Delineating groundwater prospect zones in a region with extreme climatic conditions using GIS and remote sensing techniques: A case study from central India

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Sustainable groundwater management of an extreme climatic region is very important from both social and economic point of view. This study attempts to delineate the groundwater potential zones of Sonepur district, Odisha, which falls under an extreme climatic region, using remote sensing, geographical information system and Saaty's analytical hierarchy process (AHP). Different ancillary data, multiple data sets obtained from LANDSAT 8 OLI and ASTER Level-1T were used in conjunction with Cartosat-1 imagery to study the detailed physical attributes of the study area and to prepare the groundwater prospect map using a weighted overlay method in ArcGIS 10.4 software. The AHP technique was used for determining the weights of each layer. From the groundwater prospect map, it was found that 52% of the area belongs to the moderate groundwater prospect zone followed by good to very good, very good to excellent (32%) and poor (16%) groundwater prospect zones. Statistical analysis of the number of existing wells in each of these water potential zones and their water level was used to verify the accuracy of the water potentiality estimated in this study. The groundwater potentiality map prepared as a part of this study would serve as an important tool for identifying suitable zones for rainwater harvesting and also for managing groundwater abstraction for a safe and sustainable water supply.

Keywords. Groundwater potential zones; sustainable groundwater management; Saaty's analytic hierarchy processes; weighted overlay method.

1. Introduction

Delineation of groundwater potential zones is carried out by a number of geological and geophysical methods such as electrical resistivity profiling, gravity and seismic refraction methods (Shirke *et al.* 2005; Stephen *et al.* 2011; Murasingh *et al.* 2018; Oluwasegun 2018) in addition to stratigraphy analysis, groundwater pumping and drilling tests, which are often time consuming and expensive (Kumar *et al.* 2016). In contrast, the integrated use of high-resolution remote sensing (RS) satellite imagery with a geographical information system (GIS) allows wide space and time distribution in short time frames (Ndatuwong and Yadav 2014; Sar *et al.* 2015) enabling fast and accurate results. RS and GIS tools have been employed by many authors to integrate the geomorphology, geology, drainage pattern, structure, rainfall, soil texture and topographic information

of an area and to prepare the groundwater potential maps (Mondal *et al.* 2008; Jasrotia *et al.* 2013). Ease of data handling and fast data processing qualify the RS/GIS methods as superior tools compared to the conventional approaches. Many researchers have carried out RS and GIS studies to infer the groundwater resources of different regions despite differences in climatic, topographical and geomorphological parameters (Mondal *et al.* 2008; Mohanty and Behera 2010; Suganthi *et al.* 2013; Senanayake *et al.* 2016; Pinto *et al.* 2017).

The groundwater development in Odisha state, which is situated in east central part of India, is very poor (CGWB 2013), especially in Sonepur district where the overall stage of groundwater development was estimated to be mere 18.4%. In spite of the presence of abundant water resources, extreme conditions like drought and water logging are reported in this area (CGWB 2013; Taradatt 2016), which adds to the already existing water supply management issues. This region is characterized by steep and dense drainage patterns limiting the rainwater infiltration and at the same time, the base flows are high leading to quick groundwater drainage from shallow zones (CGWB 2013). Extreme weather conditions such as drought and floods are frequent in this region (Ota 2001; Beura 2015; Jena 2018) and the rainfall is highly uneven (Taradatt 2016). The recent study reports that out of the total rainfall received by this area 21% is being evaporated, around 40% is lost through runoff and only 39% infiltrates into the soil (Taradatt 2016). The water levels are also highly variable depending on the terrain. Highly depleting water levels are found in hilly terrains (range of 10–20 m below ground level) while in some flat regions water logging was observed (0–2 m below ground level) (CGWB 2015). The situation due to depleting water levels is further compounded by excess runoff, eroding the top 15–20 cm soil and impacting both the productivity of soil and infiltration.

Many authors have used RS/GIS techniques to decipher groundwater potential zones in different parts of Odisha. Barik *et al.* (2017) have done groundwater potential zonation in Kandhamal district. Murasingh (2014) has used electrical resistivity and RS/GIS techniques to delineate groundwater potential zones in Tensa valley, Sundargarh. Das *et al.* (1997) mapped hydrogeomorphology for groundwater exploration using RS data in Keonjhar district. Mohanty and Behera (2010) studied groundwater prospect in Ganjam district, Odisha, but so far no attempt has been made to use remotely derived data to study the groundwater potential of Sonepur district which falls under extreme climatic conditions. In this study, an attempt is made to delineate the groundwater prospect zones of Sonepur district using satellite and ancillary data. This study will help to get a more comprehensive view of potential groundwater resources in this region and will provide a framework for the development plans in extreme climatic regions like Sonepur and other similar areas elsewhere.

The main objectives of the study will be:

- Preparation of thematic maps of the study area such as geology, geomorphology, land use and land cover (LULC), soil texture, drainage density, slope, rainfall and lineament density using satellite and ancillary data from different sources.
- Assessment and discussion of factors controlling groundwater recharge.
- Determination of weights of the different thematic maps using a multiple-criteria decision-making method like Saaty's analytical hierarchy process (AHP) tool and the preparation of the final potential zonation map using a weighted overlay technique.
- Validation of the groundwater potential map using available water level data.

2. Description of the study area

The study area is bounded by 20.53–21.18°N latitudes and 83.45–84.28°E longitudes covering an area of 2344 km^2 (figure 1). It comes under a tropical climate region and the drainage of the area is mainly constituted by the rivers Mahanadi, Tel and their ephemeral tributaries (GSI 2007, 2009). Meteorological data suggest that about 90% of total annual rainfall occurs during the southwest monsoon (June–October), while the northeast monsoon is scanty. The annual average rainfall over the district is about 1440 mm. The temperature during summer varies from 34.3° to 47.7°C and during winter it drops to 6.0°C (Swain 2014). The average elevation of the area ranges between 200 and 300 m above mean sea level (amsl) with the topographic slope towards east (CGWB 2013). Paddy, green gram and red gram are the main crops in the study area, which are irrigated by surface water.
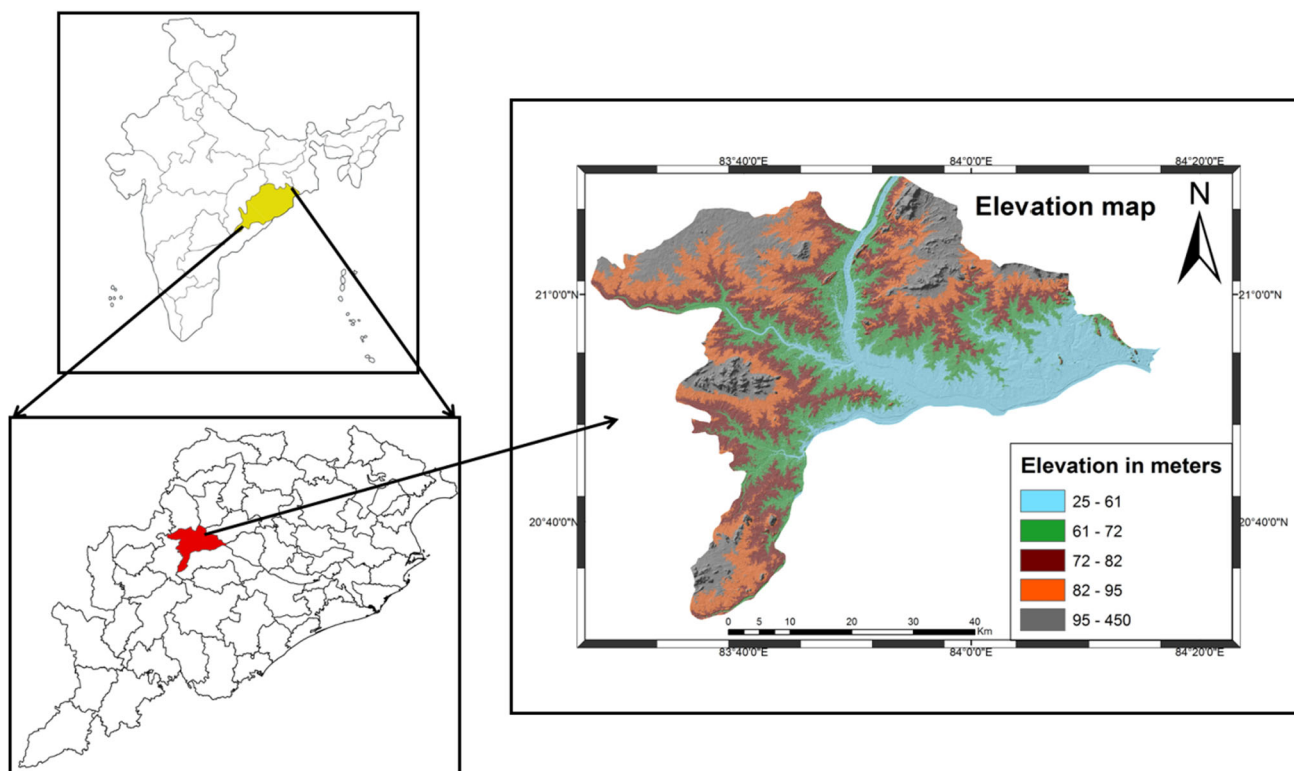
Figure 1. Map of the study area.

3. Materials and methods

3.1 *Ancillary data used*

The Survey of India (SOI) toposheets of 1:50,000 scale (64O/8, 64O/12, 64O/16, 64P/9, 64P/13, 64P/10, 64P/5, 64P/14, 73C/4, 73D/1, 73D/5) were used for the preparation of base map. The individual toposheets were geo-referenced to the spatial coordinate system, World Geodetic System (WGS) 1984 in ArcGIS 10.4 (Kumar *et al.* 2016). The geological, soil and geomorphologic maps of the study area were prepared based on the reports of CGWB (2013), IFFCO project of RRSCs, GSI and NRSC (2012) respectively. Rainfall monitoring system (Odisha) data were used to prepare the annual average rainfall spatial distribution map of the area. CGWB water level data (for year 2016) from the India–WRIS system was used to prepare the water level contour maps of the study area.

3.2 *Satellite data used*

The Cartosat-1 DEM imagery was used for the preparation of the slope and drainage map (Ibrahim-

Bathis and Ahmed 2016). The imagery of LANDSAT 8 Operational Land Imager (OLI) was used for the preparation of the LULC map of the study area (Phiri and Morgenroth 2017). ASTER data were used for extracting the lineament features of the area (Hung *et al.* 2005). The detailed description of the data used is summarised in table 1.

3.3 *Methodology*

3.3.1 *Preparation of slope and drainage density maps*

The slope tool in a spatial analyst toolbox of ArcGIS 10.4 was used to create the slope map from Cartosat-1 DEM. The drainage density map was prepared using the Arc Hydro tool box (Ibrahim-Bathis and Ahmed 2016).

3.3.2 *Preparation of the LULC map*

Bands 4 and 5 (red and near infrared, respectively) of the LANDSAT 8 OLI were used for the preparation of a NDVI map in PCI Geomatica version

Table 1. *Details of satellite data used in the study.*

Data	Sources (URL)	Tiles	Time/period	Resolution/scale
SOI toposheets	http://www.soinakshe.uk. gov.in/	64O/8, 64O/12, 64O/16, 64P/9, 64P/13, 64P/10, 64P/5, 64P/14, 73C/4, 73D/1, 73D/5	10.01.2018	1:50,000
Cartosat-1 digital elevation model	http://bhuvan.nrsc.gov.in	F44X, F44R, F45S, F45M	2005–2014 (V3R1)	2.5 m
ASTER level 1T	https://glovis.usgs.gov	WRS path:141 WRS row: 45, 46	09.11.2016 to 05.01.2017	15 m for VNIR band 3
LANDSAT 8 OLI	https://glovis.usgs.gov	WRS path: 141 WRS row: 45, 46	10.11.2016	OLI multispectral bands: 30 m OLI panchromatic band: 15 m

2017 software (Ibrahim-Bathis and Ahmed 2016). The NDVI map along with the panchromatic image (band 8, resolution 15 m; http://landsat. gsfc.nasa.gov), the false colour composite image of LANDSAT 8 OLI and unsupervised classification tool (Phiri and Morgenroth 2017) was used to prepare the LULC map of the district (Kafi *et al.* 2014). The map was verified using the NRSC (2014) LULC database and high-resolution Google earth imagery.

3.3.3 *Preparation of the lineament density map*

VNIR band 3 of ASTER data (Hung *et al.* 2005) was used for lineament extraction and making the lineament density map. Lineaments can either be extracted manually or automatically. In this study, the LINE module of PCI Geomatica Version 2017 was used for the automatic lineament extraction (Hung *et al.* 2005; Karnieli *et al.* 2006; Prasad and Gairola 2013; Kiran and Ahmed 2014; Ndatuwong and Yadav 2014; Shankar *et al.* 2016). The lineament map prepared was corrected for non-geological lineaments due to roads, fences, field boundaries, etc. using the SOI toposheets, secondary lineament map from GSI and NRSC (2012) and high-resolution Google earth imagery (Ndatuwong and Yadav 2014). The lineament density map was prepared from the lineament map using the line density tool in ArcGIS 10.4. The lineament density (L_d) is defined as (Deepa *et al.* 2016)

$$L_d = \frac{\sum_{i=1}^{n} L_i}{A}, \tag{1}$$

where $\sum_{i=1}^{n} L_i$ denotes the total length of lineament and A is the unit area.

3.3.4 *Determination of weight of each layer*

The weight of each thematic layer was decided on the basis of Saaty's scale and AHP method (Saaty 2008; Agarwal *et al.* 2013; Suganthi *et al.* 2013). The relative importance values are decided using Saaty's 1–9 scale, where a score of one represents equal importance between the two themes, and a score of nine points towards the extreme importance of one theme compared to the other one (Saaty 2008). A pairwise comparison matrix is formed using Saaty's scale based on the different thematic layers used for the delineation of the groundwater potential. From the matrix, the percentage weights were calculated for weighted overlay analysis. After determining the weights for each theme their classes were also ranked on the basis of their influence in that particular theme (Agarwal *et al.* 2013).

3.3.5 *Weighted overlay of the different thematic layers and groundwater potential zonation*

All the thematic maps were rasterised and integrated using the weighted overlay method in ArcGIS 10.4 for generating the groundwater potential map of the area. Potential zones were delineated on the basis of the percentage weights and ranks determined. Higher rank and weight reflect high groundwater potential and vice versa. The groundwater potential zone map was prepared

using groundwater potential index (GWPI). The GWPI was calculated using the formula (Kumar *et al.* 2016)

$$\text{GWPI} = \sum_{i=1}^{n} \sum_{j=1}^{m} (W_j X_i), \qquad (2)$$

where W_j is defined as the normalized percentage weight of jth factor; X_i is the rank of the ith class of a thematic layer, m is the total number of layers and n is the total number of classes in a thematic layer.

3.3.6 *Validation*

The water level contour maps prepared for the year 2016 were used for the validation of the groundwater potential map.

A brief description of the applied methodology is shown in figure 2.

4. Results

The detailed description of the thematic maps prepared is given in the following sub-sections.

4.1 *Geology*

The state of Odisha consists of rocks ranging in age from Mesoarchaean to Recent. The Precambrian terrain in the state can be distributed in the following parts (GSI 2011):

- Eastern Indian craton: northern and northwestern Odisha.
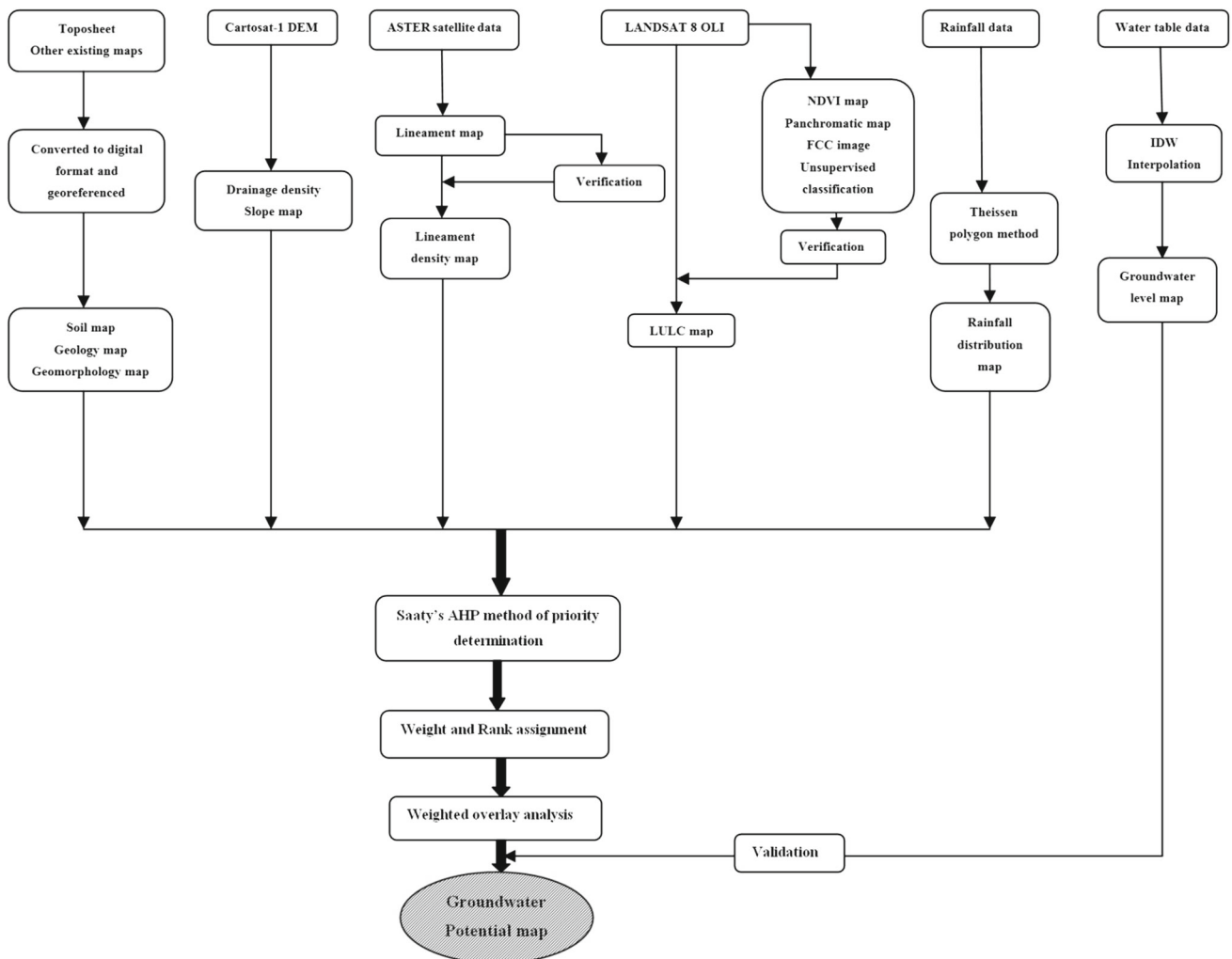- Part of Bastar craton: western Odisha.

Figure 2. Detailed methodology adopted for generation of the groundwater potential map of Sonepur district, Odisha.

Table 2. *Geologic stratigraphic succession of the study area (GSI 2007, 2009).*

Rock type		Group/Supergroup
Sand stone and shale		(Lower Gondwana)
--- Unconformity---		
Gabbro and anorthosite		
Garnetiferous granite gneiss		
Calc-silicate	Khondalite Group	Eastern Ghats Mobile Belt (EGMB)
Quartz–garnet–sillimanite schist/gneiss		
Pyroxene granulite–Charnockite suite		
----------------------------------Tectonic contact/unconformity----------------------------		
Biotite Granite Gneiss		Bastar Cratonic Gneiss (BCG)

- Part of Eastern Ghats Mobile Belt (EGMB): central and southern Odisha.

The major portion of the study area falls under three supergroups, viz., Bastar cratonic gneiss (BCG), Eastern Ghats Mobile Belt (EGMB) and Lower Gondwana (table 2; GSI 2009).

4.1.1 *BCG*

Part of western Odisha consists of Bastar craton. This cratonic strip is delimited by Mahanadi graben in the northeast and EGMB in the east and southeast. The major lithostratigraphic units in this part are: Archaean supercluster of the granite gneisses and granitoids, Bengpal and Bailadila groups with age ranging from Neo-Archaean to palaeoproterozoic.

4.1.2 *EGMB*

The EGMB extends for over 1000 km from Odisha to southeastern part of Andhra Pradesh along the coastline. It comprises garnetiferous, graphite bearing sillimanite schist and gneiss (Khondalite).

4.1.3 *Lower Gondwana*

These rocks rest unconformably on the Precambrian basement comprising granitoids, hornblende gneiss, schist and amphibolites. The base of the Gondwana sequence has been exposed along the southern margin of the basin and it is defined by Talchir formation formed by more than 325 m thick pile of glacial and periglacial deposits.

The geology of the study area (figure 3) can also be grouped into consolidated, semi-consolidated and unconsolidated formations. Consolidated formations include granites, gneiss, Khondalite,

quartzite, anorthosite and gabbro. Among these formations, granite and granite gneisses form good aquifers due to the presence of weathered and fissured zones. The thickness of the weathered zone ranges from 10 to 15 m and the groundwater yields are up to 10 litres per second (lps) (CGWB 2013). The groundwater development possibility is limited in the Khondalite suite of rocks (up to 10 lps). These types of rocks are mainly formed by quartz–garnet–sillimanite schist and gneiss. Calc-silicates and quartzite are also present in minute amounts. The quartzite group of rocks often does not have good primary porosity and is very hard in nature, but due to brittle nature of these rocks, fractures and weathering are often observed. These features contribute to secondary porosity and render the formation suitable for holding and transmitting groundwater with typical yields up to 10 lps (Unesco 1984; Cook 2003; CGWB 2013; Karanam *et al.* 2014; Senanayake *et al.* 2016). Anorthosite rocks are very hard and not suitable for groundwater movement. Hence the yields are low to moderate up to 3 lps (CGWB 2013). About 78.9% of the total area is contributed by anorthosite, granite/quartzite, khondalite, granite and gneiss rocks (table 5). The other types of formations are semi-consolidated in nature and belong to the Lower Gondwana age group (figure 3). This formation consists of sandstones and conglomerates with typical groundwater yields <5 lps (CGWB 2013). A very small patch of this formation is observed in the western part of the study area (CGWB 2013). Recent alluvium and laterites form the unconsolidated formations along the main drainage channels and possess high-water bearing capacity (figure 3). The groundwater yields in alluvial formations are up to 10 lps (CGWB 2013). Based on the reported yield values of these geological formations (CGWB 2013) the relative
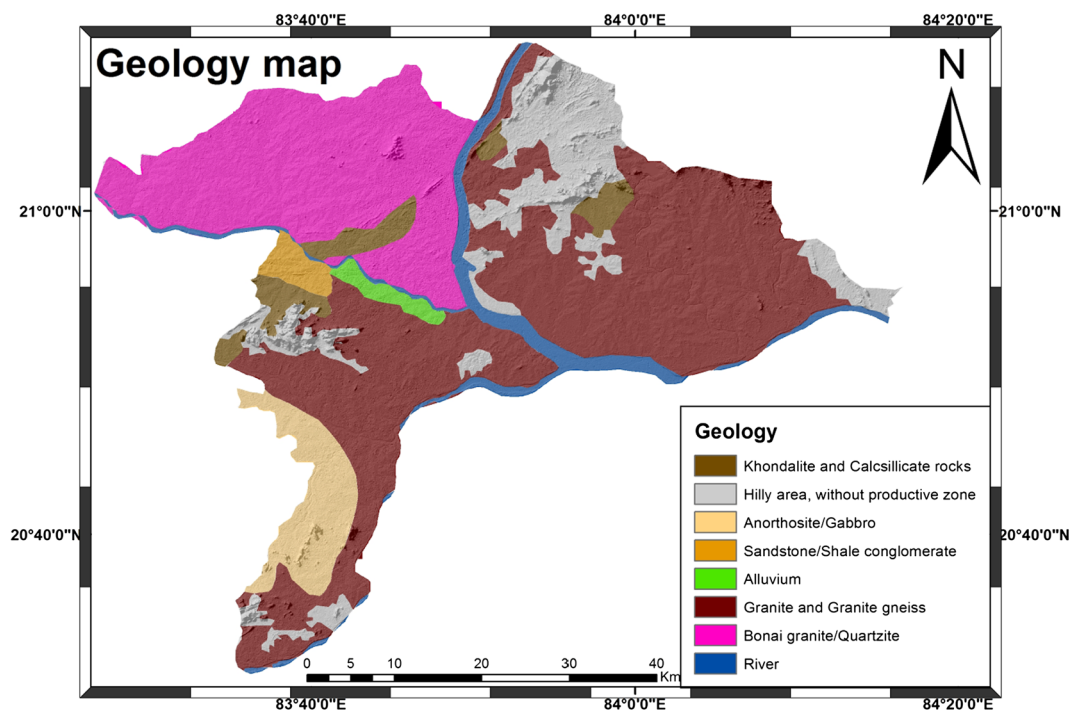
Figure 3. Geology map of Sonepur district, Odisha.

importance of each of these formations regarding groundwater movement and storage capacity was ranked as per Senanayake *et al.* (2016). The classes of the geological map and the corresponding weights assigned are given in table 5.

4.2 *Geomorphology*

The identification of different landforms and the preparation of a geomorphic map are very important in evaluating the groundwater prospects. Geomorphological features such as slope, extent of weathering and type of landform play a direct role in determining the groundwater potentiality of a region. The study area is divided into nine major landforms (according to the NRSC 2012 and ISRO 2013 classification schemes), some of the major features are viz., pediment–pediplain complex (84.4%), low-to-high dissected hills and valleys (3.9%), active flood plains (3.5%) and low to moderately dissected hills and valleys (1.5%), as shown in figure 4. The geomorphic classification is explained as the categorisation and description of the nature, origin and development of landforms. The fundamental parameters, which are considered for the classification of the geomorphic features are origin and development (process), general structure and shape (landform), dimensions and

characteristics (morphometry) and the presence and status of process overprinting (geomorphic generation). Pediments of the denudational origin are gently sloping (0.5–7.0°) weathered rock surface areas with erosional bedrock characterized by low relief and generally found in hills and plains (Deepika *et al.* 2013). It develops due to laminar sheet flows of water. Because of the massive and compact rocky structure with numerous fractures and joints, these are considered as good for groundwater movements and storage (Ndatuwong and Yadav 2014). Pediplains are defined as the gently inclined sloping surface of thick weathered granite, gneiss and weathered material formed by coalescence of pediments. This type of landform forms very good recharge and storage zones. The groundwater prospect in these zones depends on the extent of weathering (Raghu and Mruthyunjaya 2011). Denudational hills consist of jointed and fractured granites and gneisses, and are formed due to differential erosion and weathering processes. The presence of fractures, joints and topographic cuts makes infiltration of groundwater possible but with increasing slope the runoff possibility also increases limiting the groundwater recharge process (Deepika *et al.* 2013; Jasrotia *et al.* 2013). Therefore, the highly dissected hills with sharp relief, formed due to the severe erosion
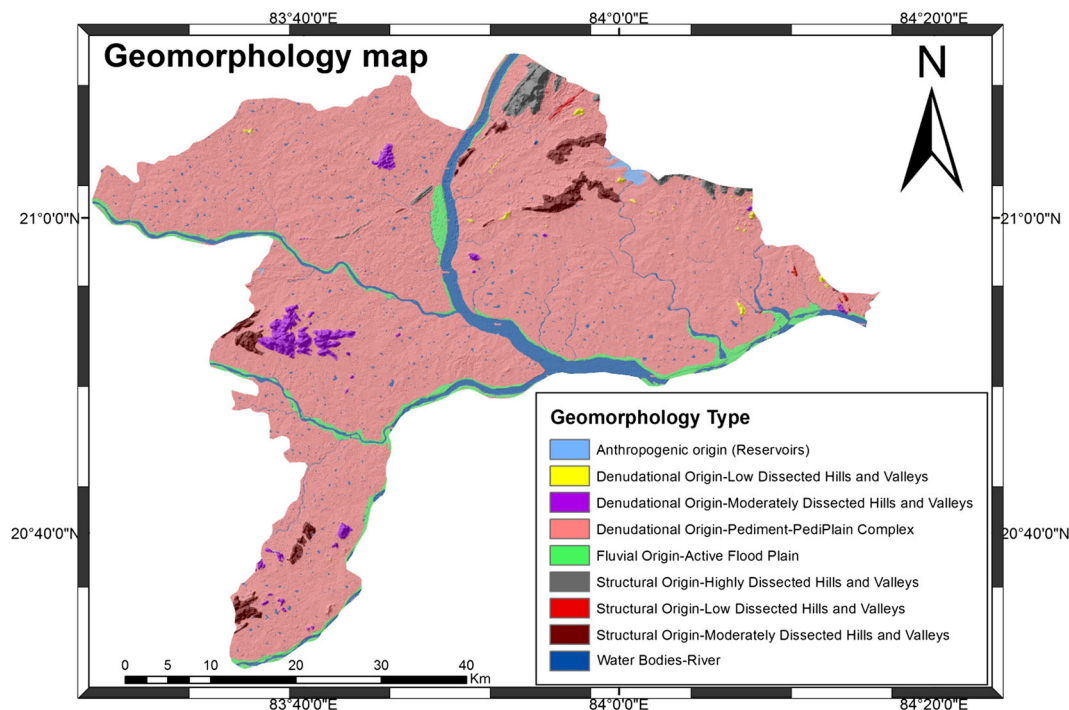
Figure 4. Geomorphology map of Sonepur district, Odisha.

process have very less groundwater prospect than the low-dissected hills. Structural hills are formed due to the combined effect of tectonism and denudation. Being compact and hard in nature these types of formations mainly act as runoff zones. The infiltration possibilities are limited only through fractures and faults (Deepika *et al.* 2013) and so why groundwater potential is very poor in this region. Active flood plains are formed by the lateral movement of a stream and by overbank deposition (Pareta and Pareta 2015), which act as good aquifers due to their high permeability (Deepika *et al.* 2013; Jasrotia *et al.* 2013). Based on the relative importance of the different landforms with respect to the groundwater potential, different ranks are assigned to each of these landforms and provided in table 5.

4.3 *Land use land cover*

LULC is an important factor reflecting the human influence on the groundwater resources. The infiltration, storage and discharge of groundwater depend on the different land use patterns (Mohanty and Behera 2010; Mishra *et al.* 2014; Barik *et al.* 2017). The LULC of this area can be classified into four types, water bodies (river/canals/reservoirs), forests, settlements/barren land and crop land (figure 5). Data suggest that most of the areas

are covered by the crop land (70.0%) with patches of the forest land in the north and central regions (table 5) and water bodies (river/canals/reservoirs) occupy 5.9% of the total area. The vegetation (forest) is an indicator of good groundwater potential while the settlements/barren lands indicate very poor groundwater prospects (Sikdar *et al.* 2004; Mishra *et al.* 2014). Table 5 summarizes the ranks assigned to each of the classes according to their relative importance.

4.4 *Soil texture*

Soil texture is an important factor for delineating the groundwater potential zones of an area (Ibrahim-Bathis and Ahmed 2016). The holding capacity and infiltration rate of water depends on soil properties like structure, porosity, adhesion and consistency (Bouwer 2006; McGarry 2006). Surface infiltration systems normally require permeable surface soils that allow high-infiltration and minimise land requirements. The vadose zones should be devoid of clay or other fine-textured material layers that restrict downward flow and create waterlogging issues reducing groundwater recharge (Bouwer 2006). The soil texture zonation map of the area shows four major classes (figure 6), viz., coarse texture soil (loamy sand/sand), medium texture soil (loam/silt/loam silt/sandy loam/
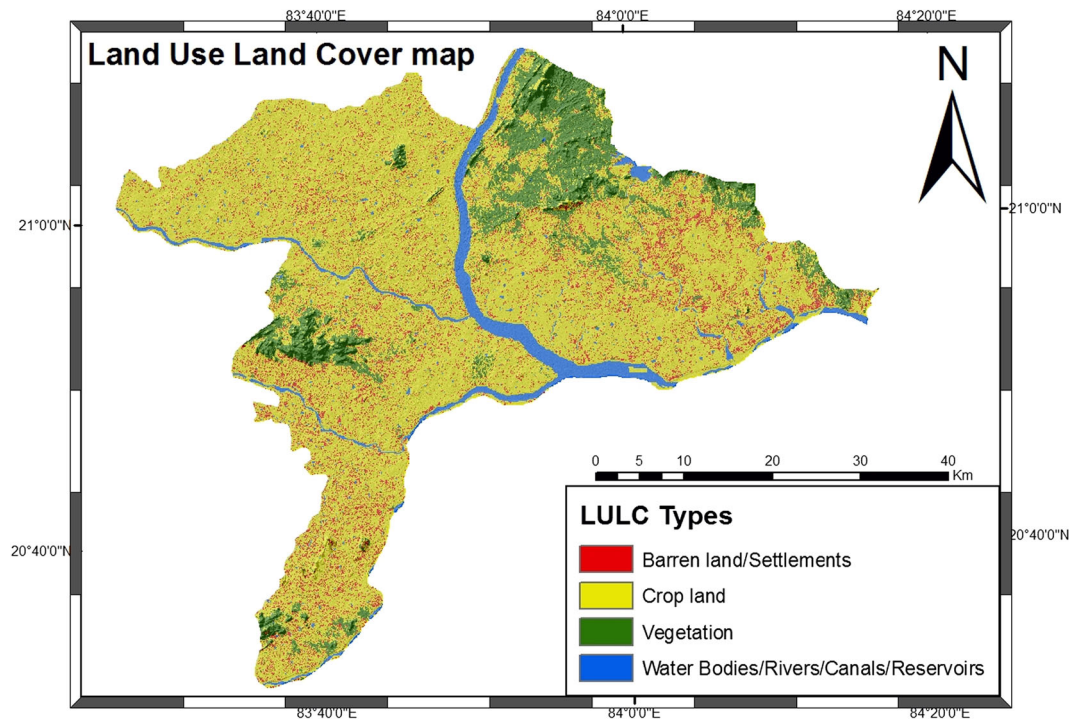
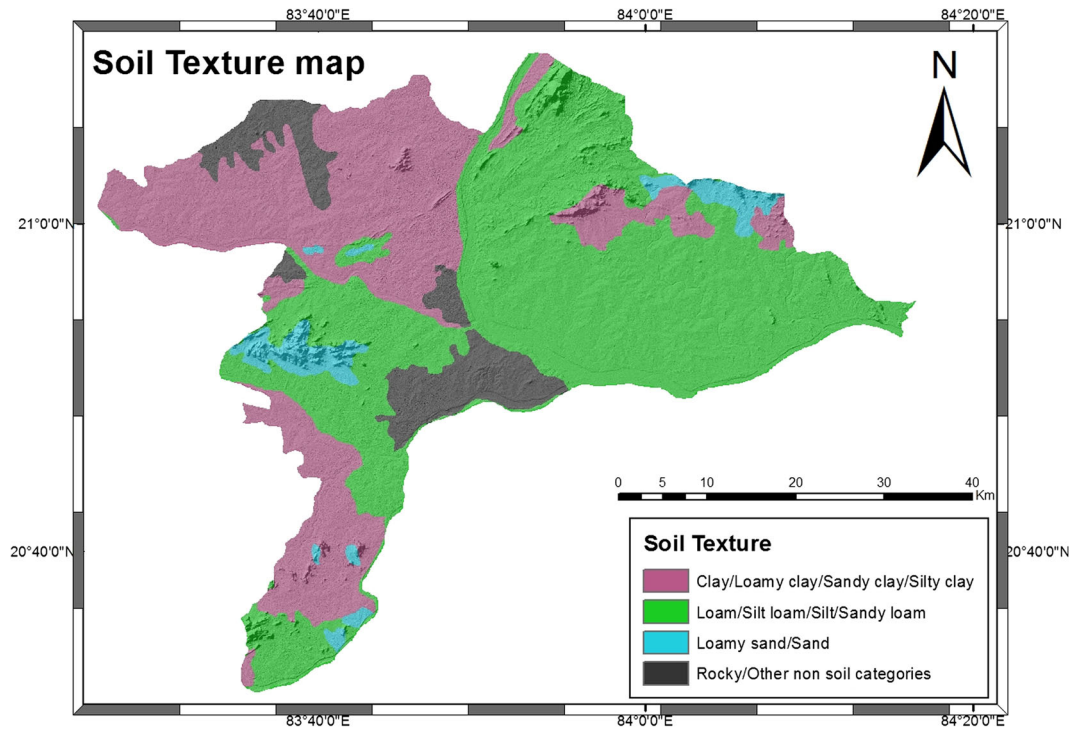Figure 5. LULC map of Sonepur district, Odisha.

Figure 6. Soil texture map of Sonepur district, Odisha.

loam), fine texture soil (clay/loamy clay/sandy clay/silty clay) and rocky/water bodies including the rock and other non-soil components. The majority of the area is covered with medium to fine texture soil (figure 6 and table 5). The respective general infiltration rates (Hillel 1982) of water in the soil types of this area are given in table 3. According to the relative movement of water

through the different soil types the ranks for the soil classes are assigned as given in table 5.

4.5 *Drainage density*

Drainage density is an important factor controlling the groundwater movement and storage of a given region (Senanayake *et al.* 2016). Transmissibility is a measure of permeability of groundwater in a terrain, which is inversely related to the square of drainage density (Carlston 1963). The drainage map of the study area was prepared from the Cartosat-1 DEM and was classified on the basis of the Strahler stream order method (Strahler 1964). The drainage pattern is mainly dendritic in nature and governed by the Mahanadi river and its tributaries (figure 7). Drainage density is a measure of the length of the streams within a square grid and it reflects the permeability and the suitability to further groundwater development (Karanth 1987). The drainage density was classified into five groups, viz., very high $(1.0–1.2 \text{ km/km}^2)$, high $(0.7–1.0 \text{ km/km}^2)$,

medium $(0.5–0.7 \text{ km/km}^2)$, low $(0.2–0.5 \text{ km/km}^2)$ and very low $(0.0–0.2 \text{ km/km}^2)$. The area with the lowest drainage density was given the highest rank while the area with the highest drainage density was given the lowest rank (table 5).

4.6 *Slope*

The slope of an area controls the infiltration and thus influences the groundwater potential (Mondal *et al.* 2008). The slope is defined as the rate of change of elevation (Kumar *et al.* 2016) of a terrain. A high slope represents steeper terrain and low-water infiltration while a lower slope represents flat terrain and high possibility of infiltration. The slope map indicates four classes, viz., nearly level $(0–6°)$, gentle slope $(6–10°)$, moderate slope $(10–15°)$ and steep slope $(15–81°)$ (figure 8). The steep slope class was given the lowest rank and the nearly level slope zone was assigned the highest rank (table 5).

4.7 *Rainfall*

Rainfall plays an important role in the groundwater recharge of an area (Zeinolabedini and Esmaeily 2015). Due to paucity of the rainfall monitoring stations in the study area, the Thiessen polygon method was used for interpolating the available rainfall data over the entire study area. Since the area is a flat terrain, the altitude effect on rainfall is ignored (Taesombat and Sriwongsitanon

Table 3. *Steady infiltration rates for general soil texture groups in very deeply wetted soil (Hillel 1982).*

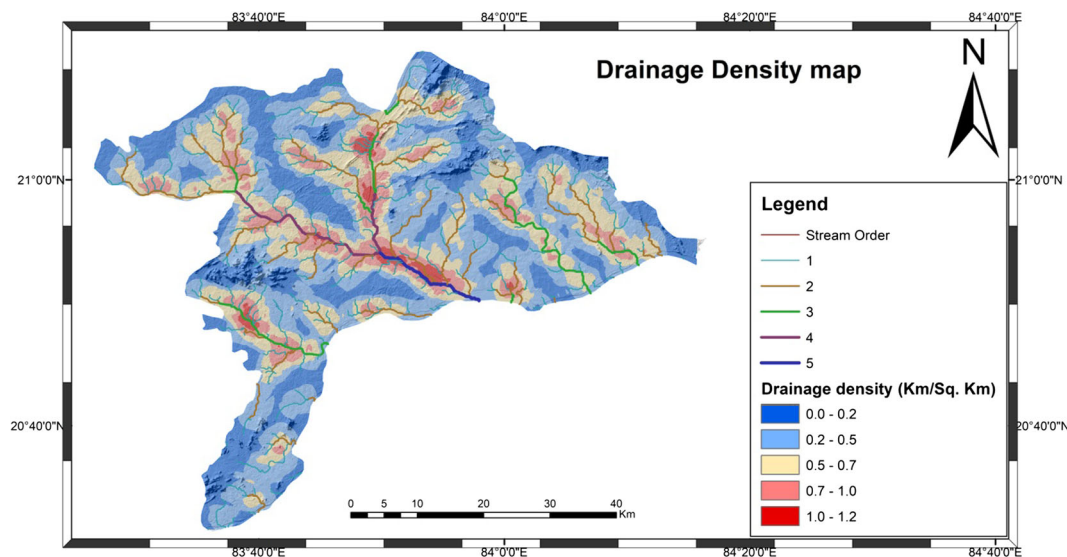| Soil type	Steady infiltration rate (in /h)
Sands	>0.8
Loams	0.2–0.4
Clays	0.04–0.2

Figure 7. Drainage density classification map of Sonepur district, Odisha.

2009). The rainfall distribution map is shown in figure 9. Higher rainfall indicates higher groundwater potential and the ranks were thus assigned (table 5).

4.8 *Lineament density*

Lineaments act as potential conduits to groundwater movement and their presence indicates good groundwater prospects (Magowe and Carr 1999; Fernandes and Rudolph 2001; Mogaji *et al.* 2011; Yeh *et al.* 2016). Generally, lineament-controlled terrains are underlined by the zone of increased porosity and permeability (Abdullahi *et al.* 2013). Thus mapping of lineament density from lineament maps is intimately associated with groundwater occurrence and is essential for groundwater management (Nag and Ghosh 2013). The lineament density map is shown in figure 10. The region with the highest lineament density was given the highest rank and vice versa (table 5).

4.9 *Delineation of groundwater potential zones*

On the basis of the relative influence of each parameter on the groundwater potential, a pairwise comparison matrix with a consistency ratio of 6.5% (<10%) was constructed (Saaty 2008) (table 4). The percentage weights of each parameter are given in tables 4 and 5. For weighted-overlay analysis each class of different parameters was ranked in such a way that the higher rank indicated higher influence of that class (table 5). Based on the Jenk's optimisation method (Jenks 1967), the generated overlaid map was grouped into five classes, viz., poor, moderate, good, very good and excellent (figure 11). The area with hills, high elevation and slope, low-to-moderate lineament density, relatively lowest rainfall and dense vegetation falls under the poor groundwater zone (16.0%) (table 5). Due to the hard rock terrain and high slope of the area, the groundwater infiltration is very poor and hence this area mostly acts as the runoff zone. The majority of the area comes under the moderate groundwater potential zone (52.0%) including gentle to moderate slope, pediment–pediplain complex, granite and granite-gneiss rock types, loamy soil type and crop lands. The pediment–pediplain complex with the flat terrain and relatively restricting geological features make the groundwater recharge and storage moderate in this zone. The presence of low-drainage density, moderate lineament density, fractured
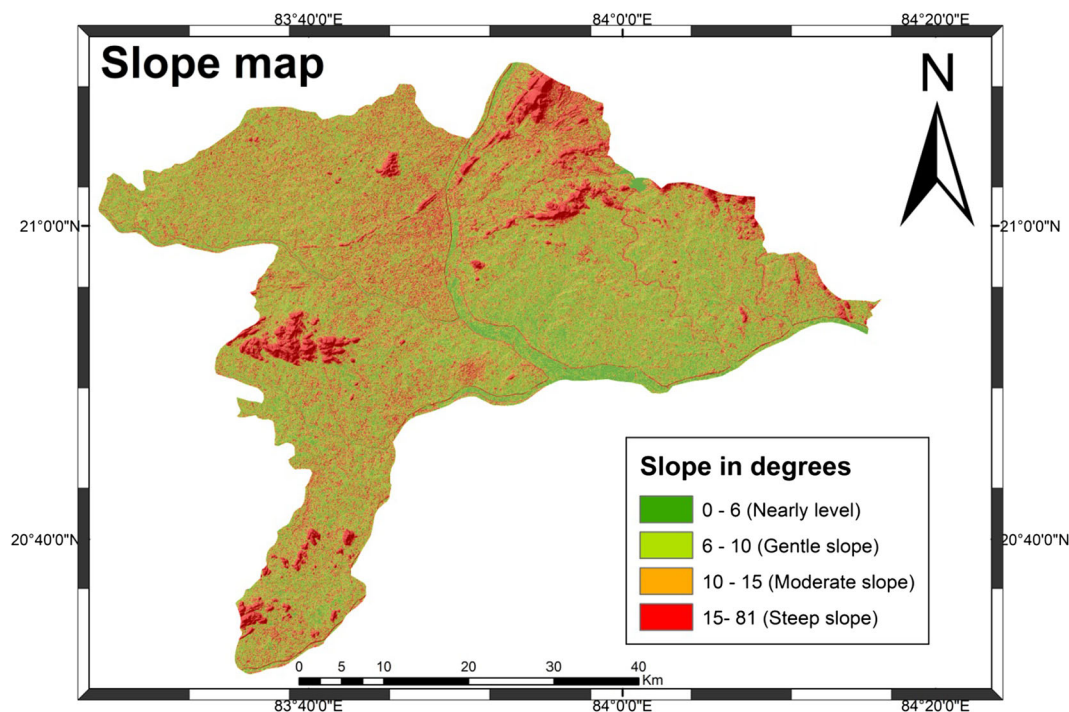

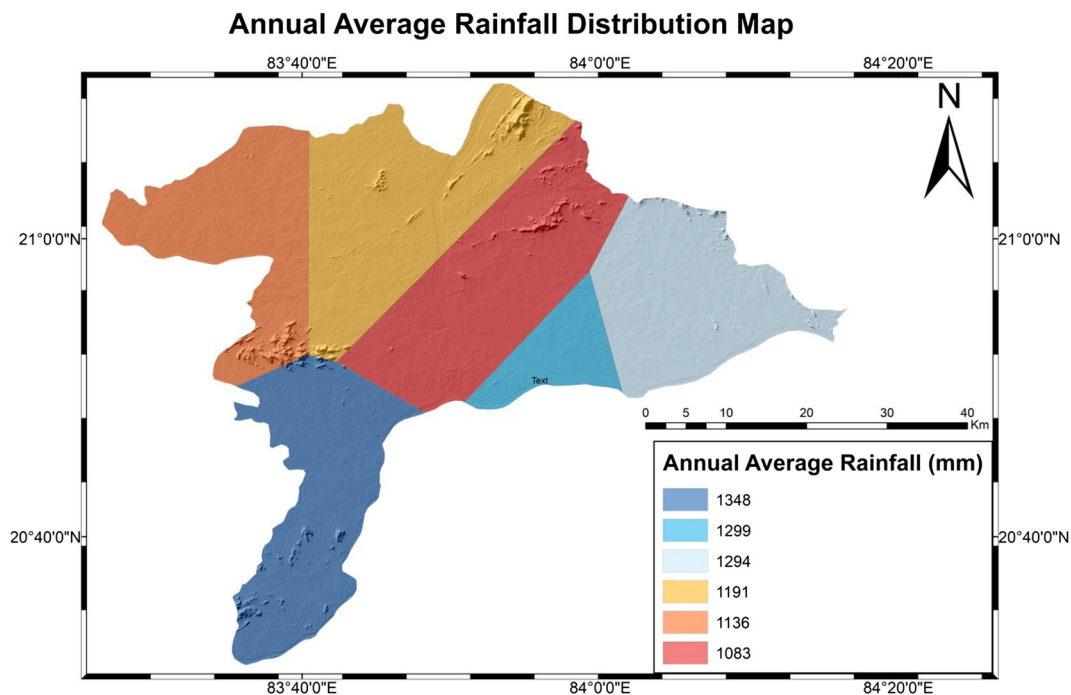Figure 8. Slope map of Sonepur district, Odisha.

Annual Average Rainfall Distribution Map

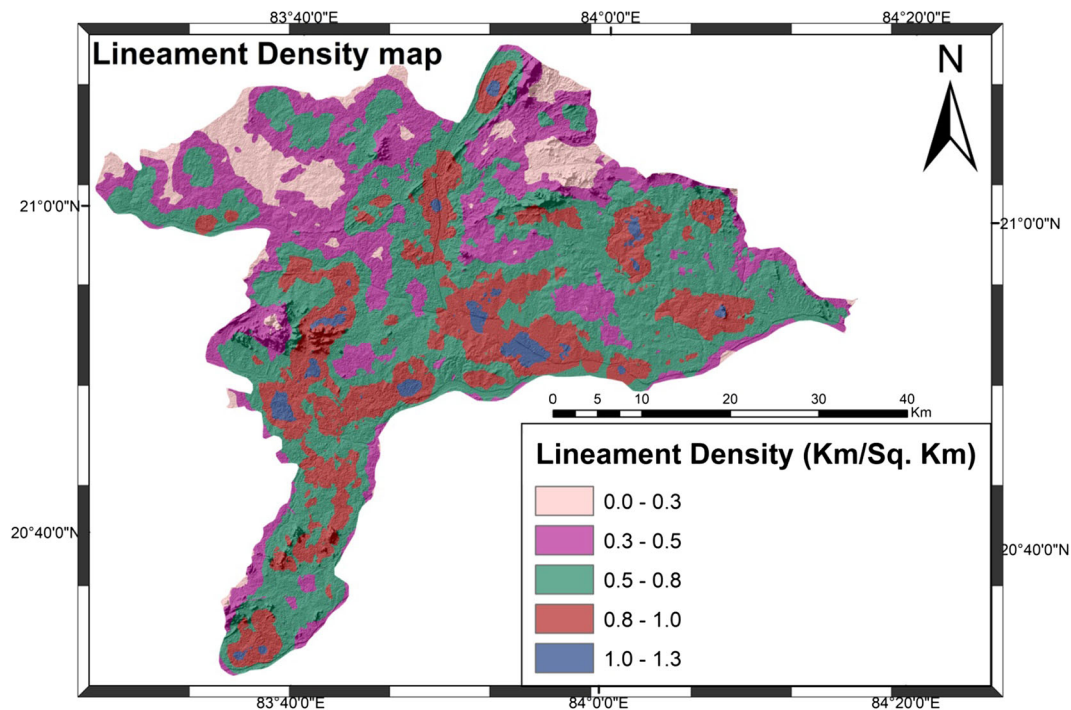Figure 9. Annual average rainfall distribution map of Sonepur district, Odisha.

Figure 10. Lineament density classification map of Sonepur district, Odisha.

rocky zones, alluvial patches and water bodies renders 26.3% of the total area as a good groundwater potential zone. Only 0.6% of the area comprising alluvial formation falls under a very good groundwater prospect zone. The areas with sandy loam soils, active flood plains and alluvial patches form an excellent groundwater potential zone, which is mere 5.1% of the study area. High-lineament density with a nearly level slope makes this zone ideal for groundwater infiltration.

Table 4. *Pairwise comparison matrix using Saaty's method and calculated percentage weight.*

Parameters	LULC	Soil	Geology	Geomorphology	Drainage density	Lineament density	Slope	Rainfall	Percentage weight (%)
LULC	1.00	4.00	0.50	5.00	3.00	2.00	4.00	4.00	24.0
Soil	0.25	1.00	0.25	4.00	2.00	3.00	1.00	1.00	10.0
Geology	2.00	4.00	1.00	6.00	3.00	2.00	4.00	4.00	30.0
Geomorphology	0.20	0.25	0.17	1.00	0.33	0.50	0.25	0.25	3.0
Drainage density	0.33	0.50	0.33	3.00	1.00	2.00	0.50	0.50	7.0
Lineament density	0.50	0.33	0.50	2.00	0.50	1.00	0.33	0.33	6.0
Slope	0.25	1.00	0.25	4.00	2.00	3.00	1.00	1.00	10.0
Rainfall	0.25	1.00	0.25	4.00	2.00	3.00	1.00	1.00	10.0

4.10 *Validation*

In order to validate the accuracy of the groundwater prospect map of the study area, a number of wells falling in each of these zones and the respective water level data were analysed. The water levels of the study area vary from 0.8 to 5.4 m bgl during the post-monsoon season and from 0.5 to 7.8 m bgl during the pre-monsoon season (of year 2016). From the water level contours, it can be observed that areas with a shallow groundwater level coincide with good to very good water potential zones while the areas with deeper water levels coincide with moderate to poor groundwater potential zones (figures 12 and 13). Further, all the available wells were segregated into four classes on the basis of the mean and standard deviation of water levels for both the seasons. It can be observed that wells fall in poor, moderate and good groundwater potential zones. The number of wells with shallow water levels (<3 m bgl during the post-monsoon season and <4.5 m bgl during the pre-monsoon season) is higher in a good water potential zone and lesser in a poor water potential zone. In contrast, the number of wells having deeper water levels (>3 m bgl during post-monsoon and >4.5 m bgl during pre-monsoon) is higher in a poor water potential zone and lesser in a good water potential zone. This pattern of well locations is clearly in agreement with the groundwater potential zones estimated in the study.

5. Discussion

The regions experiencing extreme climatic conditions are common in Indian subcontinent (Chakraborti 1999). Other hydrogeological and geological conditions prevailing in these regions also add to the complexity in identifying suitable zones for rainwater harvesting or exploitation of groundwater resources for sustainable water management. The lack of proper information on the groundwater potentiality of the region is a big concern to the water supply authorities, which can be addressed through the proper use of freely available RS and other secondary data in the GIS platform. Often the output of RS data is used for predicting monsoon, flood and drought management; however, there is a great paucity in studies which have used the water potentiality map generated from multiple thematic layers for managing the water resources (Hallberg *et al.* 1973; Sanyal and Lu 2004; Murad and Islam 2011; Bera *et al.* 2012; Menon and Bhavana 2016). As a part of this study, we attempted to demarcate the groundwater potentiality of the study area and suggest suitable actions to manage water resources in a safe and sustainable manner. Two blocks in the study area, viz., Ullunda and Sonarpur have poor water potential with high runoff and low infiltration. Rainwater harvesting can be a viable option keeping in view the low-drainage density of the area and high runoff. The north western part of the study area shows water logging issues and the drainage is poor due to the clayey nature of the soils. The surface water utilisation can be minimized in this area so that irrigation needs depend mainly on groundwater leading to reduction in water levels. The majority of the study area mainly covering Tarbha and Birmaharajpur sites represents moderate groundwater potential and because of high-drainage density the infiltrated water drains into the river/streams through vadose and shallow groundwater zones. This process does not

Table 5. *Weights and ranks assigned to the thematic layers and their respective classes.*

Theme	Class	Area percentage (%)	Rank	Weight (%)
Geology	Khondalite and Calc-silicate rocks	4.1	5	30
	Hilly area, without productive zone	13.5	1	
	Anorthosite/gabbro	5.6	2	
	Sandstone/shale conglomerate	1.3	6	
	Alluvium	1.0	9	
	Granite and granite gneiss	45.0	3	
	Bonai granite/quartzite	24.2	5	
LULC	Water Bodies/rivers/canals/reservoirs	5.9	6	24
	Vegetation	13.1	4	
	Barren land/settlements	11.0	1	
	Crop land	70.0	2	
Soil	Clay/loamy clay/sandy clay/silty clay	33.9	2	10
	Loam/silt loam/silt/sandy loam	52.9	3	
	Rocky/other non-soil categories	8.9	1	
	Loamy sand/sand	4.2	4	
Rainfall (mm)	1083	21.1	1	10
	1136	16.1	2	
	1191	21.8	3	
	1294	17.3	4	
	1299	5.6	5	
	1348	18.2	6	
Slope (deg)	Nearly level slope (0–5.7)	23.5	4	10
	Gentle slope (5.7–9.5)	27.0	3	
	Moderate slope (9.5–15.2)	25.1	2	
	Steep slope (15.2–80.7)	24.4	1	
Drainage density (km/km^2)	0–0.237	24.3	5	07
	0.238–0.474	37.3	4	
	0.475–0.712	26.2	3	
	0.713–0.949	10.6	2	
	0.95–1.19	1.7	1	
Lineament density (km/km^2)	0–0.25	7.3	1	06
	0.25–0.51	25.7	2	
	0.51–0.76	43.4	3	
	0.76–1.0	21.4	4	
	1.0–1.26	2.1	5	
Geomorphology	Water bodies – river	6.5	9	03
	Fluvial origin – active flood plain	3.5	7	
	Structural origin – highly dissected hills and valleys	1.7	1	
	Structural origin – moderately dissected hills and valleys	2.1	1	
	Structural origin – low dissected hills and valleys	0.1	1	
	Denudational origin – pediment–pediplain complex	84.4	3	
	Denudational origin – low dissected hills and valleys	0.2	2	
	Anthropogenic origin (reservoirs)	0.2	9	
	Denudational origin – moderately dissected hills and valleys	1.3	2	

allow groundwater infiltration to deeper zones, hence installing the wells tapping the shallow groundwater would be a viable option without impacting the groundwater stored in deeper horizons. The central part of the study area (Sonarpur area) as well as areas along the river channels fall under very good to excellent water potential zones, thus the wells located in these areas can be used for meeting the irrigation needs even under drought conditions (figures 14 and 15).
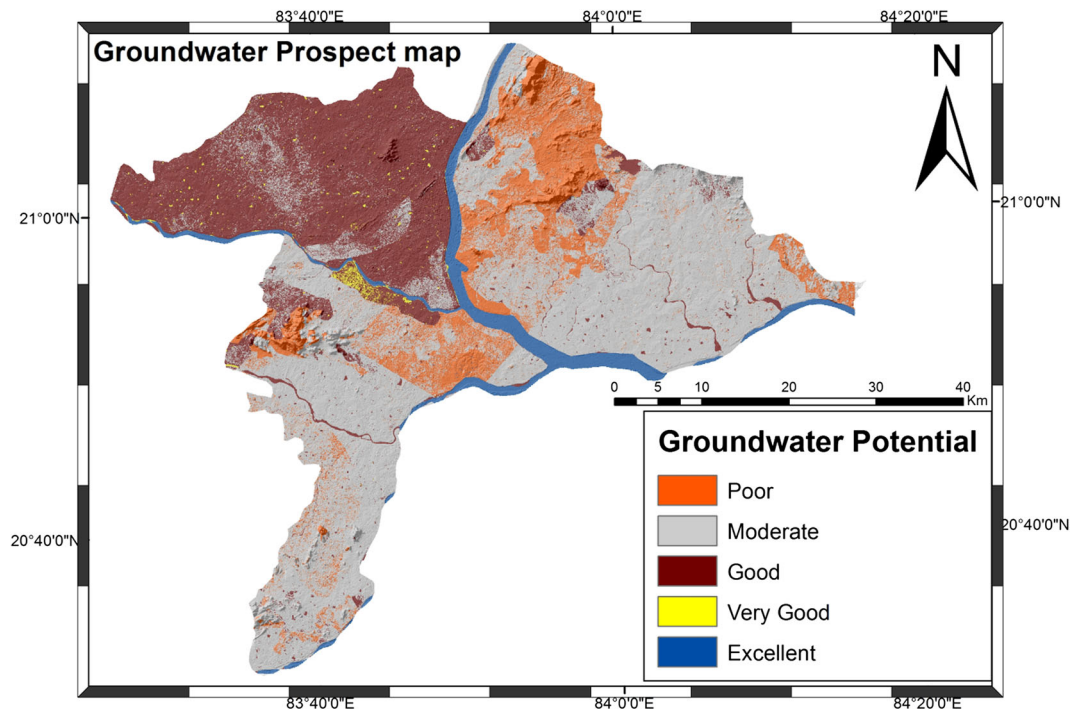
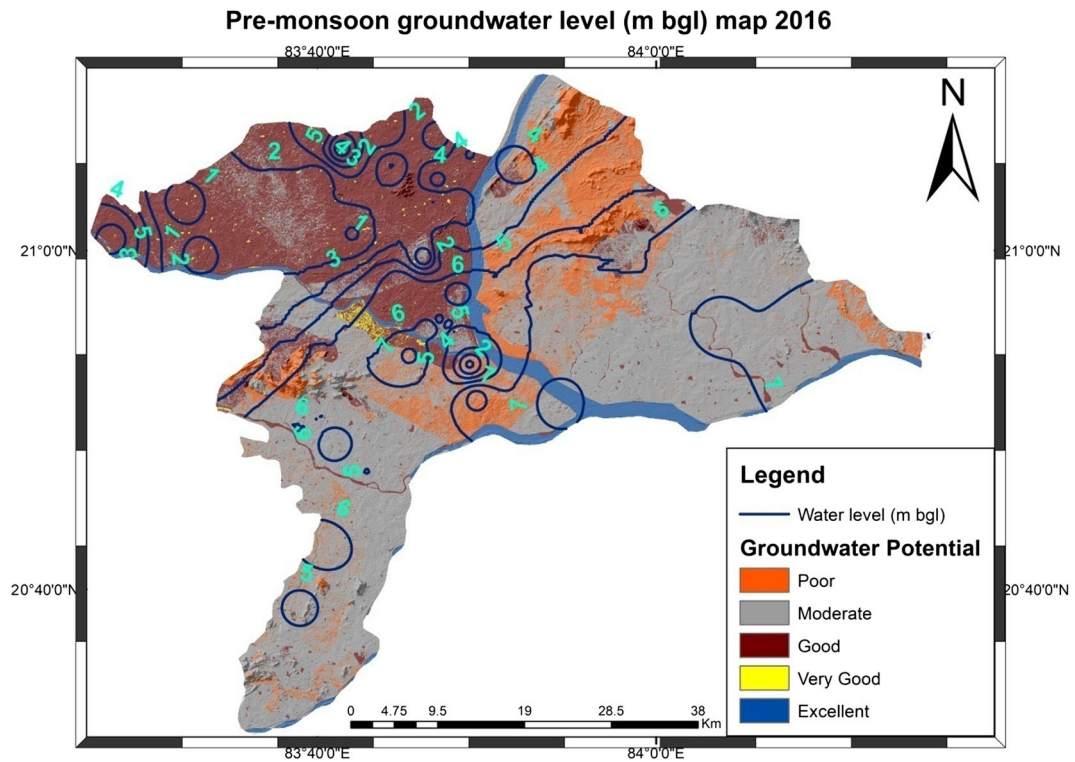Figure 11. Groundwater prospect zonation map of Sonepur district, Odisha.

Figure 12. Water level (m bgl) contour map of the pre-monsoon season (2016) of Sonepur district, Odisha.

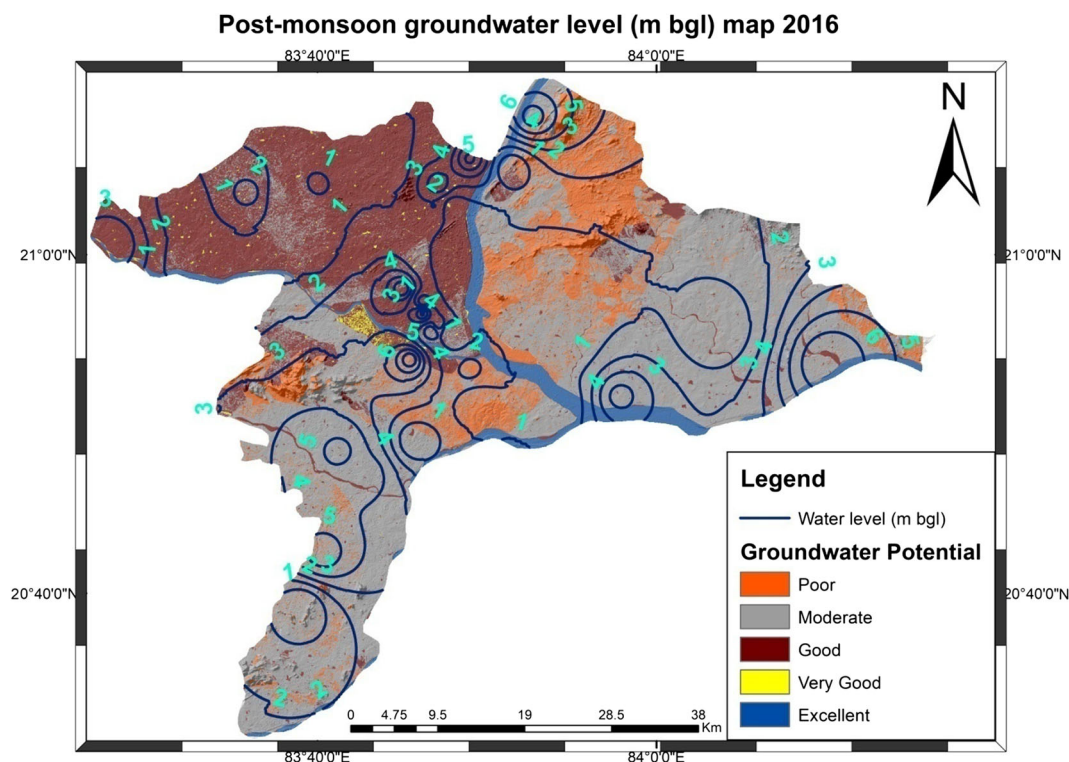**Post-monsoon groundwater level (m bgl) map 2016**

Figure 13. Water level (m bgl) contour of the post-monsoon season (2016) of Sonepur district, Odisha.

Figure 14. Statistical distribution of wells in each groundwater potential zone during the pre-monsoon season (2016).
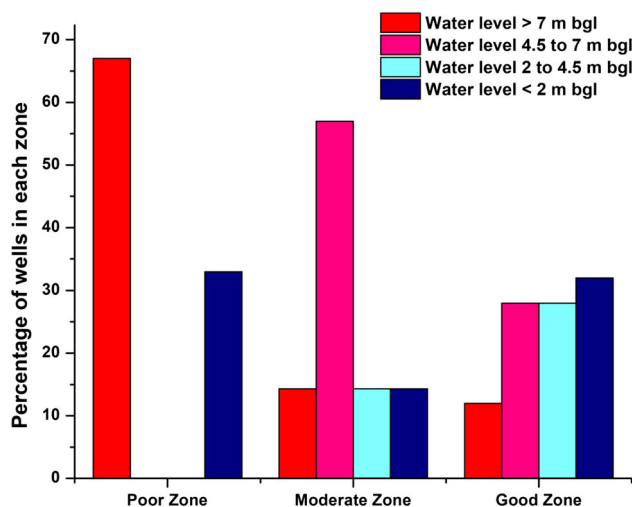

Figure 15. Statistical distribution of wells in each groundwater potential zone during the post-monsoon season (2016).

6. Conclusion

The groundwater prospect map of the study area was prepared using high-resolution satellite imagery along with secondary data from other published sources. The LANDSAT 8 OLI data, ASTER Level-1T and Cartosat-1 imagery were used for preparing the LULC, drainage density, lineament density and slope maps of the Sonepur district, Odisha. Saaty's AHP tool showed that
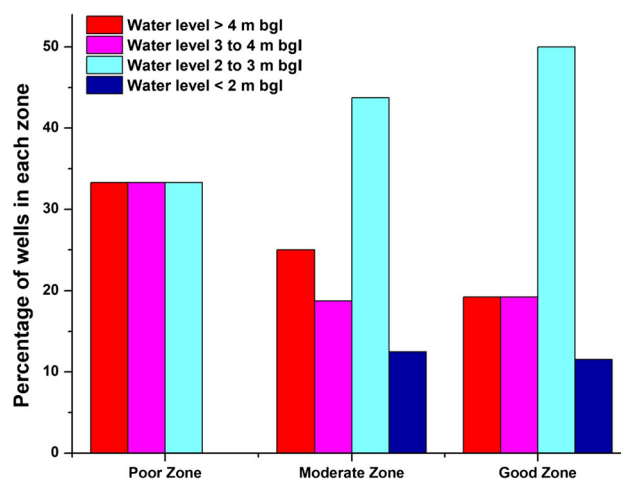
geology of the area is the major factor controlling recharge possibility followed by LULC. The groundwater potentiality map was validated by correlating with the groundwater level contours and distribution of number of wells in a particular zone. From the groundwater prospect map it can be inferred that the region with hills shows high elevation and steep slope, low-to-moderate lineament density, relatively low rainfall and dense vegetation and it falls under the poor groundwater

zone (16%). The area falling under gentle to moderate slope, pediment–pediplain complex, granite and granite–gneiss rock types (52% of the area) belong to the moderate groundwater prospect zone. Thirty-two per cent of the total area having fractured rocky surfaces, alluvial patches and water bodies comes under good to very good and very good to excellent potential zones. The inferences from the water potential map were used to suggest suitable management plans for safe and sustainable use of groundwater during drought as well as flood conditions. Considering the low-drainage density and high runoff in Ullanda and Sonarpur blocks, rainwater harvesting is a viable option. Water logging problems in the north western part of the study area can be mitigated through the use of groundwater for irrigation practices. The major portion of the Sonarpur block falls under very good to excellent potential zones, so the wells located in this region can be used for irrigation and industrial purposes even during drought conditions. This study demonstrates the potential for the combined use of RS and GIS to provide vital inputs for sustainable groundwater management in a region with extreme climatic conditions.

Acknowledgements

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