CHAPTER-4

GEOSPATIAL TECHNIQUE

Remote sensing is the science and technology of learning about an object, region, or phenomenon by analyzing data collected by a device placed far away (remotely) from the object, area, or phenomenon being evaluated. The application of remote sensing in groundwater exploration is seen mainly in its cost-effectiveness of well site selection (Lillesand and Kiefer 2000).

4.1 Review of literature related to remote sensing technique

Numerous satellite sensors have been launched into orbit since the early 1960s to view and monitor the Earth and its surroundings. The majority of early satellite sensors collected data for meteorological applications. When the first Landsat satellite was launched in July 1972, it marked the beginning of earth resources satellite sensors (those with the primary goal of mapping and monitoring land cover). Currently, over a dozen orbiting satellites offer critical data for improving our understanding of the Earth's atmosphere, oceans, snow, ice, and land (http://www.ciesin.org/TG/RS/sensors.html).

4.2 Basic principle of the remote sensing technique

Visible light is one of the different types of electromagnetic radiation, and it encompasses a wide range of wavelengths as shown in Figure 4.1. When electromagnetic energy (EM) reaches the Earth's surface, objects interact with it in distinct ways, reflecting, absorbing, or transmitting energy based on their physical properties. These interactions within the visible spectrum give rise to the diverse colors observed in different objects. By measuring the proportion of incident energy that is reflected, we can measure the reflective properties of Earth's surface features. This measurement, known as spectral reflectance, is determined based on wavelength and can be depicted as a spectral reflectance curve. The choice of wavelength regions during data acquisition for a specific investigation is strongly influenced by this curve. The information from one or more wavelength ranges can be utilized to identify various types of ground objects, such as vegetation, wet soil, dry soil, water, and snow as shown in Figure 4.2.

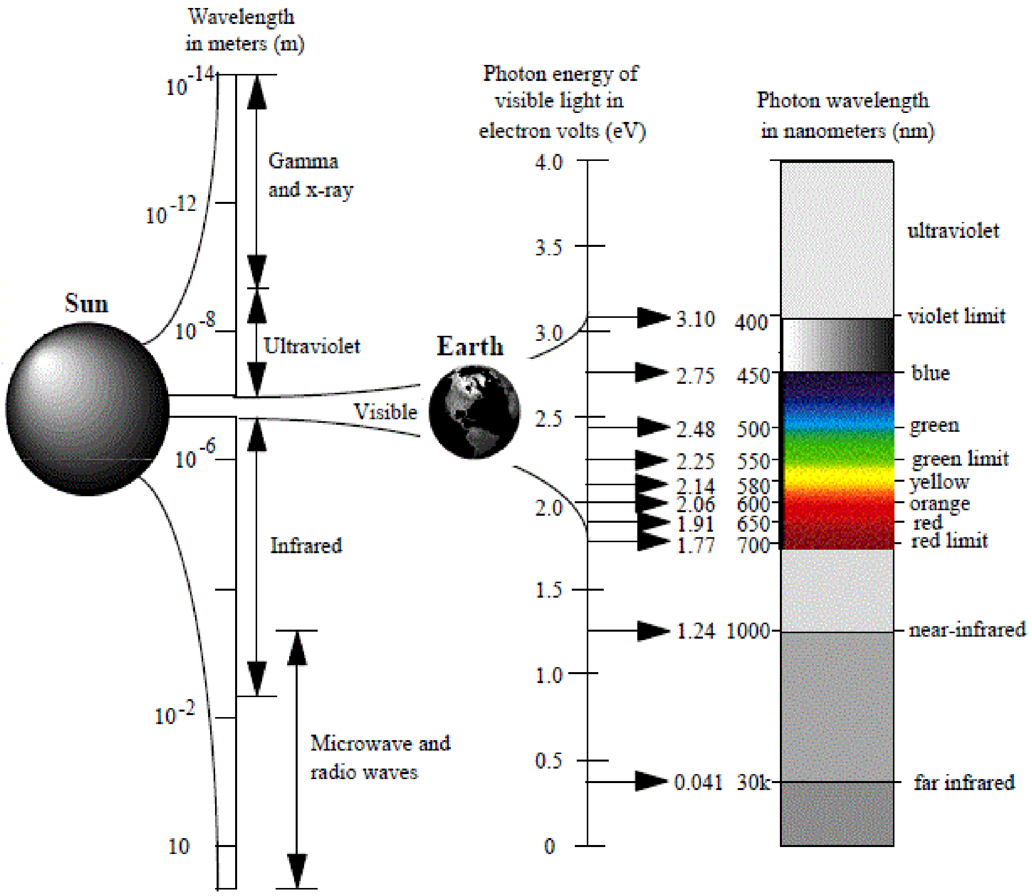

Figure 4.1 Electromagnetic spectrum and the photon energy of visible light (Jensen 2004).

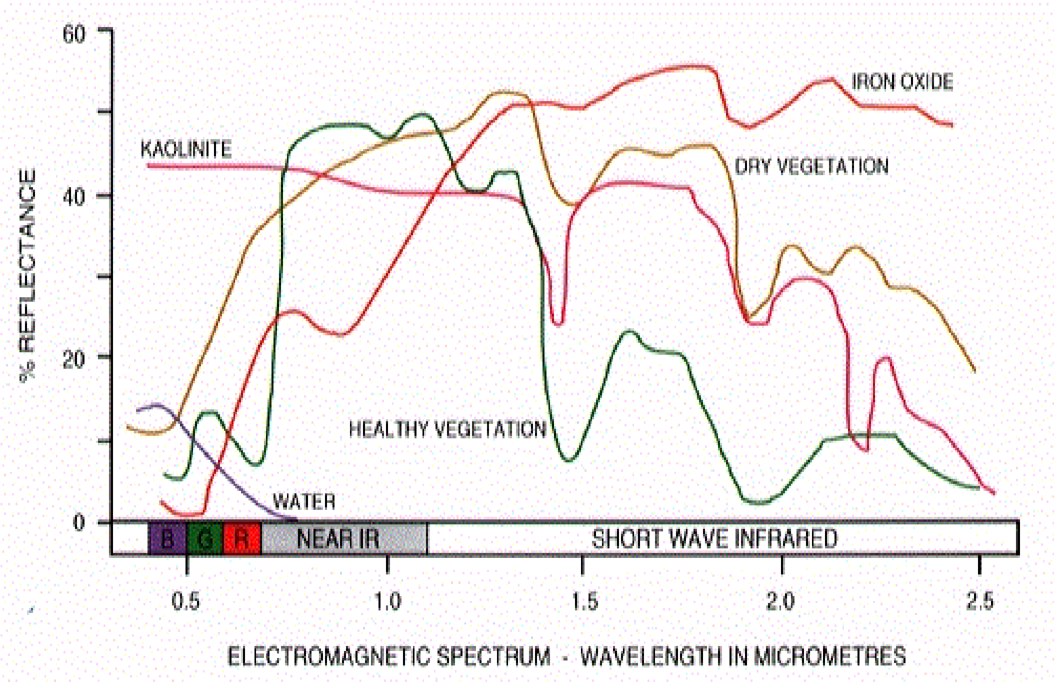

Figure 4.2 Curves of Spectral reflectance of some selected objects (Singhal and Gupta, 1999).

4.3 Material and Methods

4.3.1 Data collection

In the present study, the LANDSAT-TM (Path-142/ Row-043) data is used. The multispectral satellite image acquired from the LANDSAT-TM sensor consists of seven bands: Blue (0.45-0.515 µm), Green (0.525-0.605 µm), Red (0.63-0.69 µm), Near Infrared (0.75-0.90 µm), Shortwave IR-1 (1.55-1.75 µm), Thermal IR (10.4-12.5 µm), and Shortwave IR-2 (2.09-2.35 µm). The survey of India toposheets 63L/12 and 63L/16 with a scale of 1:50,000 are used as a source of ancillary information. To generate slope and shaded relief maps, the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) is utilized. Geographic Information System

(GIS) and Image Processing software such as ARC VIEW, ARC GIS, and ERDAS IMAGINE are employed for the analysis and mapping of the various layers.

4.3.2 Satellite data analysis and spatial database building

As described by Arkoprovo et al. (2012), the primary objective is to conduct the interpretation and analysis of satellite data to create thematic maps, including structural, lithology, land use maps, etc. The initial step involves the calibration of all images using the Survey of India (SOI) toposheet. Subsequently, the digitized images undergo processing techniques such as augmentation, filtering, categorization, and other operations within the Geographic Information System (GIS) framework.

The main task in the development of a spatial database involves the integration of relevant and associated collateral data into a GIS database. All available spatial data is compiled in a digital format and appropriately registered to ensure precise spatial alignment. Maps and collateral data are digitized and subsequent procedures such as transformation, conversion from vector to raster, buffer analysis, gridding, box calculation, interpolation, and other GIS techniques are employed. This stage leads to the creation of derived layers, including drainage, drainage density, geomorphology lithology, slope, surface water bodies, lineament density, and various other layers (Arkoprovo et al., 2012).

4.4 Generation of thematic maps

LANDSAT-TM (Path-142/ Row-043) is used in demarcating the water bodies and also in evaluating numerous lineaments and also in generating thematic maps. SRTM data is also utilized in preparing the slope map along with the SOI toposheet.

4.4.1 Geomorphology map

The geomorphologic map is prepared using a visual interpretation of the geohydrological properties of the study areas and LANDSAT-TM data at a 1:50,000 scale. The different geomorphologic units have been delineated utilizing the photogeologic elements 21, including texture, tone shape, size, association, and so on. Six distinct geomorphic units have been identified as a result of the analysis (Figure 4.3), which are systematically discussed with respect to the groundwater prospect.

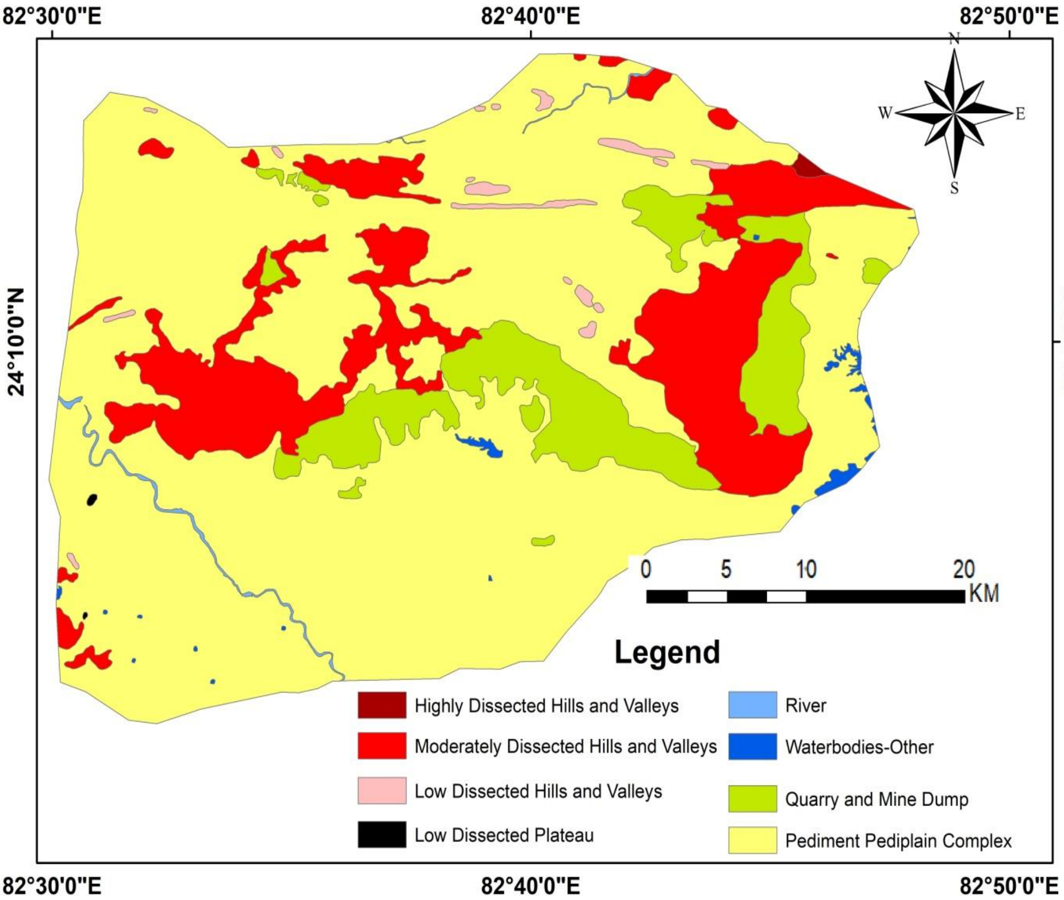

Figure 4.3 Geomorphological map of the study

(1) Dissected hills and valley

The formation of secondary structures, i.e., lineaments such as fractures or joints, is mainly responsible for dissection. The region's highly dissected hills and valleys belong to the Raniganj formation on the eastern side. Here rocks are composed of fine to medium-grained dirty to buff-colored sub-arkose to feldspathic wacke with alteration of thin lamination of grey and carbonaceous shale along with impersistent coal seams. This region is highly dissected by large numbers of lineaments, thus resulting in large numbers of the drainage system.

Moderately dissected hills and valleys were identified in a large portion of the study area, mainly in the eastern, western, and some parts of the northern region. In these regions, active opencast mining is going on, and blasting is regularly done to excavate overburden. This region belongs to the Talchir, Barakar, and Raniganj formations. Here, rocks in the Barakar formation are composed of sub-arkosic to arkosic sandstone along with siltstone, shale, carbonaceous shale, and coal seams. The Raniganj formation rocks are formed of a thin lamination of grey and carbonaceous shale along with coal seams. The Talchir formation rocks are fine-grained sandstone, pebbly sandstone, diamictite, boulder bed, and siltstone.

Low dissected hills and valleys are scattered in patches, mainly in the northeastern and some parts of the western region. The rock in these regions belongs to the Chhotanagpur gneissic complex and the lower Gondwana group. The rock in these regions comprises granite, gneiss, quartzite, phyllite, schist, and pegmatite

(2) Low-dissected Plateau

A plateau surface is generally underlain by a resistant rock layer, such as sandstone, quartz, or massive limestone. A plateau's dissection may reveal underlying strata of different resistance, the stronger of which will sustain structural benches along the valley's sides. Tilting of strata causes differential denudation, in which weaker rock complexes erode into valleys or rolling plains, while more resistant rocks form parallel ridges, escarpments, or mid-slope ledges (Goudie, 2004). The low dissected plateau covers a very small area found in the study area's western part.

(3) Pediment Pediplain complex

The term "pediments" refers to exposed rock surfaces that are open and visible. The formation of pediments involves complex processes such as weathering, rill wash, and mass wasting. Stream erosion, mass wasting, sheet wash, and sheet flood, as discussed by Ahmad (1985). However, King (1967) emphasizes that running water is the chief agent behind their creation. Pediments are characterized by gently sloping rock floors, featuring eroded bedrock with low relief situated between hills and plains. These formations result from weathering processes and consist of a compact rocky surface layer with numerous fractures and joints, allowing for the infiltration and storage of groundwater (Deepika et al., 2013). This region covers around 60% of the study area and promotes crop cultivation.

(4) Quarry and Mine dump

A quarry is a location where structural stone or aggregate (coal, sand, gravel, or crushed rock) is mined. Dimension stone quarries produce prismatic blocks of rock such as coal, marble, granite, limestone, sandstone, and slate. Dimension stones are mined carefully, utilizing time-consuming and expensive techniques to isolate the blocks from the surrounding rock. Quarrying involves drilling and blasting to fracture the rock. A massive number of charges are fired simultaneously, producing up to 20,000 tons of broken stone in a single explosion.

Mine dump (Overburden) in mining refers to material that lies above a region that lends itself to commercial exploitation, such as the rock, soil, and ecology that lies above a coal seam or ore body. Overburden is different from tailings, which are the materials that remain after economically valuable components have been taken from the normally finely mined ore. Surface mining removes overburden, which is often not polluted with harmful toxins. Overburden may be used to restore an exhausted mining area during the mine reclamation.

Coalfields and overburden are found in the pattern of W shaped in the central, eastern, and western parts of the study area.

(5) Water bodies and other

The primary water bodies in the study area are the Govind Vallabh Pant reservoir, Kachani River, Motwani Dam, and various Nallas. Govind Vallabh Pant reservoir is located on the south-eastern side of Amlohri block, Kachani River is on the south-western side of Moher block, and Motwani dam is on the south side of Jayant block.

4.4.2 Slope Map

The study area's slope map was produced using a DEM generated from ASTER data and exported to ArcGIS software. The slope has been classified into five categories: very gentle (0°-3.5°), gentle (3.6°-8.0°), moderate (8.01°-14.31°), steep (14.32°-27.1°), and very steep(27.2°-57.03°) as shown in Figure 4.4.

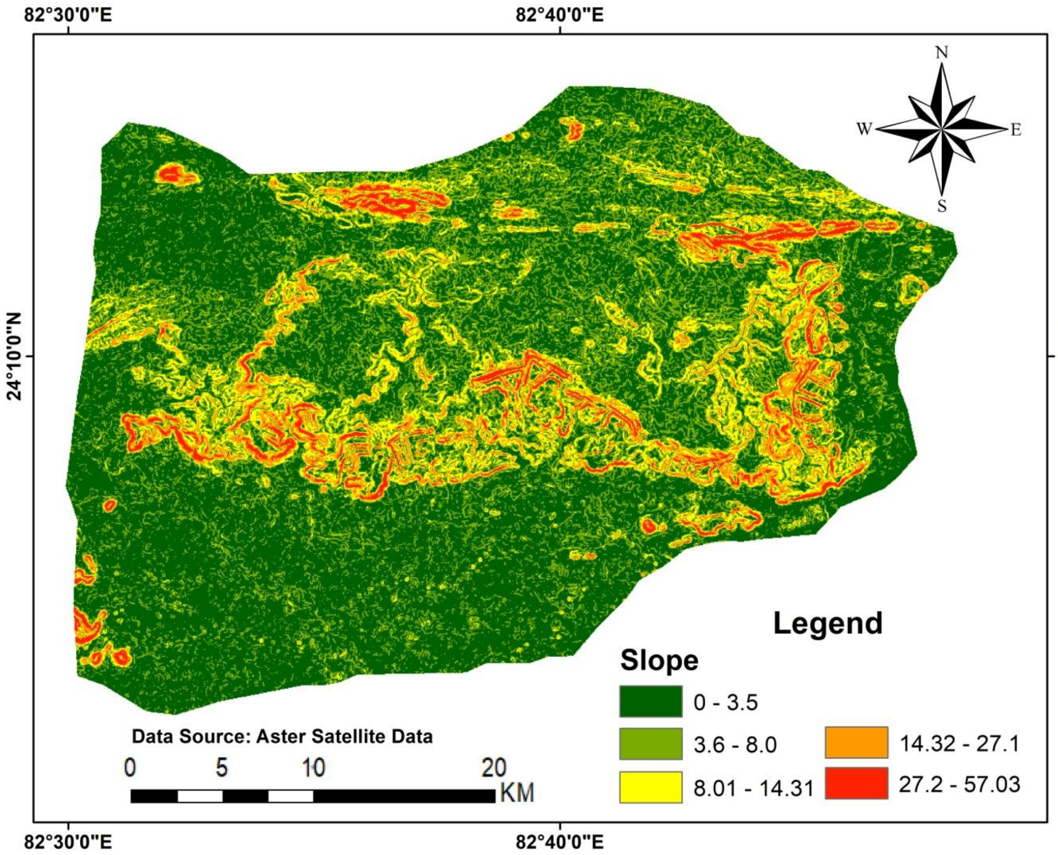

Figure 4.4 Slope map of the study area

The very gentle and gentle slope is identified in the significant part of the study area in the north and south, whereas moderate and steep slopes are observed in the north-east, north-west, south-east, and central region, and very steep slopes are found in the east and central part. Due to the overburden dump, a steep slope has occurred in the shape of a W in the central portion of the study area. The slope is always an essential factor in determining groundwater potential. A steep slope will cause more runoff and less infiltration, resulting in a poor groundwater prospect compared to a gentle slope region.

4.4.3 Digital elevation model (DEM)

A digital elevation model (DEM) shows the topography of the earth's surface. The topography of the sub-basin is based on a digital elevation model produced using

SRTM data, which is made available on several USGS websites .A digital elevation model (DEM) shows the topography of the earth's surface. The SRTM data is overlaid with the study area's coordinates, and the DEM is prepared for the specified boundaries assigned to the software as shown in Figure 4.5. According to the DEM, altitudes ranges from 194 to 642 meters above mean sea level (mamsl).

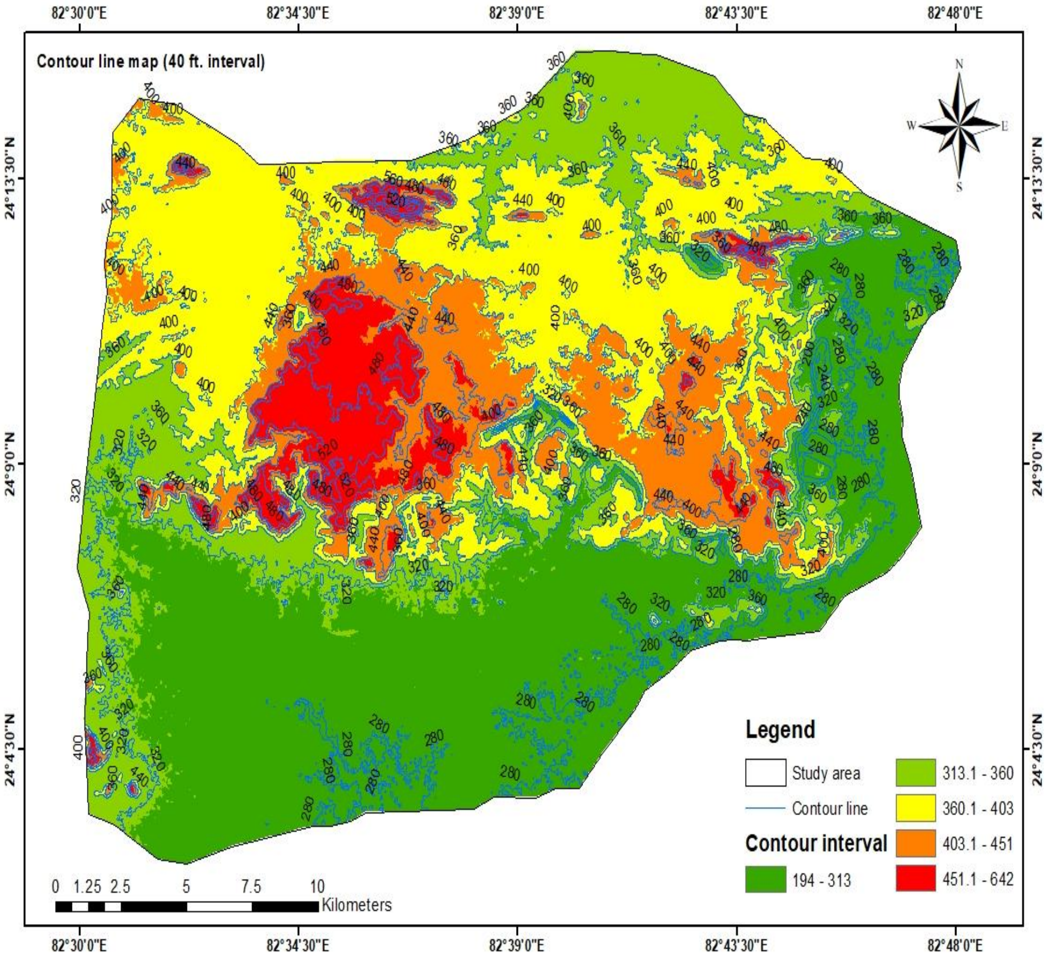

Figure 4.5 Digital elevation model (DEM) of the study area.

The study area has a steep, undulating topography. The general elevation above mean sea level (amsl) ranges from 235 meters in the plains to more than 550 meters on the plateau, as shown in Figure 4.5. The eastern portion of the study area in Uttar Pradesh is characterized physiographically by a cluster of hills and a plateau to the north and an undulating plain to the south. The geography of the mining block region is undulating and hilly, sloping in three different directions: east, west, and south. The coalfields stand as a high plateau above the surrounding plains covered with Barakar, Talchir, and Raniganj deposits, and the plateau's base spreads to roughly 325 m above mean sea level.

4.4.4 Drainage map

The drainage system plays a more significant role in shaping ecological patterns as well as the socio-cultural life of man. It is influenced by certain physical factors like climate, relief, geology, structure, natural vegetation, etc., and socio-cultural factors such as agriculture, land use, and other anthropogenic features. Drainage mainly serves to remove surplus water from an area. A surface drainage map (Figure 4.6) is prepared from SOI toposheet at 1:50,000 scale and satellite data (described in chapter-3 as Figure 3.3). The drainage pattern is mostly dendritic in nature. Details of the drainage pattern of the study area are discussed in the third chapter.

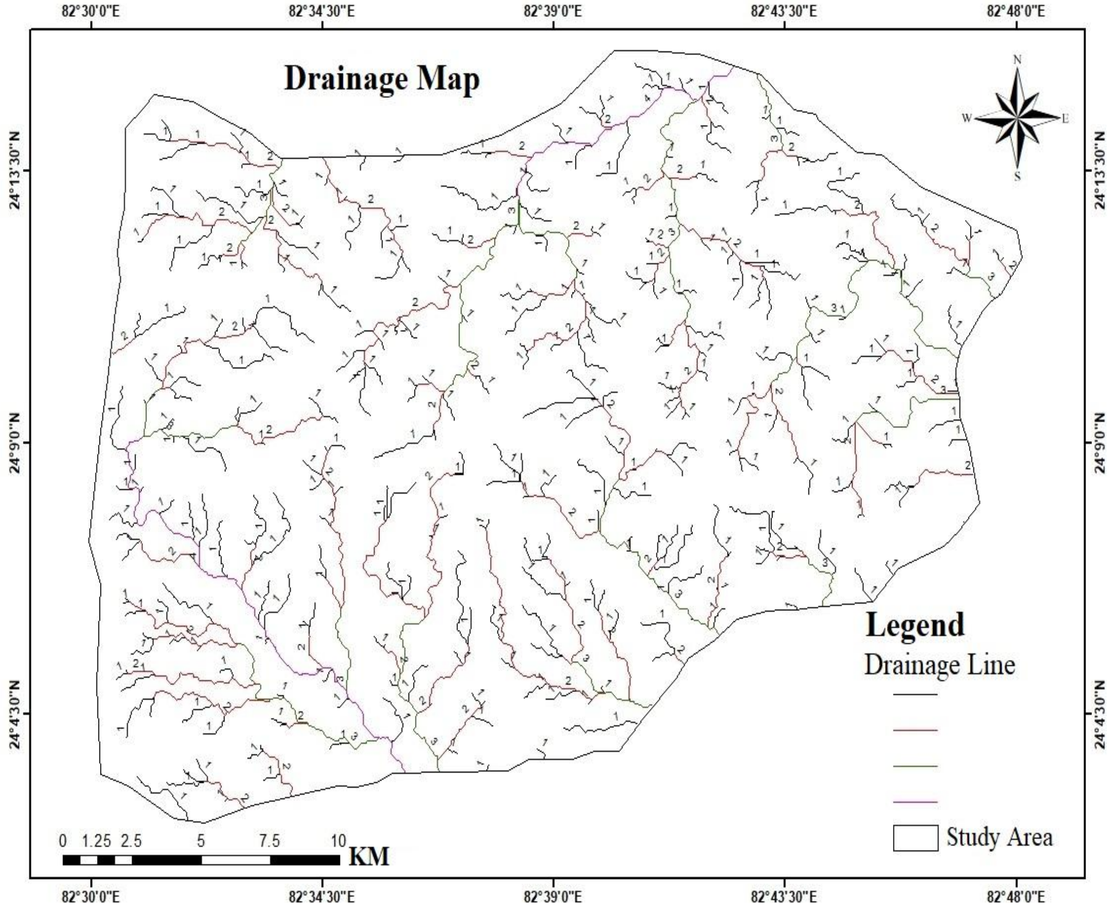

Figure 4.6 Drainage map of the study area.

4.4.5 Lineament and Lineament density

Lineaments play an important role in the detection and exploration of various resources such as groundwater, hydrocarbons, mineral deposits, and geothermal energy. They also serve as important indicators for monitoring earthquakes and landslides (Guild, 1974; Dix and Jackson, 1981; Boucher, 1995; Rowland and Sibson, 2004; Masoud et al., 2007). Key properties of lineaments, such as their spatial coverage, density, intersection, and orientation, have been confirmed to be crucial in these endeavors. They provide insights into zones and patterns of porous structures and areas with low pressure, which can serve as migration pathways and targets for increased reserves. Lineaments can also indicate faults that influence the formation of basins and the distribution of resources (Warner, 1997). Regional lineaments are often considered surface manifestations of weaker geological zones along tectonic boundaries of basins and plates, as well as faults and fractures in rocks. These lineaments are normally associated with partially weathered zones that exhibit increased porosity and permeability. The lineament map of the study area is depicted in Figure 4.7.

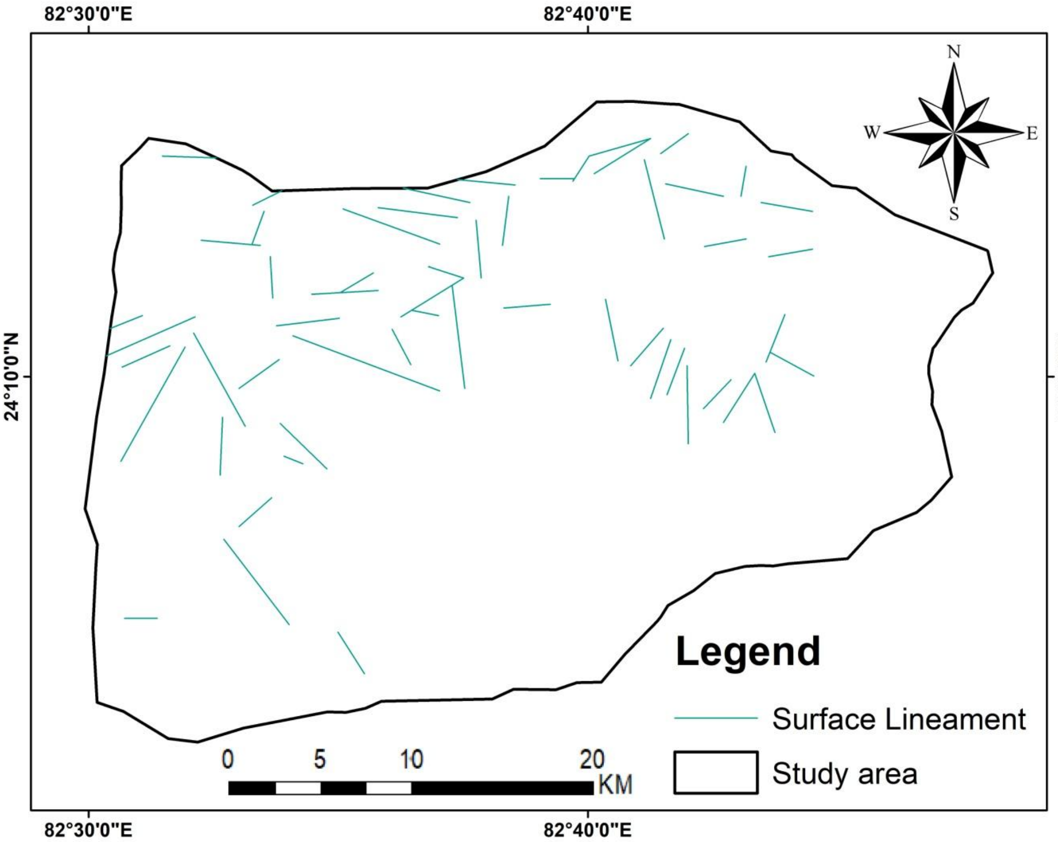

Figure 4.7 Lineament map of the study area.

Meanwhile, several studies investigated correlations between groundwater production and the number of lineaments within specified locations (Hardcastle, 1995). As a result, mapping the lineaments associated with the occurrence and production of groundwater is crucial for the assessment, development, and management of groundwater resources. Several groundwater exploration activities have reported improved success rates when drilling or conducting detailed geophysical surveys based on lineament mapping using satellite images (Teme and Oni, 1991).

Satellite images produce better information than traditional aerial photographs due to their many capabilities, such as synoptic aerial coverage, multispectral data captivity, temporal resolution, and so on (Lillesand and Kiefer, 1999), so they were chosen for the task of extracting surface lineament. The median filter is quite effective for eliminating isolated random noise. A 3*3 median filter is applied to all bands of LANDSAT-TM (Path-142/Row-043) satellite images. Surface lineament may be extracted in large part using digital image enhancement techniques. Spectral rationing (Arlegui and Soriano, 1998), filtering techniques (Suzan and Topark, 1998), and principal component analysis (PCA) (Qari, 1991; Nama, 2004) are the most commonly used image improvement methods.

The Singrauli basin's northern boundary is characterized by a significant east-west boundary fault, which is most likely an offshoot of the Son-Narmada lineament as shown in Figure 4.7. The coal-bearing strata strike in an east-west direction, and the strata dip ranges from 1° to 5° in a northward direction. The northern and northwest portions of the Singrauli coalfield are predominantly affected by different fault systems. The lineament density map is shown in Figure 4.8.

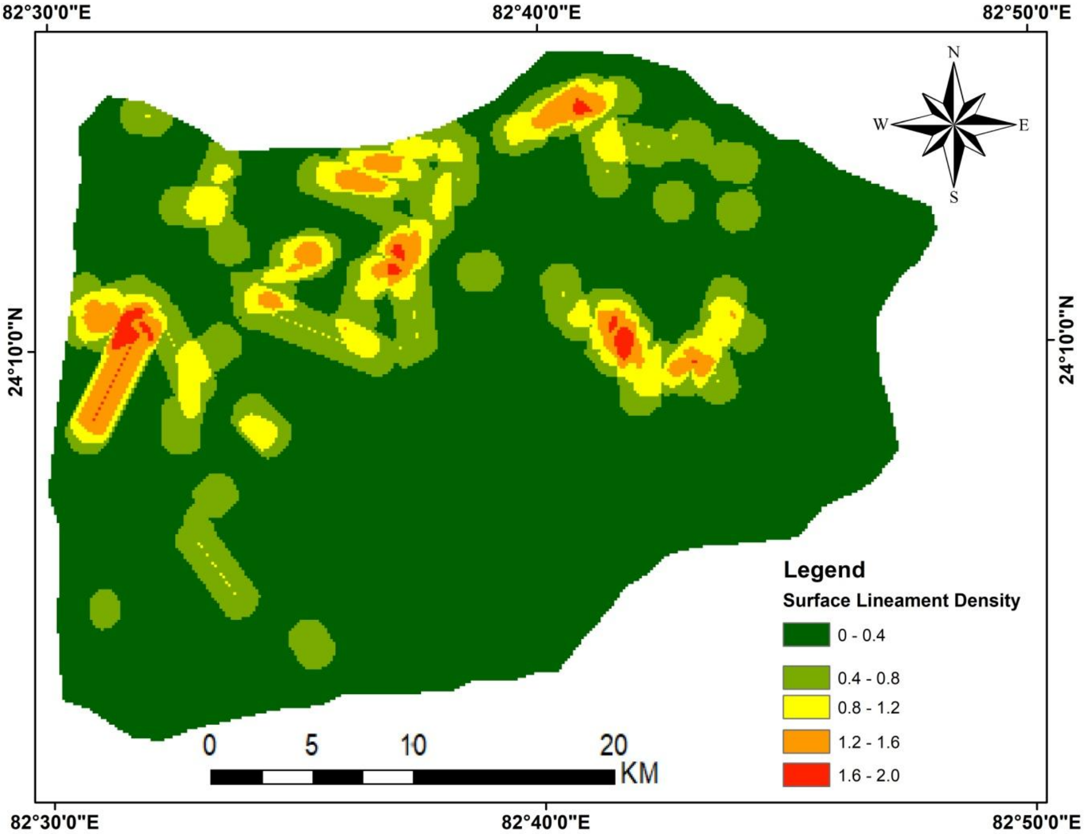

Figure 4.8 Lineament density map of the study area.

4.4.6 Land Use and land cover Map (LULC)

Through visual interpretation, an attempt has been made to recognize and map the different types of land use and land cover classes in the study area. The categorization system developed by the remote sensing agency (NRSA, 1990) has been utilized for this purpose. The terms "land use" and "land cover" encompass various elements such as natural vegetation, water bodies, rock/soil, human-made structures, and other manifestations of land transformation (Balachandar et al., 2010). The land use and land cover map of the study area can be observed in Figure 4.9.

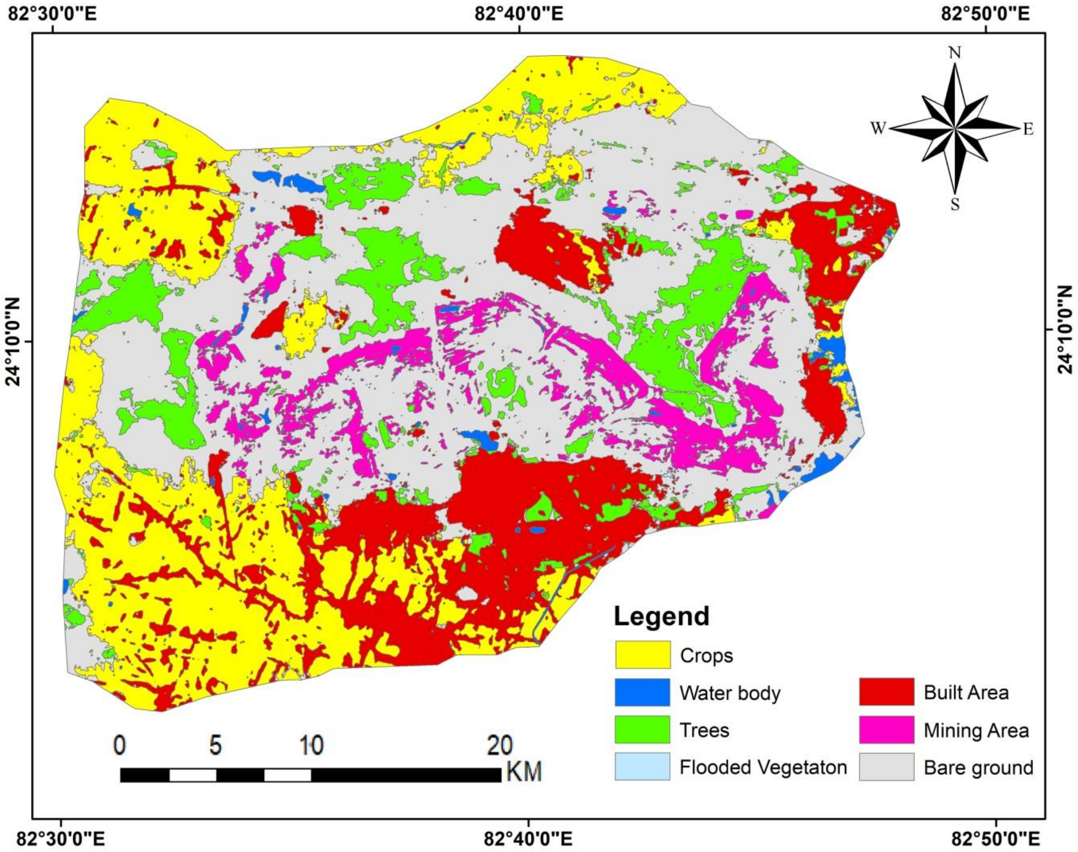

Figure 4.9 Land use and land cover map of the study area

The land use/land cover map has been generated at a scale of 1:50,000 using data from LANDSAT-TM (Path-142/Row-043). The land use map is created by analyzing satellite data and identifying specific elements such as tone, texture, drainage patterns, structural features, and relief present in the imagery. The resulting map delineates different classes of land use/land cover in the study area, including cropland, surface water bodies, tree cover, flooded vegetation, built-up areas, mining areas, and bare ground as shown in Figure 4.9

Table 4.1: Land use/ Land cover classification scheme used in the study area.

Code	Class	Color	Area (Sq.km)	Area in (%)
1	Cropland	Solar Yellow	124.78	23.87
2	Surface Water body	Cretan Blue	5.72	1.09
3	Trees	Medium Apple	50.67	9.69
4	Flooded Vegetation	Sodalite Blue	0.07	0.01
5	Built area	Poinsettia Red	92.32	17.66
6	Mining area	Ginger Pink	35.12	6.72
7	Bare ground	Gray 10%	213.86	40.92
		Total Area	522.54	100

Table 4.1 shows the Land use/ Land cover classification scheme used in the study area. The table indicates that the surface water body occupies a small part, about 1.09% of the study area. The agricultural land, i.e., the cropland and trees, occupies approximately 33.56% of the study area. The combined mining area and bare ground occupy the largest area of about 47.64% of the study area.

4.5 Evaluation of groundwater level fluctuation

Mining plays a crucial role in the country's economy; however, it also has detrimental effects on the environment. Throughout the mining process, various stages exert pressure on the environment. Environmental issues arising from mining activities include land degradation, deforestation leading to loss of biodiversity, soil contamination, air pollution, pollution of surface and groundwater, noise and ground vibrations, and disruption of the natural drainage system. Among these impacts, the effects on water resources are particularly significant. Mining can cause water-related problems such as spills and tailings, erosion, sedimentation, acid mine drainage, reduction in the water table, subsidence, disturbance of the hydrological cycle, and changes in rainfall patterns.

Open-cast coal mining activities have a disruptive impact on numerous hydrogeological parameters such as slope, elevation, geology, soil, and drainage patterns. These changes result in a lowering of the water table and disturb the movement of groundwater in the subsurface (Jhariya et al., 2016; Hudson, 2016; Karmakar et al., 2012), as shown in Figure 4.10. A study carried out by Chauhan (2010) in the Bijolia Mine, Rajasthan, India, focused on sandstone mining. It was found that the mined material, composed of non-soluble silica dust particles, these particles settles at the bottom of reservoirs like ponds and wells. Although it does not affect the portability of the water, it does reduce the groundwater's recharge capacity, resulting in the decline of the water level.

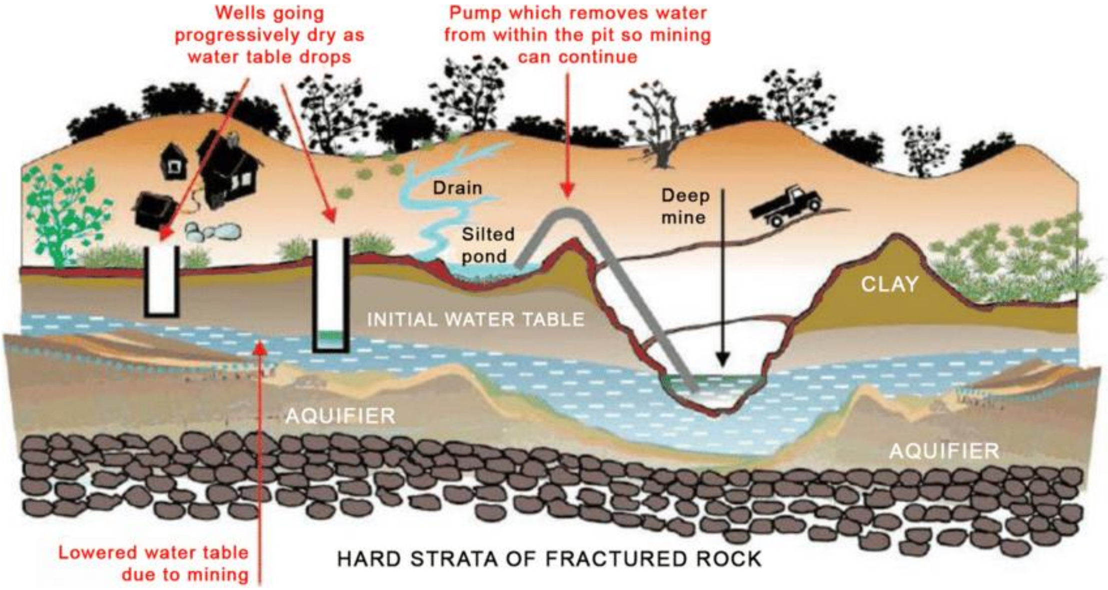

Figure 4.10 Impact of mining on water table (Llavina Pascual et al., 2013).

4.5.1 Methodology adopted for evaluation of groundwater level fluctuation

This study aims to assess the factors that contribute to groundwater level fluctuations in the Singrauli Coalfield region. To accomplish this objective, remote sensing, GIS, and field-based water level data were used for three different seasons.

Thematic maps were prepared to represent the key parameters that significantly influence groundwater level fluctuations, including geology, drainage patterns, slope, and elevation. These maps were created using digital elevation models and Survey of India Toposheets within a GIS framework. The collected groundwater level data was then analyzed in combination with these maps to gain insights into the overall water level conditions in the study area. The research methodology employed in this study is depicted in the form of a flow chart as shown in Figure 4.11 (Tiwari et al., 2016).

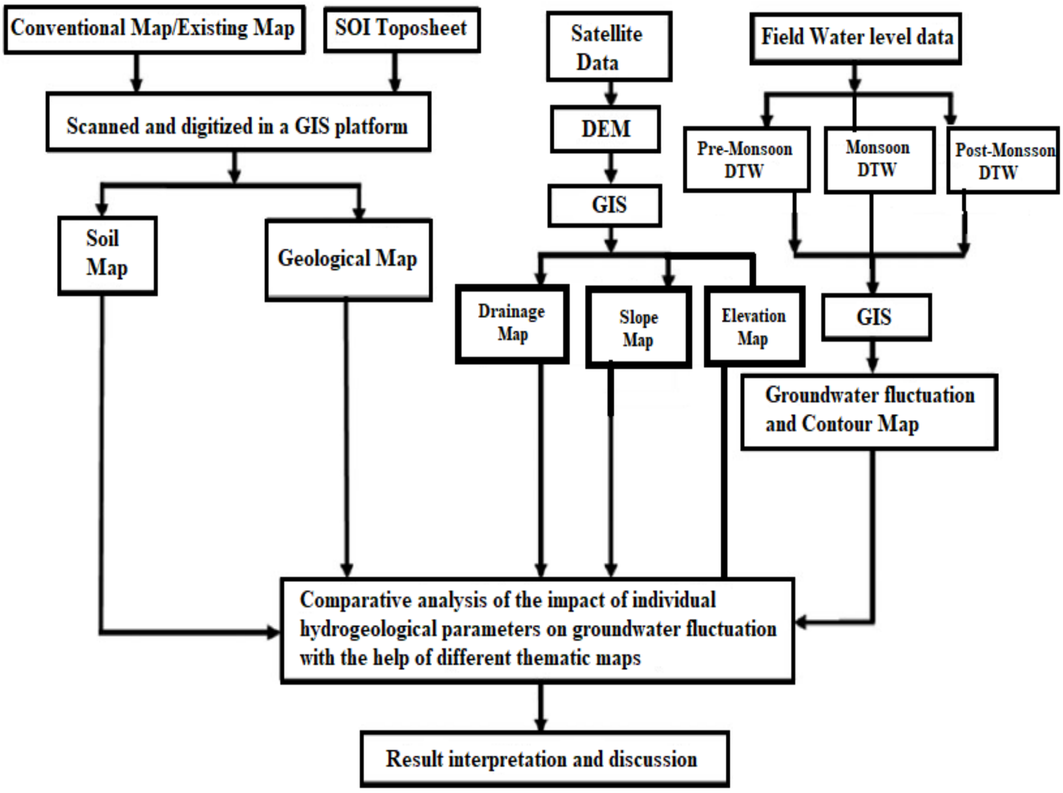

Figure 4.11 The methodology adopted for carrying out the research (Tiwari et al., 2016).

4.5.1.1 Groundwater level measurement

In the Singrauli Coalfield region, 100 dug wells have been selected to monitor water levels for Pre-monsoon, monsoon, and post-monsoon for the year 2021. Depth to water level has been recorded using sensor-based electric water level probes, as shown in Figure 4.12.

Figure 4.12 Sensor-based Electric water level probes

Electric water level probes are made up of a spool of dual conductor wire, a probe, and an indicator. When the probe comes into contact with water, the circuit closes and a metre light or audio alarm linked to the spool indicates contact. Read the depth from the wire's graded markings. Pre-monsoon, during-monsoon, and post-monsoon water level data were collected in the month of May, August, and November, respectively, for the year 2021**(Appendix A)**.

Directions for using Electric Water Level Probes

1. Before using the probe, clean it with a diluted solution of chlorine bleach to avoid polluting your well. Dip the probe into a bucket of fresh water to verify the device is working.
2. Gently move down the probe into the well casing, ensuring a slow and controlled movement. If the probe encounters any obstructions such as wires,

pipes, or other materials within the well, carefully pull out it and attempt again. It might be necessary to repeat this process multiple times until a clear path to the water is identified.

3. If the probe is trapped, avoid cutting it off and allowing it to drop into the well as this can cause harm to the pump. Instead, securely fasten the measuring probe to the upper part of the wellhead and retrieve it during the next pump maintenance or repair session.
4. Once the electronic indicator light or buzzer indicates that the water has been reached, make a note of the cable's position at the upper part of the well casing and record the depth-to-water measurement.

4.5.1.2 Location of monitoring dug wells

In the Singrauli coalfield area, 100 dug wells have been selected for monitoring of water level data for the pre-monsoon, monsoon, and post-monsoon for the year 2021, as given in **Appendix A** and monitoring dug wells coded from DW-1 to DW-100. The location of the monitoring Dug well is shown in Figure 4.13.

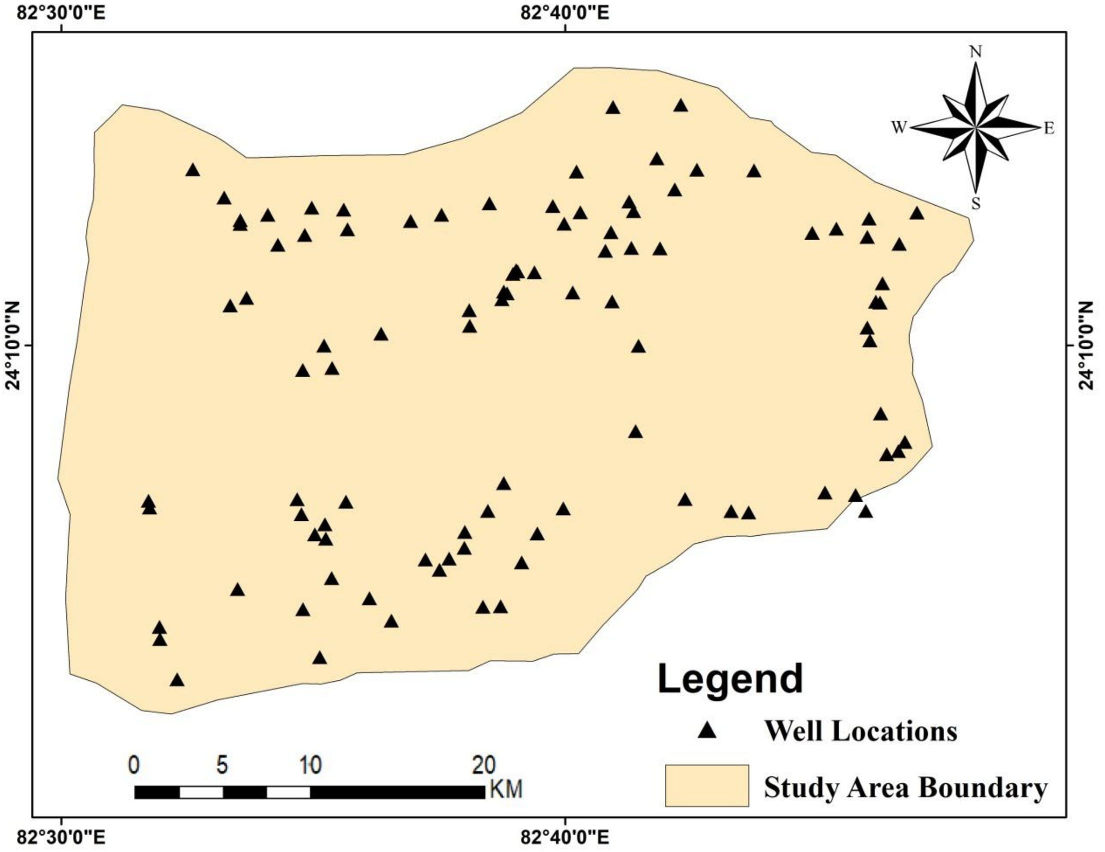

Figure 4.13 Location map of monitoring dug wells.

4.5.2 Results and Discussion

4.5.2.1 Spatio-temporal distribution of groundwater level data for the Year 2021

Hundreds of dug wells have been selected around the Singrauli coalfields region for monitoring of water level data for the pre-monsoon, monsoon and post-monsoon for the year 2021, as given in **Appendix A**. The Spatio-temporal distribution of depth to the groundwater level during pre-monsoon, monsoon, and post-monsoon for the years 2021 is prepared using ArcGIS software version 10.4.

4.5.2.1.1 The groundwater level in Pre-monsoon

Groundwater levels were measured from 100 wells in the study area for the pre-monsoon season in the month of May, 2021. Data show that depth to the water level in pre-monsoon season varied from 0.85 to 22.97 m below ground level (mbgl); the average value was 7.27mbgl. A map of spatial variation in the depth of water level during the pre-monsoon season is shown in Figure 4.14.

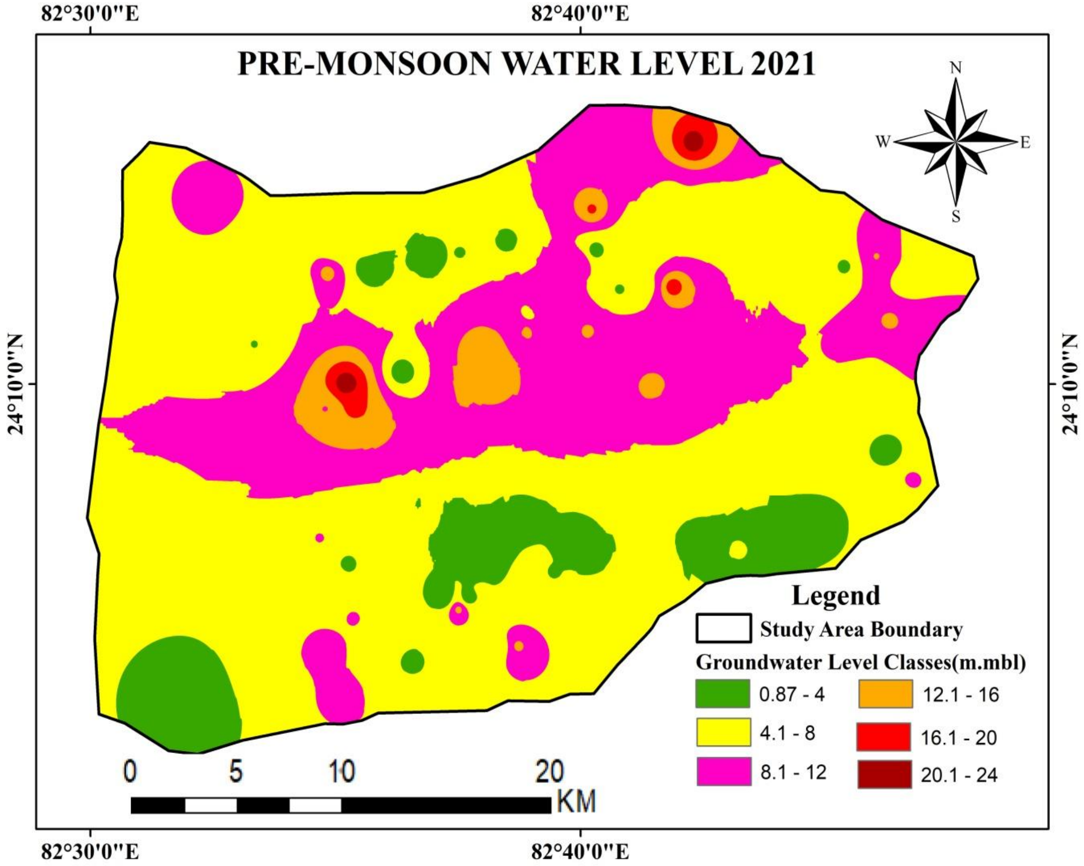

Figure 4.14 Spatial groundwater level variation map during the pre-monsoon season.

The spatial map shows that the significant portion, i.e., along northern, southern, north-western, north-eastern, and south-western, show moderate (0.4 to 8 mbgl) depth to water level. Small patches in the southern, southwestern, and south-eastern sides show low (0.87 to 4mbgl) depth to water level. The portion in the central axis extending along the western, eastern, and north-eastern sides shows higher (8.1 to 16mbgl) depth to water level. Small portion of the area in the central axis and north-eastern side show very high (>16mbgl) depth to water level. Higher depth to water levels occurs in these regions because of higher elevation and man-made activities like coal mining. Due to coal mining, aquifers in these regions are disturbed, so it is not properly recharged from surface water.

4.5.2.1.2 The groundwater level in Monsoon

Groundwater level data for the monsoon period was recorded in the month of August, 2021.Water level data in the monsoon period varied from 0.25 to 21.87mbgl, and the average variation was 4.91mbgl. By observing the spatial map of water level data, as shown in Figure 4.15, it is inferred that a major portion of Southern, south-western, northern, and south-eastern show low (0.25 to 4.4mbgl) depth to water level. Moderate (4.1 to 8mbgl) is observed in the western, eastern, and central axes. A higher (8.1 to 12mbgl) is observed in the middle of the central axis. High depth to water levels occur in these regions because of high elevation and active coal mining; aquifer geometry is disturbed in these regions. By comparing the pre-monsoon and monsoon maps, it is found that there is good infiltration of surface water to the sub-surface aquifer in a major portion of the region except for some parts in the central axis.

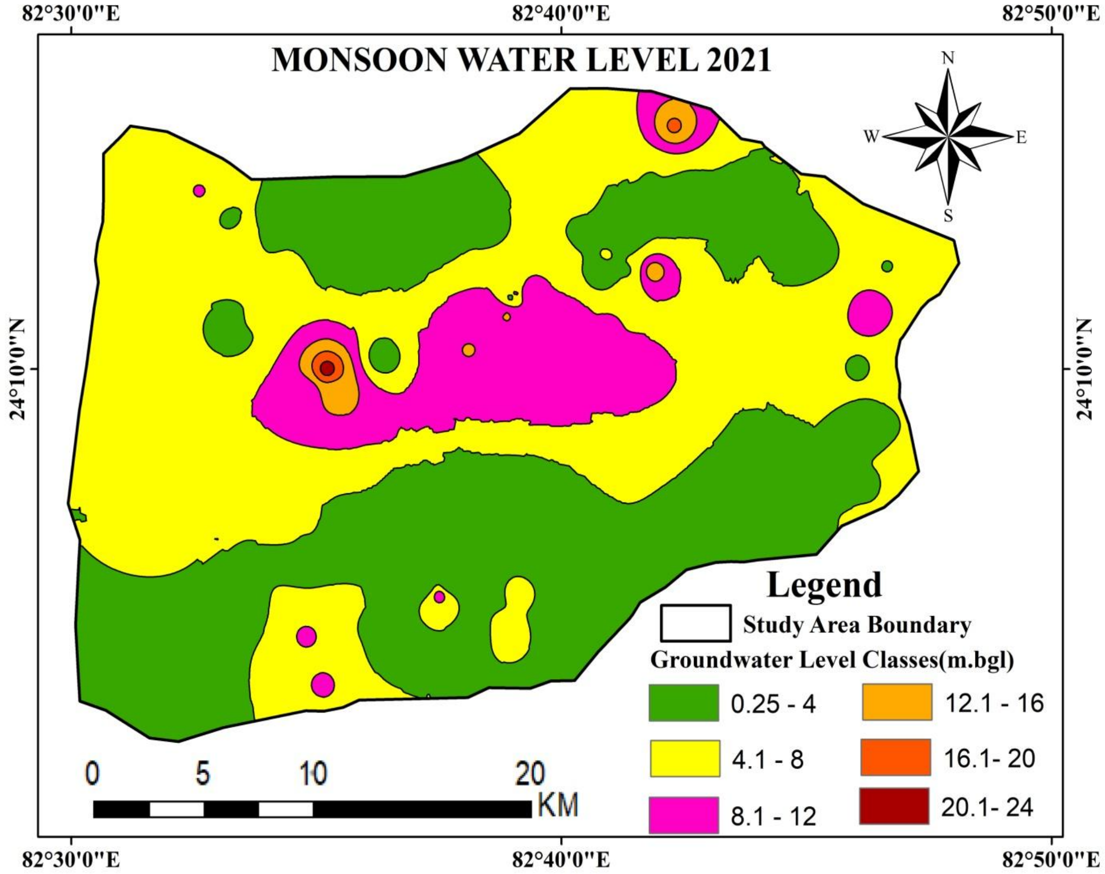

Figure 4.15 A map showing spatial variation in water level during the monsoon season.

4.5.2.1.3 The groundwater level in post-monsoon

The depth to the water level in the post-monsoon season ranged from 0.65 to 23.97 meters below ground level (mbgl), with an average of 5.88mbgl. Figure 4.16 shows spatial variation in water level depth during the post-monsoon season, by analyzing the spatial map of depth to groundwater level, it is concluded that the major portion of the study area shows moderate(4.3 to 8 mbgl) water level variation. Appreciable portions in northern, southern, and south-western regions show low(0.66 to 4mbgl) water level variation. High water level variations (8.1 to 12mbgl) are observed in the central axis and in the form of small patches in the eastern, southwestern, and north-eastern regions.

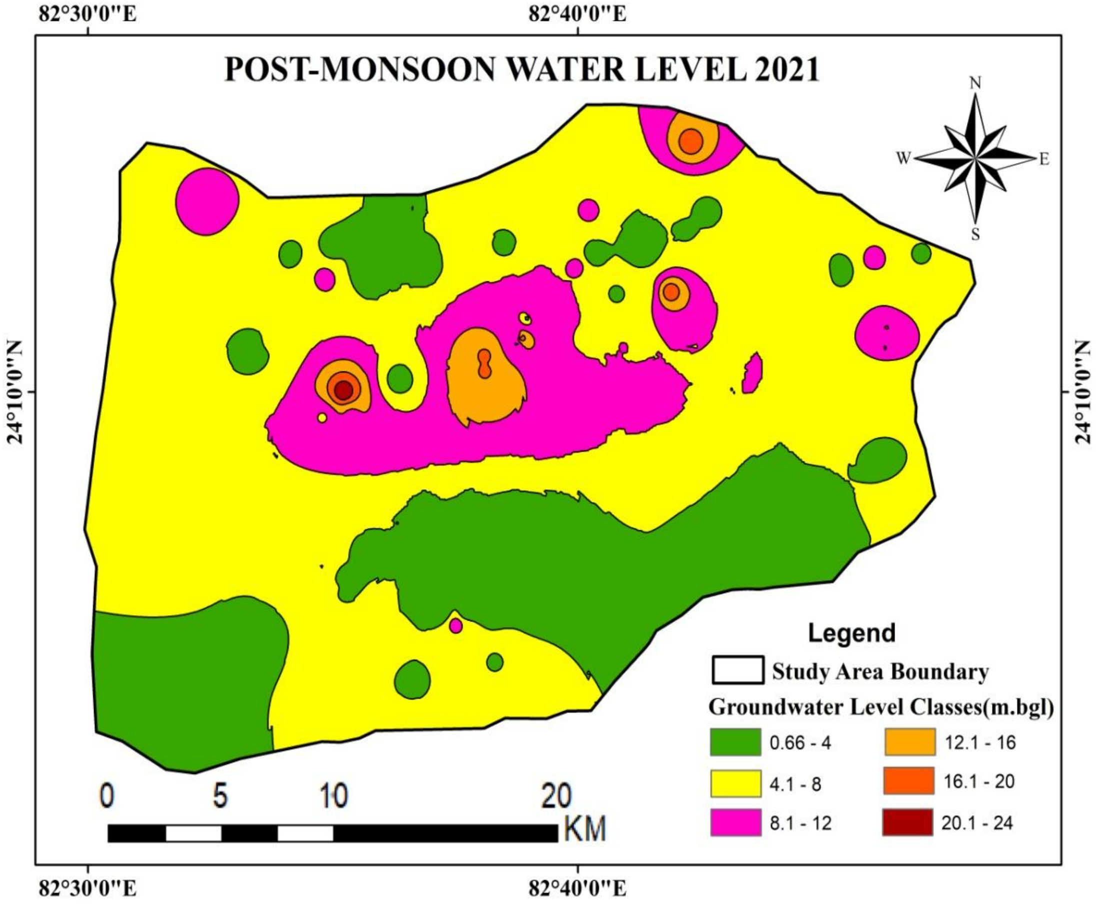

Figure 4.16 Spatial groundwater level variation map during the post-monsoon season.

By correlating the pre-monsoon, monsoon, and post-monsoon spatial map, it is found that the central axis region continuously shows higher groundwater level variation. These locations are near Jayant, Nigahi, and Amlohri mines. From the elevation map, it is observed that these places have higher elevations, and at these places, active coal mining is going on, so the geometry of the aquifer at these places is disturbed, so there is not good infiltration of surface water in the aquifer. On the north-eastern side, location Churki shows higher water level variation continuously in three seasons because there is a hard rock formation, and maybe the aquifer in this region is not fractured.

4.5.2.1.4 Water level fluctuation (WLF) of the study area for the year 2021

By analyzing the water level fluctuation map for the year 2021 as shown in Figure 4.17, it is inferred that the WLF map has been categorized into two groups: rise (0.01 to 9m) and fall (-3.8 to 0m). The rise and fall correspond to positive WLF and negative WLF, respectively. Investigating the WLF map, it is found that 90% of the study area shows positive (rise) WLF. Only some parts of the central region, north-western and north-eastern, show negative WLF. This may be due to higher elevation, steep slopes, and artificial activities such as coal mining. A significant portion of the central region, north-western, south-eastern, eastern, and south-western regions show a rise of 0.01 to 1.5, and western, north-eastern, and southern regions show a rise of 1.6 to 3m.

The WLF of 0.1 to 4.5m was observed in a significant portion of the study area. From the analysis of WLF, it is concluded that the regions showing positive WLF are acting as recharge, and areas showing negative WLF are acting as discharge.

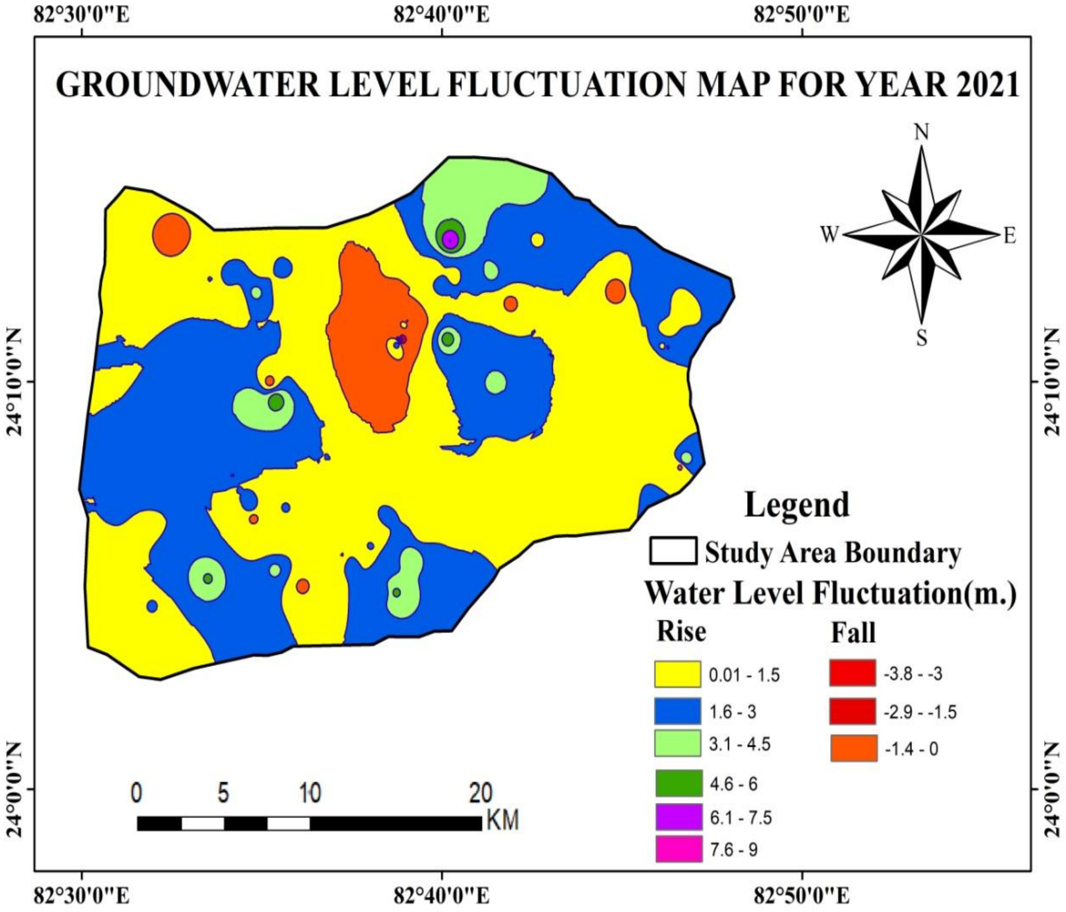

Figure 4.17 Water level fluctuation (WLF) maps for the year 2021

4.5.2.2 Water level fluctuation (WLF) analysis with different hydrogeological parameters using GIS

To evaluate the effect of different hydrogeological factors on groundwater recharge, a comparative analysis of the WLF for the year 2021 has been done as shown in Figure 4.17.

4.5.2.2.1 WLF under different geological Classes

The study area's geological formation consists of coal seam in-crop, Mahadeva, Raniganj, Barren measure, Barakar, Talchir, and metamorphic formation, as shown in Figure 4.18. From the map of WLF Figure 4.17, it is found that wells present in the western, southern, central axis and north-eastern of Barakar, Talchir, and Raniganj show higher positive WLF (1.6-3m). The wells in the northern, central axis, north-western, south-eastern, south-western, and eastern sides of the Barakar, Talchir, Raniganj, Metamorphic, and Barren measure show lower WLF (0.01-1.5m). Some wells in the central axis towards the northern side of Barakar and Metamorphic show negative WLF. Small patches of the area on the north-western side of the metamorphic formation show negative WLF (-1.4-0m).

Such behavior of WLF with different geological formations can be understood based on the stratigraphic sequence of Singrauli coalfield, given in Table 3.1 in Chapter 3. Wells present in the Barakar formation can be explained by the fact that Barakar formation consists of conglomerate, coarse to fine-grained sandstone, shales, coal seams, and clay; as we know, the hydraulic conductivity of clay and compact sandstone is very low order ranging from 10^{--13} to 10^{-9} m/s and 10^{-11} to 10^{-6} m/s respectively (Tiwari et al., 2016), which causes very less amount of rainwater to infiltrate down to aquifer at a very slow rate. The presence of coal seam in Barren Measures and Barakar formation makes it a very attractive place for mining due to which regional geology of the area is significantly disturbed, which further affects the infiltration rate of rainwater to aquifers. In Metamorphic formation, basement rock is hard, facilitating very little surface water and reaching the aquifer through secondary porosity like lineaments, cracks, etc. However, in the Raniganj formation infiltration rate is better, which causes rainwater to percolate down to the aquifer.

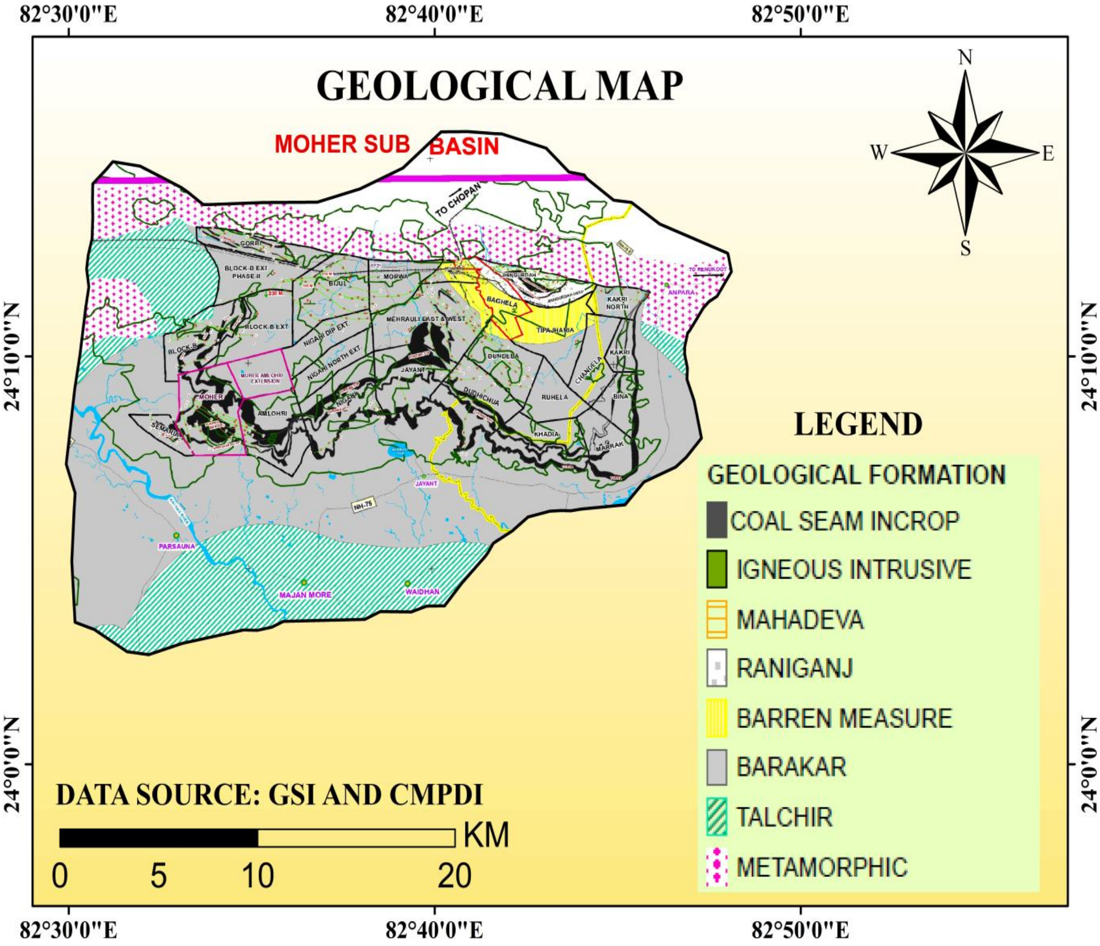

Figure 4.18 Geological map of the Singrauli coalfields.

4.5.2.2.2 WLF under different elevation ranges

From the elevation map, as shown in Figure 4.5, a major portion of the study area has an elevation of 194-360m above mean sea level. Higher elevations 403.1-642m amsl are observed in the central axis towards the northern and eastern sides. From the map of WLF Figure 4.17, it is found that the area with lower elevation shows positive WLF, and the region with higher elevation shows negative WLF. Such behavior of WLF occurs because lower plains are considered suitable for recharge, and areas with higher elevation have less potential for rainwater infiltration (Murthy, 2000). Thus it can be understood that there is a positive correlation between elevation and WLF, as the water table in any region mimics the elevation of the land surface (Bhiyan, 2010).

4.5.2.2.3 WLF under different drainage pattern

One of the significant factors influencing aquifer recharge in a given area is drainage pattern. The spatial arrangement of streams results in a specific design known as a drainage pattern. The drainage pattern reflects an area's original slope, structure, folds, faults, joints, and wrappings (Tiwari et al., 2016). The drainage pattern also provides information regarding deposition by the river, wind, sea glaciers, and volcanic activity.

The drainage pattern in the study area follows a dendritic pattern, mainly influenced by the underlying lithology and topography. In the southern region, streams flow towards the Kachani and Mayar rivers, merging near Tusa and eventually joining the Govind Ballabh Pant Sagar. The study area's perennial flow is sustained by Mehrauli Nala in the north and Baliya Nala and Motwani Nala in the south. Streams with a high branching tend to distribute runoff more evenly across the landscape, leading to lower and slower discharge in each stream segment. On the other hand, streams with fewer branches tend to concentrate water flow in a few stream segments, resulting in higher discharge levels (Tiwari et al., 2016).

The drainage map of the study area Figure 4.6 shows that high branching areas are the western, south-western, north-eastern, southern, and central axis towards the eastern side. By observing the WLF map Figure 4.17, it is found that high branching areas are associated with high positive WLF (1.6-3m). The major portion of the central axis, north-western and south-eastern, has slightly lower branching than above, so from the map of WLF Figure 4.17, it is observed that these regions show lower positive WLF (0.01-1.5m). In the central axis towards the northern portion branching area is low compared to the whole study area; hence, from the map of WLF, it was noticed that these areas show negative WLF (-1.4-0 m).

4.5.2.2.4 WLF under different slope classes

The presence and movement of groundwater are strongly influenced by the slope of the land. The slope plays a crucial role in determining the flow of runoff and the course of infiltration. In areas with gentle slopes, surface runoff tends to be slow, allowing sufficient time for rainwater to percolate into the ground and contribute to groundwater recharge. On the other hand, in areas with steep slopes, surface runoff is accelerated, resulting in less time for rainwater to infiltrate and recharge local groundwater aquifers. Therefore, the degree of infiltration for surface runoff is inversely proportional to the slope of the terrain.

The slope of the terrain is influenced by various factors such as geological structure, relief (both absolute and relative), climate, vegetation cover, drainage patterns, and frequency. It is a significant morphometric attribute that aids in the study of landforms within a drainage basin (Singh and Srivastava, 1974).

From the slope map of Singrauli coalfields, as shown in Figure 4.4, it is observed that a major portion of the study area in the southern, south-western, north-western, central axis, and north-eastern has a gentle slope ($0\text{-}8^o$). By correlating these regions with the WLF map, Figure 4.17, it is inferred that these regions correspond to positive WLF (0.1-3m). Steep slopes are observed as a ‘W’ shape in the central axis extending towards the west-eastern side. The steep slopes occur in these regions because of active coal mining in these areas. From the map of WLF, Figure 4.17 it is observed that these regions show low WLF. In the central axis towards the northern side steep slope (14.32-57.03) was observed, so these regions show negative WLF (-1.4-0 m).

In this chapter, the hydrogeomorphologic and morphometric analyses were carried out using geospatial techniques to evaluate important parameters, which will support further detailed study. These parameters are geomorphologic unit, slope, elevation, drainage, lineament (surface lineament), and its density map extracted from satellite imagery on 1:50,000 scales of the study area. The surface lineament and lineament density maps give the appropriate locations for a selection of resistivity survey and further detailed study. Thus lineament and lineament density map are beneficial for conducting resistivity surveys, which are cost and time-effective tools for groundwater exploration in the study area.

The comprehensive analysis conducted in this chapter has revealed the importance of GIS-based maps in assessing groundwater level fluctuations. Five significant hydrogeological parameters, namely geology, elevation, drainage, slope, and lineament have been carefully examined within the study area and found to have a substantial impact on groundwater level fluctuation. Based on the results and discussion, it has been found that all the portions of the study area show positive WLF except some parts in the central axis extending toward the northern side and some small patches on the north-western side showing negative WLF.

The influencing factors such as elevation, slope, lineament, and geology have been identified as more significant in affecting groundwater level fluctuation compared to drainage patterns. Furthermore, the presence of mining activities and associated industries has been observed to exert a noticeable influence on groundwater level fluctuations within the study area. The insights derived from this study may be helpful in the planning and management of water resources in the Singrauli coalfield region.

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