the primary and secondary interrelationships among the factors. Each relationship is weighted according to its strength. The representative weight of a factor of the recharge potential is the sum of all weights from each factor. A factor with a higher weight value shows a larger impact on groundwater recharge.

6.4 Results and discussion

6.4.1 Kattachira subwatershed (W1)

Thematic layers

Geomorphology

In the present study, the geomorphological map was prepared based on specific tone, texture, size, shape and association characteristics of remotely sensed data and significant geomorphic units were identified and delineated viz., valley fill, lower lateritic plateau and flood plain (Fig. 6.3). Floodplain deposits occur mainly along the stream channels in the eastern part of the study area and comprise chiefly poorly sorted to well-sorted clay, silty clay, loam, clayey silt and silt containing scattered granules and pebbles along with moderately to well-stratified loam, sandy loam or fine sand. Valley-fill deposits are generally unconsolidated alluvial and colluvial materials consisting of sand, silt, gravels, pebbles, etc., deposited along the floor of a stream valley. This type of landform is mostly present along the major river systems of the study area with a width of 3–4 km. Laterites are iron-rich duricrusts which have formed directly from the breakdown of materials in their immediate vicinity, and so do not contain any readily identifiable allochthonous component, whereas, ferricretes are duricrusts which incorporate materials non-indigenous to the immediate locality (Widdowson, 2003). Table-lands is a general term for a flat elevated region. Lateritic plateaus are also popularly known as rock outcrops,
Chapter 6  Assessing Groundwater Potentiality

i.e., habitats where portions of freely exposed bedrocks protrude above the soil level due to natural reasons (Watve, 2009).

Flood plains and valley fills are comprised of charnockites and mostly covered with paddy fields. About 75% of the study area is falling under the lower plateau lateritic geomorphologic feature. This region has dense lineaments. It is moderate to suitable for groundwater occurrence.

Lithology

Kattachira subwatershed comprises of charnockite, dolerite, magnetite-quartzite and quartzite (Fig. 6.4). The flood plain with dolerite consists of thick deposits of alluvium with high water holding capacity. Valley fills with dolerite consists of loose and unconsolidated materials, indicating recharge zone. Flood plains with charnockite come under the suitable category. Loose unconsolidated fill materials add more water to the valley fills with charnockite. Casings are required in the case of dug wells.

Drainage density

Drainage density is defined as the closeness of spacing of stream channels. It is a measure of the total length of the stream segment of all orders per unit area. The drainage density is an inverse function of permeability. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. Drainage density measurements range from 0 to 2.01 km km$^{-2}$. The drainage density map for the study area is shown in Fig. 6.5. Based on the drainage density of the micro-basins, it can be grouped into three classes: (1) 0–0.75 km km$^{-2}$, (2) 0.75–1.5 km km$^{-2}$ and (3) 1.5–2.5 km km$^{-2}$ as illustrated in Fig. 6.5. Accordingly, these classes have been assigned to ‘good,’ ‘moderate’ and ‘poor’ categories, respectively. High drainage density is recorded in the eastern parts of the study area (Fig. 6.5). The high drainage density area indicates low-infiltration rate whereas the low-density areas are favourable with high infiltration rate.
Fig. 6.3: Thematic layer of geomorphology Kattachira subwatershed (Ajaykumar, 2010)
Fig. 6.4: Thematic layer of lithology Kattachira subwatershed  (Ajaykumar, 2010)
Chapter 6  Assessing Groundwater Potentiality

Fig. 6.5: Drainage density map Kattachira subwatershed
Chapter 6  Assessing Groundwater Potentiality

**Lineament density**

Lineaments like joints, fractures and faults are hydrogeologically very important and may provide the pathways for groundwater movement (Sankar, 2002). Presence of lineaments may act as a conduit for ground water movement which results in increased secondary porosity and therefore, can serve as groundwater prospective zone. The extension of large lineaments representing a shear zone or a major fault can extend subsurface from hilly terrain to alluvial terrain. It may form a productive groundwater reserve. Similarly intersection of lineaments can also be the probable sites of groundwater accumulation. Therefore, areas with high lineament density may have important groundwater prospects even in hilly regions which otherwise have nil groundwater prospects. In Kattachira subwatershed, regions with high lineament density, less drainage density, flood plains and valley fills with charnockite served as suitable regions for groundwater exploration (Fig. 6.6).

**Slope**

A slope map prepared from the Survey of India toposheets of the study area is shown in Fig. 6.7. The identified slope category varies from 1° to >35° in the study area and are classified into five classes like, 0–8° (gentle slope), 9–15° (moderate slope), 16–25° (pronounced slope), 26–35° (steep slope) and >35° (very steep slope) (Figure 6.7).

Based on the slope, the study area can be divided into five slope classes. The areas having 0–8° slope fall into the ‘very good’ category because of the nearly flat terrain and relatively high infiltration rate. The areas with 9° -15° slope are considered as ‘good’ for groundwater storage due to slightly undulating topography with some runoff. The areas having a slope of 16°–25° are categorized as ‘moderate’. The areas having a slope of 26–35° cause relatively high runoff and low infiltration, and hence are categorized as ‘poor’ and areas having a slope >27° are considered as ‘very poor’ due to higher slope and runoff.
Fig. 6.6: Lineament density map Kattachira subwatershed
Fig. 6.7: Slope map Kattachira subwatershed
Landuse/land cover

The identified landuse/land cover features from the IRS imagery of the study area are agricultural land (palm, rubber and tea plantations, paddy fields and cropland), waste land (land with or without scrub and barren rocky area), water bodies (river), mixed vegetation, grasslands and built-up land. Out of the total area, >85% is falling under rubber plantation. From figure 6.8, it is clear that about >70% come under the category of suitable (value 2) groundwater potential, whereas 20% shows the potential value of 4 (less suitable) (Fig. 6.9). Very few areas are covered by the values of 3 (good to very good) and 5 (poor to very poor).

6.4.2 Koduvan subwatershed (W2)

Thematic layers

Geomorphology

Geomorphological mapping involves the identification and characterization of the fundamental units of landscape. The underlying lithology, slope and the type of existing drainage pattern influences the genesis and processes of different geomorphic units. The significant geomorphic units identified based on their image characteristics include residual hill complex, residual hill, residual mound, pediment, valley fills, valley flat, flood plain and alluvial plain (NRSA, 2000; Soman, 2002). The eastern part of the study area covered by residual hill complex where as residual hill spread over the central and eastern part of the study area. Residual hills are the end products of the process of pediplanation, which reduces the original mountain masses in to a series of scattered knolls standing on the pediplains (Thornbury, 1990). The residual hills are identified in the imageries grey tone and coarse texture in black and which images and dark reddish colour in standard false colour composite with radial drainage pattern. Groundwater potentiality is found to be poor in the areas. The isolated relief projections, residual mounds are scattered in western and central part of the study area. In between the hills, a significant area is covered by pediments. Being subjected to stream actions, the land forms are interspersed with well defined narrow and flat valleys by the deposition of
unconsolidated sediments (valley fills and valley flat). The central part of the area was covered by valley flat. The flat land surface, flood plain by lateral erosion, characterized by thin cover of alluvium composed mostly of sand and silt and is exposed at western and central part of the study area (Fig. 6.10).

**Lithology**

Geologically, the study area has been divided into two classes; Precambrian formations and recent formations. Even though majority of the study area covered by Precambrian formation (Charnockite), the western part of the area under recent formation (Sandy silty alluvium). There are nine rock types identified in the area and are, sandy silty alluvium, laterite, lignite gritty sandstone, pegmatite and quartzveins, garnet biotite gneiss, cordierite gneiss, charnockite, quartz feldspar and quartzite. The predominant rock types, charnockite and sandy silty alluvium are found in the central and western part of the study area (Fig. 6.11).

**Drainage density**

The drainage pattern of any terrain reflects the characteristics of surface as well as subsurface information. The drainage density (in terms of km/km$^2$) indicates the closeness of spacing of channels. More the drainage density, higher would be the run-off. Thus drainage density characterizes the run-off in the area or, in the other words, the quantum of rainwater that could have infiltrated. Hence lesser the drainage density, higher is the probability of recharge or potential groundwater zones (Fig. 6.12). The drainage density in the area has been calculated as 1.87 km/km$^2$.

**Lineament density**

The lineaments and fractures present in the area shows a general trend of NNW-NNE (Fig. 6.13).
Fig. 6.8: Landuse map Kattachira subwatershed
Fig. 6.9: Groundwater potential zone map Kattachira subwatershed
Fig. 6.10: Thematic layer of geomorphology Koduvan subwatershed
Fig. 6.11: Thematic layer of lithology Koduvan subwatershed
Fig. 6.12: Drainage density map Koduvan subwatershed
Fig. 6.13: Lineament density map Koduvan subwatershed
**Chapter 6  Assessing Groundwater Potentiality**

*Slope*

For the generation of slope, the digital elevation modelling (DEM) has done by the interpolation of contours, which in turn digitized from SOI toposheets using ArcGIS. DEM is a digital representation of continuous variation of topographic surface with the elevation or ground height above any geodetic datum. The generated DEM is used for generation of slope using ‘3D analyst’ an extension tool of ArcGIS. This helps for appreciating, the terrain and a supporting factor for the slope analysis. A slope map prepared from the Survey of India toposheets of the study area is shown in Fig. 6.14. The slope analyses have been carried out in the subwatershed level and are divided into five classes according to groundwater holding capacity. The integrated potential zone map indicate that, alluvial plain, flood plain, with sandy silty alluvium, coastal sand and brown sand with gentle slope (0–7°) having excellent potentiality. Valley flat, valley fills with lignite gritty sandstone, sandy silty alluvium with a slope (8–15°) are coming under very good potential zones. The other areas come under good, moderate and poor has covered with residual hill complex, residual hill and residual mound etc (Fig. 6.16).

*Landuse/Land cover*

Realizing the importance of landuse/land cover in groundwater potentiality, landuse/land cover map was prepared using geocoded IRS P6 LISS III (P100/R67) images acquired on 19th February 2004 and IRS LISS-III data acquired in 2007 and field data. The various landuse/land cover classes delineated by employing the standard methods of visual interpretation and the identified features includes, paddy field, fallowland, settlements/mixed crop, rubber plantation, palm/coconut, settlements and water body (Fig. 6.15). In this, majority of the area was used for rubber plantation followed by paddy fields. In some areas, paddy fields are reclaimed and are used for other mixed crop cultivation.
Chapter 6
Assessing Groundwater Potentiality

Fig. 6.14: Slope map Koduvan subwatershed
Fig. 6.15: Landuse map Koduvan subwatershed
Fig. 6.16: Groundwater potential zone map Koduvan subwatershed
Chapter 6  Assessing Groundwater Potentiality

6.4.3 Mannani subwatershed (W3)

Thematic layers

Geomorphology

Valley fills are linear depressions present in between the hill ranges and occupy the lowest reaches in topography, commonly filled with pebbles, cobbles, gravel, sand, silt, and other detrital material. The groundwater potential ranges from moderate to good. These valleys are developed along the fractures and such places can be exploited for groundwater through deep bores. In general, it is observed that adequate recharge source of groundwater is met within valley fillings. Valley fills in the study area occupy the central portion. In such places, the groundwater is considered to be moderately better with adequate source of water. This has very good porosity and permeability but sometimes the presence of clay may make it impermeable.

Flood plains and valley fills are comprised of charnockites and mostly covered with paddy fields. About 80% of the study area is falling under the lower plateau lateritic geomorphologic feature (Fig. 6.17). This region has dense lineaments. It is moderate to suitable for groundwater occurrence. Mannani subwatershed, slope class of 0-32°, geomorphological units such as residual mound, settlement/mixed crop area of landuse/land cover units and geology with charnockite rocks make the zone less suitable (Fig. 6.23).

Lithology

Mannani subwatershed 92.4% of the total area is covered by precambian formations, mainly charnockite followed by intrusive rocks such as dolerite and gabbro (Fig. 6.18).

Drainage density

The drainage density in the area has been calculated after digitization of the entire drainage pattern and shown in Fig. 6.19. The subwatershed experiences a maximum of 2.83 km km\(^{-2}\). The high drainage density area indicates low-infiltration rate whereas the low-density areas are favourable with high infiltration rate.
Fig. 6.17: Thematic layer of geomorphology Mannani subwatershed (Ajaykumar, 2010)
Fig. 6.18: Thematic layer of lithology Mannani subwatershed (Ajaykumar, 2010)
Fig. 6.19: Drainage density map Mannani subwatershed
Chapter 6 Assessing Groundwater Potentiality

Lineament density

In the study area, slope and lineaments play a significant role in groundwater potentiality. Lineaments, particularly joints, fracture and their intersection enhances the potential of hydrogeomorphic units. Areas with high lineament density are good for groundwater development (Figure 6.20).

Slope

A slope map prepared from the Survey of India toposheets of the study area is shown in Fig. 6.21. The identified slope category varies from 1° to >35° in the study area and are classified into five classes like, 0–8° (gentle slope), 9–15° (moderate slope), 16–25° (pronounced slope), 26–35° (steep slope) and >35° (very steep slope) (Figure 6.21).

Based on the slope, the study area can be divided into five slope classes. The areas having 0–8° slope fall into the ‘very good’ category because of the nearly flat terrain and relatively high infiltration rate. The areas with 9°-15° slope are considered as ‘good’ for groundwater storage due to slightly undulating topography with some runoff. The areas having a slope of 16°–25° are categorized as ‘moderate’. The areas having a slope of 26–35° cause relatively high runoff and low infiltration, and hence are categorized as ‘poor’ and areas having a slope >27° are considered as ‘very poor’ due to higher slope and runoff.

Landuse/land cover

The identified landuse/land cover features from the IRS imagery of the study area fallow land, settlements, settlement/mixed crops, rubber plantations and river channel (Figure 6.22). Out of the total area, >85 % is falling under rubber plantation. From figure 6.23, it is clear that about >70 % come under the category of suitable (value 2) groundwater potential, whereas 28% shows the potential value of 3 (good to very good).
Chapter 6  Assessing Groundwater Potentiality

Fig. 6.20: Lineament density map Mannani subwatershed
Fig. 6.21: Slope map Mannani subwatershed
Fig. 6.22: Landuse map Mannani subwatershed
Fig. 6.23: Groundwater potential zone map Mannani subwatershed
6.4.4 Payappara subwatershed (W4)

Thematic layers

Geomorphology

Topography is an important indicator of groundwater conditions in crystalline rock terrains (Davis and De Wiest, 1966). The geomorphic imprints can be considered as surface indicators for identification of subsurface water conditions. This information provides a reliable base for effective planning, development and management of groundwater resources of an area. The MRB has a dominant rocky terrain where the upland region is manifested by hills and undulating surfaces and the low land region form a gently undulating plain. Eight distinct geomorphologic units have been identified and delineated from the study area (Fig. 6.24); include structural hills, residual hills, denudational hills, lower plateau lateritic (LPL), LPL valley, piedmont, flood plain and valley. These distinct geomorphic features are resulted from the complexity of geomorphic evolution. The distribution and extent of these geomorphic zones are varying from place to place.

The upstream regions of the subwatershed are mainly characterized by the structural and denudational hills. The structural hills are controlled with complex folding, faulting and criss-crossed by numerous joints which facilitate some infiltration and mostly act as null off zones. The denudational hills are marked by sharp to blunt crest lines with rugged tops indicating that the surface runoff at the upper reaches of the hills has caused hill erosion.

The slope of the hills ranges more than 50 degree. Denudational hills are comprised of charnockites and mostly covered with rubber plantations.

Residual hills are described as isolated hills. These are found as an isolated patch western part of the study area. The groundwater prospect in this zone is also described as moderate. Floodplain deposits occur mainly along the stream channels in the southern part of the study area. Valley deposits are generally unconsolidated alluvial and colluvial materials consisting of sand, silt, gravels, pebbles, etc., deposited along the floor of a
stream valley. This type of landform is mostly present along the major river systems of the study area with a width of 3–4 km. These units are characterized by the high porosity and permeability resulting in high infiltration rate. These geomorphic units are moderate to highly suitable potential zones. About 80% of the study area is falling under the lower plateau lateritic geomorphologic feature. This region has dense lineaments. It is moderate to suitable for groundwater occurrence.

Lithology

Of course, the lithologic character of the exposed rocks is significant in governing recharge. Some studies neglected this factor once they use the lineament and drainage (El-Shazly et al., 1983; Edet et al., 1998). This is because they consider the lineaments and drainage characters as a function of primary and secondary porosity, thus providing information on the lithology. But others (Salman, 1983; El-Baz and Hamida, 1995) incorporate the lithology factor because of its strong influence on water percolation. In this paper, the lithology is used to serve confirming and supporting assessment of recharge factors. This will tend to minimize erroneous interpretations that may result from using lineaments and drainage factors alone.

The area forms part of the Precambrian granulite terrain and it is traversed by intrusives of later age (Fig. 6.25). The main rock types of the area belong to Charnockite Group of Archaean age. This group includes charnockite and pyroxene granulite. The quartzite belong to Khondalite group of Archaean age, biotite gneiss belongs to Migmatite complex of Archaean. NNW – SSE and NW – SE trending numerous dolerite and gabbro intrusions belong to Basic intrusives of Mesocainozoic age are the main attractions regarding the petrology of the area (Ajaykumar, 2010). Numerous dolerite and gabbro dykes trending NW-SE traverse the older basement rocks in the central and eastern parts. A prominent gabbro dyke extends from north to south with a NNW – SSE trend.
Fig. 6.24: Thematic layer of geomorphology Payappara subwatershed (Ajaykumar, 2010)
Chapter 6 Assessing Groundwater Potentiality

Fig. 6.25: Thematic layer of lithology Payappara subwatershed (Ajaykumar, 2010)
Chapter 6  Assessing Groundwater Potentiality

Drainage density

The drainage pattern of any terrain reflects the characteristics of surface as well as subsurface information. The drainage density (in terms of km/km²) indicates the closeness of spacing of channels. More the drainage density, higher would be the run-off. Thus drainage density characterizes the run-off in the area or, in the other words, the quantum of rainwater that could have infiltrated. Hence lesser the drainage density, higher is the probability of recharge or potential groundwater zones. Drainage density measurements range from 0 to 1.69 km km⁻². The drainage density map for the study area is shown in Fig. 6.26. Based on the drainage density of the micro-basins, it can be grouped into three classes: (1) 0–0.75 km km⁻², (2) 0.75–1.5 km km⁻² and (3) 1.5–2.5 km km⁻² as illustrated in Fig. 6.26. Accordingly, these classes have been assigned to ‘good,’ ‘moderate’ and ‘poor’ categories, respectively. High drainage density is recorded in the southern parts of the study area (Fig. 6.26). The high drainage density area indicates low-infiltration rate whereas the low-density areas are favourable with high infiltration rate.

Lineament density

Sabins (2000) have defined lineaments as extended mappable linear or curvilinear features of a surface whose parts align in straight or nearly straight relationships that may be the expression of folds, fractures, or faults in the subsurface. Several sets of lineaments have been identified from the imageries of the study area of Payappara subwatershed (Fig 6.27). Areas with such high lineament density usually host high-yielding aquifers especially at the zones of intersection. Nair (1990) has identified five major sets of lineaments in Kerala as a whole, but the most dominant trends in the study area are NNW-SSE, NW-SE and ESE-WNW. The lineaments can be correlated with the fractures and joints in the rocks of the area. The Payappara subwatershed is very much within an area marked by historic as well as recent low-intensity seismicity. The river courses follow the lineament trends and the NNW-SSE lineaments cut across E-W trending course of Meenachil River. The shifts north and south from the E-W trend of Meenachil river could be due to the shifts along the later NNW-SSE lineaments (Rajendran et al., 2009).
Fig. 6.26: Drainage density map Payappara subwatershed
Fig. 6.27: Lineament density map Payappara subwatershed
Chapter 6  Assessing Groundwater Potentiality

Although lineaments have been identified throughout the area, it is the lineaments in the Lower plateau lateritic (LPL) which is considered significant from groundwater occurrence point of view. Those across the denudational hills (DH), residual hills (RH) and high-slope area or in the area occupied by clay zones are of less significance as there could be high runoff along them and these may act only as conduit to transmit infiltrated rain water.

Slope

Slope is an important factor for the identification of groundwater potential zones. Higher degree of slope results in rapid runoff and increased erosion rate with feeble recharge potential (Magesh et al., 2011a & b). A slope map prepared from the Survey of India toposheets of the study area is shown in Fig. 6.28. The identified slope category varies from 1° to >35° in the study area and are classified into five classes like, 0–8° (gentle slope), 9–15° (moderate slope), 16–25° (pronounced slope), 26–35° (steep slope) and >35° (very steep slope).

Based on the slope, the study area can be divided into five slope classes. The areas having 0-8° slope fall into the ‘very good’ category because of the nearly flat terrain and relatively high infiltration rate. The areas with 9° -15° slope are considered as ‘good’ for groundwater storage due to slightly undulating topography with some runoff. The areas having a slope of 16°–25° are categorized as ‘moderate’. The areas having a slope of 26–35° cause relatively high runoff and low infiltration, and hence are categorized as ‘poor’ and areas having a slope >27° are considered as ‘very poor’ due to higher slope and runoff.

Landuse/land cover

Land cover/land use is a significant factor affecting the recharge process. This factor involves a number of elements but the major ones are the soil deposits, human settlements and vegetation cover. The major effect of soil deposits on water percolation into the subsurface media is attributed to its clayey content, as it controls the retention capacity of water. It is usually related to the terrain slope. Their geographic distribution in
the study area is obviously different. Isolated thin soil deposits can be found in the mountainous regions, while thick and well-developed soil deposits are located on relatively flat areas. However, thick accumulations of soil deposits reduce the rate of water percolation. The human settlement has a definite role in retarding the recharge process. Man-made constructions, such as concrete embankments, buildings, roads, etc. create a compacted terrain that seals the ground surface, thus preventing water to recharge easily (Bou Kheir et al., 2003). Vegetation cover can be considered as an enhancing one, notably in the humid tropical climate. In this respect, the higher the vegetation cover, the higher the evapotranspiration rate and this implies less chance for percolation to the subsurface layers. But the density of the cover has to be considered as well as its geographic extent. Nevertheless, these processes are contradictory. First, the biochemical disruption of the terrain surfaces, whether it is soil or rock, by the roots and organisms. Second is that the vegetal cover helps in confining the water under the vegetal zone (in an umbrella scheme), therefore preventing water from direct evaporation. The third is the ability of plants to hold soil in place rather than to erode with an increase in water runoff. In summary, it can be assumed that the vegetation cover is an effective factor in the enhancement of recharge rate.

The identified landuse/land cover features from the IRS imagery of the study area are agricultural land (palm, rubber and tea plantations, paddy fields and cropland), waste land (land with or without scrub and barren rocky area), water bodies (river), mixed vegetation, grasslands and built-up land. Out of the total area, >85 % is falling under rubber plantation. From figure 6.29, it is clear that about >70 % come under the category of suitable (value 2) groundwater potential, whereas 20% shows the potential value of 4 (less suitable) (Fig. 6.30). Very few areas are covered by the values of 3 (good to very good) and 5 (poor to very poor).
Chapter 6  Assessing Groundwater Potentiality

Fig. 6.28: Slope map Payappara subwatershed
Fig. 6.29: Landuse map Payappara subwatershed
Fig. 6.30: Groundwater potential zone map Payappara subwatershed
6.4.5 Thikovil subwatershed (W5)

Thematic layers

Geomorphology

The study area has a dominant rocky terrain, which is manifested by hills and undulating surfaces. Nine distinct geomorphologic units have been identified and delineated from the study area (Fig. 6.31); include structural hills, structural valley, residual mounds, denudational hills, lower plateau lateritic, piedmont, flood plain and valley. These distinct geomorphic features are resulted from the complexity of geomorphic evolution. The distribution and extent of these geomorphic zones are varying from place to place. Floodplain deposits occur mainly along the stream channels in the southern and eastern part of the study area. Valley-fill deposits are generally unconsolidated alluvial and colluvial materials consisting of sand, silt, gravels, pebbles, etc., deposited along the floor of a stream valley. This type of landform is mostly present along the major river systems of the study area with a width of 3–4 km. Except for the eastern portion where mainly floodplain deposit and valley-fill deposit types of geomorphologic features predominate. These units are characterized by the high porosity and permeability resulting in high infiltration rate. The geomorphic units such as valley fill and valley flat are good to excellent potential zones. The upstream regions of Thikovil subwatershed are mainly characterized by the structural and denudational hills. The structural hills are controlled with complex folding, faulting and criss-crossed by numerous joints which facilitate some infiltration and mostly act as null off zones. These hills are structurally controlled with complex folding, faulting and criss-crossed by numerous joints/fractures, which facilitate some infiltration and mostly act as run off zones. These units are found to be at northwestern parts of the study area. The slope of the hills ranges more than 3 degree. The denudational hills are marked by sharp to blunt crest lines with rugged tops indicating that the surface runoff at the upper reaches of the hills has caused hill erosion. The most dominant geomorphic unit in the basin is denudational slopes which cover more than 40% of the total area. The residual mounds are mainly concentrated in the midstream to downstream regions. Among various geomorphic units, structural hill,
denudational hill, lateritic upland and residual mound are considered as moderate to poor potential zones.

**Lithology**

Of course, the lithologic character of the exposed rocks is significant in governing recharge. Some studies neglected this factor once they use the lineament and drainage (El-Shazly, *et al.*, 1983; Edet *et al.*, 1998). This is because they consider the lineaments and drainage characters as a function of primary and secondary porosity, thus providing information on the lithology. But others (Salman, 1983; El-Baz and Hamida, 1995) incorporate the lithology factor because of its strong influence on water percolation. In this paper, the lithology is used to serve confirming and supporting assessment of recharge factors. This will tend to minimize erroneous interpretations that may result from using lineaments and drainage factors alone.

The area forms part of the Precambrian granulite terrain and it is traversed by intrusives of later age (Fig. 6.32). The main rock types of the area belong to Charnockite Group of Archaean age. This group includes charnockite and pyroxene granulite. The quartzite belong to Khondalite group of Archaean age, biotite gneiss belongs to Migmatite complex of Archaean age and granite belongs to Acid intrusives of Proterozoic age are also present in the basin. NNW – SSE and NW – SE trending numerous dolerite and gabbro intrusions belong to Basic intrusives of Mesocainozoic age are the main attractions regarding the petrology of the area (Ajaykumar 2010).

**Drainage density**

The drainage density is an inverse function of permeability. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. This gives rise to a well-developed and fine drainage system. Since the drainage density can indirectly indicate the suitability for groundwater recharge of an area because of its relation with surface runoff and permeability, it was considered as one of the indicators of artificial groundwater recharge. Drainage density measurements range from 0.5 to 2.62 km km\(^{-2}\). The drainage density map for the study area is shown in Fig. 6.33.
Based on the drainage density of the micro-basins, it can be grouped into three classes: (1) 0–0.75 km km$^{-2}$, (2) 0.75–1.5 km km$^{-2}$ and (3) 1.5–2.62 km km$^{-2}$ as illustrated in Fig. 6. Accordingly, these classes have been assigned to ‘good,’ ‘moderate’ and ‘poor’ categories, respectively. Most of the study area (90%) has a drainage density of 0.75–1.5 km km$^{-2}$. High drainage density is recorded in the north and eastern parts of the study area (Fig. 6.33).

**Lineament density**

Sabins (2000) have defined lineaments as extended mappable linear or curvilinear features of a surface whose parts align in straight or nearly straight relationships that may be the expression of folds, fractures, or faults in the subsurface. Several sets of lineaments have been identified from the imageries of the study area of Thikovil subbasin (Fig. 6.34). Areas with such high lineament density usually host high-yielding aquifers especially at the zones of intersection. Nair (1990) has identified five major sets of lineaments in Kerala as a whole, but the most dominant trends in the study area are NNW-SSE, NW-SE and ESE-WNW. The lineaments can be correlated with the fractures and joints in the rocks of the area. The Thikovil subwatershed is very much within an area marked by historic as well as recent low-intensity seismicity. The river courses follow the lineament trends and the NNW-SSE lineaments cut across E-W trending course of Meenachil River. The shifts north and south from the E-W trend of Meenachil river could be due to the shifts along the later NNW-SSE lineaments (Rajendran et al., 2009).

Although lineaments have been identified throughout the area, it is the lineaments in the valley fill (VF) which is considered significant from groundwater occurrence point of view. Those across the denudational hills (DH), residual hills (RH), in the high-drainage density and high-slope area or in the area occupied by clay zones are of less significance as there could be high runoff along them and these may act only as conduit to transmit infiltrated rain water.
Fig. 6.31: Thematic layer of geomorphology Thikovil subwatershed (Ajaykumar, 2010)
Chapter 6 
Assessing Groundwater Potentiality

Fig. 6.32: Thematic layer of lithology Thikovil subwatershed (Ajaykumar, 2010)
Fig. 6.33: Drainage density map Thikovil subwatershed
Assessing Groundwater Potentiality

Fig. 6.34: Lineament density map Thikovil subwatershed
Chapter 6  Assessing Groundwater Potentiality

Slope

Slope is an important factor for the identification of groundwater potential zones. Higher degree of slope results in rapid runoff and increased erosion rate with feeble recharge potential (Magesh et al., 2011a & b). A slope map prepared from the Survey of India toposheets of the study area is shown in Fig. 6. The identified slope category varies from 1° to >35° in the study area and are classified into five classes like, 0–8° (gentle slope), 9–15° (moderate slope), 16–25° (pronounced slope), 26–35° (steep slope) and >35° (very steep slope) (Figure 6.35).

Based on the slope, the study area can be divided into five slope classes. The areas having 0-8° slope fall into the ‘very good’ category because of the nearly flat terrain and relatively high infiltration rate. The areas with 9° -15° slope are considered as ‘good’ for groundwater storage due to slightly undulating topography with some runoff. The areas having a slope of 16°–25° are categorized as ‘moderate’. The areas having a slope of 26–35° cause relatively high runoff and low infiltration, and hence are categorized as ‘poor’ and areas having a slope >27° are considered as ‘very poor’ due to higher slope and runoff.

Landuse/land cover

Landuse/land cover is an important factor in groundwater recharge. It includes the type of soil deposits, the distribution of residential areas, and vegetation cover. Shaban et al. (2006) concluded that vegetation cover benefits groundwater recharge in the following ways. (1) Biological decomposition of the roots helps loosen the rock and soil, so that water can percolate to the surface of the earth easily. (2) Vegetation prevents direct evaporation of water from soil. (3) The roots of a plant can absorb water, thus preventing water loss. Leduc et al. (2001) estimated the difference in the amount of groundwater recharge due to changes of land utilization and vegetation from changes in the groundwater level. Land use/cover was included in this study as an important factor affecting the groundwater recharge process.
Chapter 6  Assessing Groundwater Potentiality

Fig. 6.35: Slope map Thikovil subwatershed

A WATERSHED APPROACH FOR SUSTAINABLE ECOSYSTEM MANAGEMENT OF MEENACHIL RIVER BASIN WITH EMPHASIS ON REMOTE SENSING AND GIS
Fig. 6.36: Landuse map Thikovil subwatershed
Fig. 6.37: Groundwater potential zone map Thikovil subwatershed
The identified landuse/land cover features from the IRS imagery of the study area are agricultural land (palm, rubber and tea plantations, paddy fields and cropland), waste land (land with or without scrub and barren rocky area), water bodies (river), mixed vegetation, grasslands and built-up land. Out of the total area, >76% is falling under rubber plantation. From the figure 7, it is clear that about >75% come under the category of suitable (value 2) groundwater potential, whereas 20% shows the potential value of 4 (less suitable) (Fig. 6.36). Very few areas are covered by the values of 3 (good to very good) and 5 (poor to very poor). No area comes under the category of highly suitable with a value of 1.

6.5 Conclusion

The ultimate objective of the investigation was to find out the areas, which are promising groundwater in the hard rock terrain of the Western Ghats. In the present study, the choice among a set of zones for development of groundwater is based upon multiple criteria, which gives linear combination of probability weights for lithology, geomorphology, lineament density, drainage density, slope and land use/land cover. The composite map represents regions with weight factors as values. The integrated final map has generated a range of values from 1–5, which is reclassified into four zones, to represent the groundwater potentiality of the area. The groundwater potentiality is classified as suitable, moderately suitable, less suitable and highly unsuitable. Majority of the area come under the moderately suitable category. Hydrogeomorphological units such as fracture valley, valley fill pediments and denudational slope are potential zones for groundwater exploration and development of the study area. In the study area, slope and lineaments play a significant role in groundwater potentiality. Lineaments, particularly joints, fracture and their intersection enhances the potential of hydrogeomorphic units. Areas with high lineament density are good for groundwater development. The lineaments mapped from the satellite images cut across slope categories and litho-units, thereby indicating the possibility of acting as major conduits for subsurface movement and linear aquifer for the storage of water. It has been observed in the field and from the groundwater potential map; the gentler slope has more potential for groundwater.
Chapter 6 Assessing Groundwater Potentiality

Thus the above study has demonstrated the capabilities of a remote sensing data and GIS technique for demarcation of groundwater potential zones in hard rock terrain. This vital information could be used effectively for identification of suitable locations for extraction of potable water for rural populations. The current multiparametric approach using GIS and remote sensing is holistic in nature and will minimize the time and cost especially for identifying groundwater-potential zones and suitable site-specific recharge structures, especially in hard rock terrain on a regional as well as local scale, thus enabling quick decision-making for water management.

6.6 References


Chapter 6 Assessing Groundwater Potentiality


Chapter 6 Assessing Groundwater Potentiality


Chapter 6 Assessing Groundwater Potentiality


Chapter 6  Assessing Groundwater Potentiality


Chapter 6 Assessing Groundwater Potentiality


Chapter 6 Assessing Groundwater Potentiality


Chapter 6  Assessing Groundwater Potentiality


