

Chapter 9

Application of AHP for Groundwater Potential Zones Mapping in Plateau Fringe Terrain: Study from Western Province of West Bengal



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Abstract The water-stressed Joyponda river basin is situated on the hard rock terrain of *Chotanagpur Granite Gneiss Complex* of Archean age and older alluvium of Quaternary. An assessment is carried out to delineate the groundwater prospect zones for this densely populated river basin taking into account eleven hydro-geological factors, namely, geology, lineament, geomorphology, slope, curvature, drainage, rainfall, soil, infiltration number, topographic wetness index and land use land cover. To prepare the thematic layers of all these parameters, different maps, satellite images and data are collected from various national and international organizations and analysed in different Remote Sensing (RS) and Geographical Information System (GIS) softwares. The Analytical Hierarchy Process (AHP) model is considered in this study to assign weight for all factors depending upon their influencing capacities in the development of groundwater. The map of groundwater prospect zones is prepared integrating all the factors in GIS software. The applied model is also validated computing overall accuracy assessment and Kappa co-efficient. The study confirms that an area of 37.49% of the Joyponda river basin bears good to very good groundwater potentiality. Around 10.97% of the basin is delineated as very poor groundwater prospect zones. A significant proportion of basin area of 28.93% is moderately potential for groundwater. The result of accuracy assessment of the study ensures the 85% validity of the model. Moreover, the Kappa co-efficient is calculated as 0.81 and describes an almost perfect agreement between simulated model and reference points.

Keywords AHP · Groundwater assessment · Hydro-geology · Joyponda river basin · RS and GIS

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9.1 Introduction

Water is the most precious natural resource for all living organisms in the world. But in the last few decades, a rapid population growth, unsustainable use of water and climate change altogether have decreased the volume of freshwater across the globe (Hinrichsen and Tacio 2002; Lakshmi et al. 2018). It is estimated that around 844 million people in the world are devoid of fresh drinking water, and 3 out of 10 people cannot use safely managed drinking water (Gun 2012). The amount of available freshwater in the world is 2.50%, and 1.5% of this total freshwater is recorded as groundwater (Chow et al. 2008). This little amount of freshwater, i.e. groundwater, is considered as the only source of potable water supply to the half of the world population (World Water Assessment Programme 2009); and around 15 million people of the world use it as the main source of freshwater supply for their multi-purpose activities (Agarwal et al. 2013; Teixeira et al. 2013). Even most of the rural (about 90%) settlements of the world directly depend on the groundwater for drinking purpose (Jaiswal et al. 2003; Sar et al. 2015). The excessive rate of groundwater exploitation to keep parity with the demands of ever-increasing populations has been taking the world towards the serious crisis of freshwater (Suhag 2016; Guru et al. 2017). It is reported by the Central Water Commission (CWC) of India that around 1800 million people of the world will suffer from the severe freshwater crisis in the near future (Central Water Commission 2010). It is estimated that the Asian countries withdraw around two-thirds of the globally explored groundwater, and India is the largest user in this regard (World Bank 2010), because 80% of rural areas and 50% of urban areas in India directly bank on groundwater for the domestic purposes (Lakshmi and Reddy 2018). According to the Central Ground Water Board (CGWB) of India, around 230 billion cubic meter groundwater is withdrawn every year in India (Central Ground Water Board 2017), out of which 89% and 9% are used for agricultural irrigation and domestic purposes, respectively, and remaining groundwater is used for industrial and other activities of the country (Suhag 2016). If the rate of groundwater exploitation maintains this present trend, a drastic decline of groundwater table will be experienced by 60% of districts of India in the coming two decades compromising Indian agricultural productions not less than 25% (World Bank 2010). Extensive rate of groundwater extraction will definitely be decreasing the storage of the aquifers in the near future. In India, most of the aquifers (53.31%) are found in hard rocks terrain (Groundwater Estimation Committee 2017), where around 65% of India's geographical areas are made of hard rocks with less than 5% of porosity level (Saraf and Choudhury 1998). Generally, groundwater in hard rocks terrain is mainly concentrated in different fractured zones, and it becomes very difficult to account the availability of groundwater without proper assessment of aquifers (Sivaramakrishnan et al. 2015). Broadly, there are two types of groundwater assessment methods, namely, conventional and advanced methods (Goldman and Neubauer 1994; Lakshmi and Reddy 2018). The geophysical technique of conventional method is used to explore the aquifer characteristics and identification of sites

for borehole drilling (Lakshmi and Reddy 2018; Etikala et al. 2019). The main drawbacks of conventional method to delineate groundwater potential zones are expensive instruments, extensive field visits, more labour supports and time requirements (Mukherjee et al. 2012). In contrast, the geospatial technologies of advanced method are proved to be more cost-effective and less time consuming in preliminary estimation of groundwater prospect zones (Faust et al. 1991; Hinton 1996; Jha et al. 2007; Razandi et al. 2015; Santharam and Elangovan 2018). The Remote Sensing (RS) and Geographical Information System (GIS) are the indirect means in groundwater exploration using several directly related hydro-geological factors, which determine the availability of groundwater (Javed and Wani 2009). These factors are geomorphology, slope, soil, geology, rainfall, lineament, infiltration number, drainage, land use land cover, curvature and topographic wetness index (Subba Rao 2006; Magesh et al. 2012; Rajaveni et al. 2017; Santharam and Elangovan 2018; Arulbalaji et al. 2019). In recent past, several researchers from various disciplines have successfully integrated different hydro-geological factors in RS and GIS environment to delineate groundwater prospect zones employing different statistical and mathematical models, such as Analytical Hierarchy Process (AHP) (Mandal et al. 2016; Maity and Mandal 2017; Panahi et al. 2017; Aydi 2018), Frequency Ratio Model (FRM) (Ozdermir 2011; Trabelsi et al. 2019), Multi-Influencing Factor (MIF) (Magesh et al. 2012; Nasir et al. 2018; Ghosh et al. 2020), Certainty Factor Model (CRM) (Razandi et al. 2015; Hou et al. 2018) and Artificial Neural Network (ANN) (Baghapour et al. 2016; Lee et al. 2019). The AHP model is one of the most popular Multi-Criteria Decision-Making (MCDM) techniques and has been used with RS and GIS techniques more widely for its capacity to simplify the complex system of groundwater occurrence in various natural environments (Mandal et al. 2016; Arulbalaji et al. 2019; Kumar et al. 2020), such as in hard rocks regions (Shekhar and Pandey 2014; Maity and Mandal 2017; Murmu et al. 2019), semi-arid regions (Machiwal et al. 2011; Kumar et al. 2014; Singh et al. 2018; Rajasekhar et al. 2019) and also for coastal regions (Gangadharan et al. 2016; Swetha et al. 2017). In general, the western part of West Bengal experiences the high intensity rainfall for short period of time followed by high rate of runoff due to high topographic slope that leads to water scarcity during hot dry season (Nag and Das 2017; Government of West Bengal 2017). The present study deals with the delineation of groundwater prospect zones of Joyponda river basin situated on the plateau fringe zone of *Chotanagpur Granite Gneiss Complex* (CGGC) of Bankura district in the state of West Bengal, India. The uniqueness of the basin is that it is composed of heterogeneous lithology. The upper reach is mainly comprised of hard rocks, and the lower reach is composed of alluvium. This region has already been identified as one of the drought-prone areas in West Bengal (Government of West Bengal 2017). The demand for freshwater remains always high among the people of the river basin throughout the year because the population density of the basin ($528/\text{km}^2$) is much higher than the national average ($382/\text{km}^2$) of India (Census of India 2011), though the total groundwater withdrawal of Bankura district is 40% out of the total net available groundwater (Central Ground Water Board 2017). This report indicates that there are plenty scopes of groundwater exploration, and it can only be done by

the proper investigations. There have several works already been carried out in different parts of CGGC to assess the availability of groundwater. Majority of the studies mention that the abundance of groundwater varies from space to space depending upon the different hydro-geological factors (Chowdhury et al. 2010; Shekhar and Pandey 2014; Ghosh et al. 2015, 2020; Das 2017; Nag and Das 2017; Maity and Mandal 2017; Das et al. 2019; Murmu et al. 2019). In this context, an attempt has been made here to delineate groundwater potential zones of the Joyponda river basin considering various significant hydro-geological parameters of the study of interest using the RS and GIS techniques along with the AHP model.

9.2 Study Area

The river Joyponda, a left-hand tributary of the Shilabati River, originates near Boga village of Indpur Community Development (C.D.) block of Bankura district, West Bengal. The river flows over the four C.D. blocks of Bankura district, such as Indpur, Onda, Taldangra and Simlapal, and meets the river Shilabati at Chakrasol village of Simlapal C.D. block. The total stretch of the river is 60.63 km covering the basin area of 396.69 km². The shape of the basin is elongated, and the river Joyponda starts its journey from north-west direction to south-east direction, almost in a diagonal path. The geographical extension of the basin is 22°53'33.87" N to 23°10'31.68" N and 86°50'56.035" E to 87°12'52.68" E (Fig. 9.1). The basin area is mainly consisted of Pre-Cambrian metamorphic rocks of CGGC and older alluvium of Lalgah formation and Sijua formation (Vaidyanadhan and Ghosh 1993; Geological Survey of India 2001). The presence of the pediment-pediplain complex makes the upper part of the basin more undulating (Sen et al. 1998). The hot and dry tropical climate prevails over the study area with maximum temperature of 45 °C and minimum temperature of 7 °C. The rainfall of this area, blessed by the South-West Monsoon, is recorded as 1353 mm, which takes place mostly in between June to September (Government of West Bengal 2014). The hard rock terrain with rolling topography and less permeability increases the surface runoff during the Monsoon period, and the area encounters severe shortage of surface water (Maity and Mandal 2017; Ghosh et al. 2020). Thus, the non-perennial Joyponda river basin experiences semi-arid type of climatic conditions except rainy season. This adverse nature of the region helps to grow the deciduous type of natural vegetation, namely, sal (*Shorea robusta*), palash (*Butea monosperma*), mahua (*Madhuca longifolia*) and babla (*Vachellia nilotica*). Moreover, different types of cactus, shrubs and bushes in bare land of the study area are also found (Forest Survey of India 1985). A total number of 244 villages with 209,522 populations come under the jurisdiction of the Joyponda river basin. The river basin shares 5.83% of the total population of Bankura district (Census of India 2011).

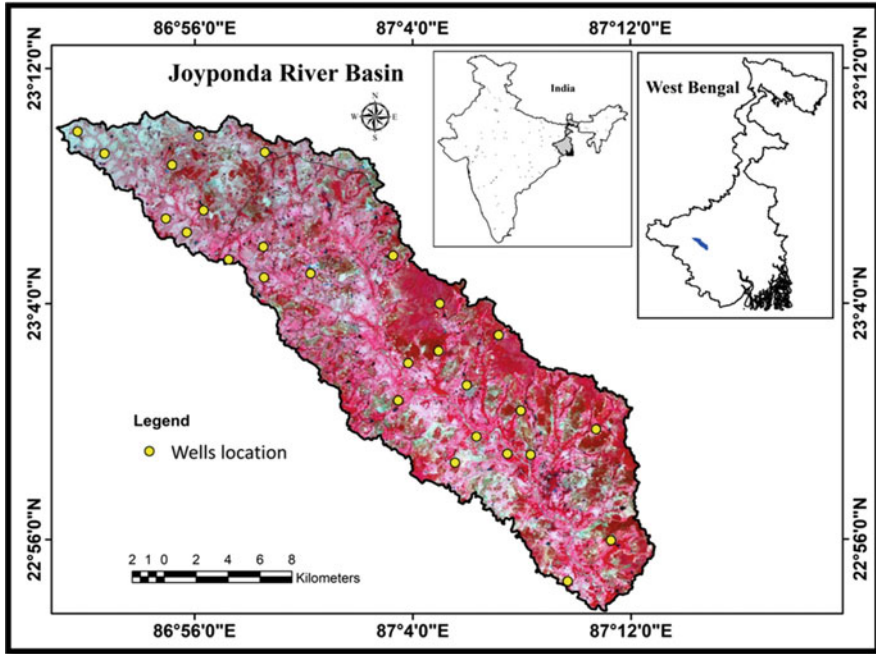


Fig. 9.1 Location map of the Joyponda river basin

9.3 Materials and Methods

9.3.1 Data Sources

To assess the groundwater prospect zones of the Joyponda river basin, a total number of eleven influential hydro-geological factors, such as geology, lineament, geomorphology, slope, curvature, drainage, rainfall, soil, infiltration number, topographic wetness index and land use land cover, are taken into consideration. We obtain different data sets for these selected factors from various sources, such as Digital Elevation Model (DEM) of Shuttle Radar Topography Mission (SRTM) with spatial resolution of 1-Arc second (downloaded from <https://earthexplorer.usgs.gov>) acquired on 23 September 2014; Landsat-8 Operational Land Imager (OLI) satellite image with 30 m spatial resolution acquired on 24 April 2018 (downloaded from <https://earthexplorer.usgs.gov>); district resource map of the Geological Survey of India (GSI) on a 1:50000 scale; geomorphology map of GSI on a 1:250000 scale; soil map of National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) of India on a 1:250000 scale; and station-wise rainfall data of Central Water Commission (CWC) of India to prepare individual thematic layer. The application of RS and GIS softwares is done here using Erdas Imagine 2014, PCI Geomatica 2016 and ArcGIS 10.3.1 to process and analyse different data.

9.3.2 Preparation of Thematic Layers

The drainage basin of the Joyponda River, which is the base map of the present study, is delineated from SRTM-DEM using hydrology tool in ArcGIS software. The drainage density and infiltration number of thematic layers are prepared using hydrology tool of spatial analyst in ArcGIS software using SRTM-DEM. On the contrary, the surface tool of spatial analyst is adopted to create slope, curvature and topography wetness index thematic layers employing the SRTM-DEM. The OLI satellite image of Landsat-8 is taken to produce land use land cover thematic layer applying the raster tool in Erdas Imagine software. The OLI image is then classified into different categories of land use land cover types using maximum likelihood algorithm of supervised classification. To prepare the lineament density map, a Principle Component Analysis (PCA) of OLI image is performed in Erdas Imagine software adopting spectral tool. The extracted lineaments based on the output of PCA of the study of interest are produced adopting line algorithm tool of PCI Geomatica software. The thematic layer of lineament is also verified with 'lineament (50k) theme layer' of the study area prepared by the National Remote Sensing Centre (NRSC) of India, and it is freely available on NRSC portal (downloaded from <https://bhuvan.nrsc.gov.in>) at 'Thematic Services' option. Moreover, the prepared lineament density map is also validated with the district resource map of GSI. The geology and geomorphology maps of the Joyponda river basin are reproduced from the GSI maps using the editor tool of ArcGIS software. The CWC data of rainfall from 2014 to 2018 of four nearby rain gauge stations of the basin are considered to prepare the rainfall map interpolating the rainfall data adopting Inverse Distance Weighted (IWD) method of spatial analyst tool in ArcGIS software. The editor tool of ArcGIS software is also used to make a soil map of the study area from the map of NBSS&LUP. During the preparation of different thematic layers, the maps are geo-coded following Universal Transverse Mercator (UTM) projection, World Geodetic Survey-84 (WGS-84) and 45 N zone as per requirements.

9.3.3 Application of AHP Model

All the eleven selected hydro-geological factors are mutually interrelated, and the groundwater development almost depends on these factors. The AHP model is used in this study to assign weight to each factor and their respective sub-classes depending upon the gravity of influence of each factor in the occurrence and movement of groundwater.

The AHP model developed by T. Saaty in 1980 is an effective multi-criteria decision-making technique, which helps to quantify the weight of a selected factor in numerical form. This model can easily solve many complexities in resource exploration and planning adopting the best possible opportunities (Olson 1988; Chowdhury et al. 2010; Shekhar and Pandey 2014; Malik et al. 2014; Pintu et al.

2017; Maity and Mandal 2017; Waris et al. 2019; Kumar et al. 2020). To assign weight considering the nine-point scale of Saaty (1980), all the eleven factors are now arranged in a hierarchical structure based on priorities. Each score of nine-point scale (Saaty 1990) has a specific definition of importance, such as (1) equal, (2) weak, (3) moderate, (4) moderate plus, (5) strong, (6) strong plus, (7) very strong, (8) very, very strong and (9) extreme. The priority of employing weight to each factor is done based on proper field investigations and review of literatures. In the next step, a pair-wise comparison matrix is formed to compute the normalized weight of an individual factor (Table 9.1).

The justification of assigned weight of each factor given by the decision-maker can be verified with the help of consistency index, and it is the best part of this model (Saaty and Vargas 1982; Ramanathan 2001; Arulbalaji et al. 2019; Das et al. 2019; Waris et al. 2019). The consistency index is calculated using the following equation (formula 9.1):

$$CI = \frac{(\lambda_{\max} - n)}{(n - 1)} \tag{9.1}$$

where *CI* simply denotes consistency index. The λ_{\max} represents the principle eigenvalue, which is calculated using eigenvector technique (Malik et al. 2014), and *n* is the total number of factors used in the study. The Consistency Ratio (CR) is computed for the verification of judgement coherence. If the value of CR happens to be more than 0.1, the judgement value cannot be accepted. Thus, it becomes necessary to consider new judgement values for all factors to reach the CR value less than 0.1. The following expression is used to calculate the CR (formula 9.2), where *RCI* is the random consistency index, which is proposed by Saaty in 1980 (Saaty 1990):

$$CR = \frac{CI}{RCI} \tag{9.2}$$

9.3.4 Calculation of Groundwater Potential Zones Index and Accuracy Assessment

The Groundwater Potential Zones Index (GPZI) is computed taking into account all the 11 thematic layers of selected parameters adopting weighted linear combination method of map algebra tool in ArcGIS software. The derived GPZI is dimensionless. Formula 9.3 is used to calculate the GPZI. Here, W_i is the normalized weight of i^{th} factor, R_j represents the rank of j^{th} sub-class in respective i^{th} factor, m denotes the total number of factors, and n is the total number of sub-classes of all factors. Finally, obtained GPZI values are divided into five distinct classes, such as very poor, poor, moderate, good and very good using natural break classification system in ArcGIS

Table 9.1 Pair-wise comparison matrix of considered factors and normalized weight

Geology	9/9	Geomorphology	9/8	Slope	9/7	9/7	Land use land cover	9/6	Soil	9/6	Infiltration number	9/5	Drainage density	9/5	Rainfall	9/4	Topographic wetness index	9/3	9/3	Curvature	9/3	Geometric mean	1.67	Normalized weight	0.14
Geomorphology	8/9	8/8	8/7	8/7	8/7	8/7	8/7	8/6	8/6	8/6	8/5	8/5	8/5	8/5	8/4	8/4	8/3	8/3	8/3	8/3	8/3	1.48	0.13		
Slope	7/9	7/8	7/7	7/7	7/7	7/7	7/7	7/6	7/6	7/6	7/5	7/5	7/5	7/5	7/4	7/4	7/3	7/3	7/3	7/3	7/3	1.29	0.11		
Land use land cover	7/9	7/8	7/7	7/7	7/7	7/7	7/7	7/6	7/6	7/6	7/5	7/5	7/5	7/5	7/4	7/4	7/3	7/3	7/3	7/3	7/3	1.29	0.11		
Lineament density	6/9	6/8	6/7	6/7	6/7	6/7	6/7	6/6	6/6	6/6	6/5	6/5	6/5	6/5	6/4	6/4	6/3	6/3	6/3	6/3	6/3	1.11	0.10		
Soil	6/9	6/8	6/7	6/7	6/7	6/7	6/7	6/6	6/6	6/6	6/5	6/5	6/5	6/5	6/4	6/4	6/3	6/3	6/3	6/3	6/3	1.11	0.10		
Infiltration number	5/9	5/8	5/7	5/7	5/7	5/7	5/7	5/6	5/6	5/6	5/5	5/5	5/5	5/5	5/4	5/4	5/3	5/3	5/3	5/3	5/3	0.93	0.08		
Drainage density	5/9	5/8	5/7	5/7	5/7	5/7	5/7	5/6	5/6	5/6	5/5	5/5	5/5	5/5	5/4	5/4	5/3	5/3	5/3	5/3	5/3	0.93	0.08		
Rainfall	4/9	4/8	4/7	4/7	4/7	4/7	4/7	4/6	4/6	4/6	4/5	4/5	4/5	4/5	4/4	4/4	4/3	4/3	4/3	4/3	4/3	0.74	0.06		
Topographic wetness index	3/9	3/8	3/7	3/7	3/7	3/7	3/7	3/6	3/6	3/6	3/5	3/5	3/5	3/5	3/4	3/4	3/3	3/3	3/3	3/3	3/3	0.56	0.05		
Curvature	3/9	3/8	3/7	3/7	3/7	3/7	3/7	3/6	3/6	3/6	3/5	3/5	3/5	3/5	3/4	3/4	3/3	3/3	3/3	3/3	3/3	0.56	0.05		

Saaty's CR = (<0.1); CR = 0.0001507, the computed matrix is accepted based on derived CR value

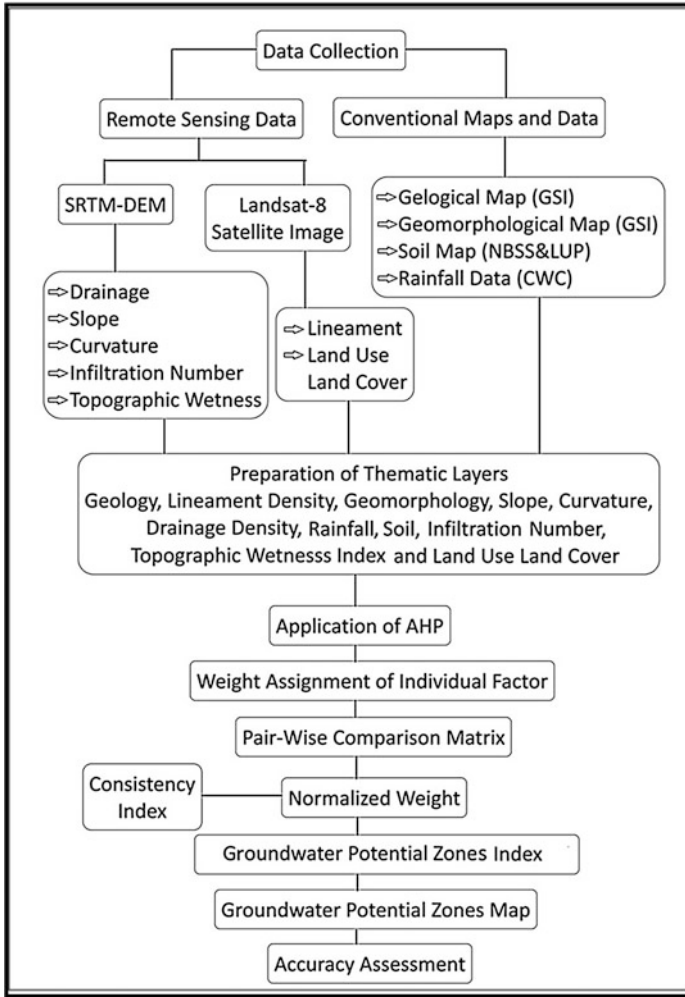


Fig. 9.2 Flow chart showing the methodology adopted

software. The final Groundwater Potential Zones (GPZ) map is validated with the Pre-Monsoon groundwater level data, which are collected from 27 pre-existing dug wells distributed across the river basin. The groundwater level data of 14 dug wells are collected from CGWB, and remaining groundwater level data of 13 dug wells are gathered during the field investigation in the month of March 2020. The overall accuracy assessment is computed to understand the accuracy level of the applied model, and the Kappa co-efficient is also calculated to validate the model. The complete description of used methodology of this present study is shown by a flow chart diagram for better understanding (Fig. 9.2).

$$GPZI = \sum_{i=1}^n \sum_{w=1}^m (W_i \times R_j) \quad (9.3)$$

9.3.5 Groundwater Recharge Estimation

The identification of potential groundwater recharge zones can be delineated with the help of GPZ map. If the amount of potential recharge is estimated for the present river basin, it will be easy to identify good groundwater potential zones, and ultimately it will facilitate in groundwater planning and management (Reese and Risser 2010; Nemaxwi et al. 2019). The spatial distribution of natural groundwater recharge is calculated adopting the rainfall infiltration factor method of Groundwater Estimation Committee (GEC) 2015 of Government of India (formula 9.4). R_r is the amount of natural groundwater recharge, ppt denotes the average annual rainfall and R_{np} represents the rainfall infiltration factor, which is obtained from GEC-1997 norms (Groundwater Estimation Committee 2017). Now, IDW method of spatial analyst tool is used in ArcGIS software to prepare the map of potential groundwater recharge amount.

$$R_r = (ppt \times R_{np} \times \text{area}) \quad (9.4)$$

9.4 Results and Discussions

9.4.1 Geological Setting

Geological setting of an area plays a significant role in determining the thickness of groundwater bearing strata (Arulbalaji et al. 2019). The Joyponda river basin area is consisted of different rock types of various geological ages ranging from Proterozoic to Quaternary (Sen et al. 1998; Geological Survey of India 2001). The entire basin area can be divided almost into two broad equal halves in general. The upper portion consists of granitic gneiss (45.34%) of extended part of Chota Nagpur Plateau of Archean age with a couple of scattered concentration of lateritic patches (Lalgarh formation), while the lower portion of the basin (51.74%) is mainly developed by the accumulation of alluviums (Table 9.2). The concentration of older alluvium is observed more in the basin with smaller amount of deposition of newer alluviums near the confluence point of the Joyponda and Shilabati rivers (Fig 9.4). The laterite deposition in the lower basin area is seen in some small pockets from east to west direction (Fig. 9.3). From the hydro-geological point of view, the older and newer

Table 9.2 Classification of factors and assignment of rank for sub-classes on the basis of influencing capacity in development of groundwater

Factors	Normalized weight	Sub-classes	Area (%)	Rank
Geology	0.14	Granitic gneiss	45.34	3
		Laterite	2.24	4
		Older alluvium	51.74	5
		Newer alluvium	0.69	6
Geomorphology	0.13	Upland plain	60.61	4
		Pediment-pediplain complex	34.79	3
		Flood plain	2.50	5
		Water bodies	2.09	6
Slope (degree)	0.11	<1.04	29.86	6
		1.04–2.26	39.69	4
		2.26–3.78	23.73	3
		3.78–12.04	6.72	2
Land use land cover	0.11	Agricultural land	62.12	5
		Forest cover	5.42	5
		Shrub land	23.42	4
		Barren land	6.56	3
		Water bodies	1.00	6
		Fallow land	1.48	2
Lineament density (km/km ²)	0.1	0.11–0.31	24.84	2
		0.31–0.39	46.78	3
		0.39–0.49	19.38	5
		0.49–0.74	9.00	6
Soil	0.1	Fine-fine silty	38.29	4
		Fine loamy	28.65	5
		Coarse loamy	23.78	6
		Loamy skeletal	2.99	3
		Clayey skeletal	6.29	2
Infiltration number	0.08	0.11–0.73	27.65	2
		0.73–1.06	35.79	3
		1.06–1.42	29.33	5
		1.42–2.14	7.23	6
Drainage density (km/km ²)	0.08	0.63–0.95	13.62	6
		0.95–1.09	47.35	4
		1.09–1.25	30.12	3
		1.25–1.51	8.91	2
Rainfall (mm)	0.06	1147–1178	12.62	2
		1178–1201	17.40	3
		1201–1222	25.87	5
		1222–1241	44.11	6

(continued)

Table 9.2 (continued)

Factors	Normalized weight	Sub-classes	Area (%)	Rank
Topographic wetness index	0.05	5.01–7.95	56.11	2
		7.95–10.39	26.27	3
		10.39–14.05	14.43	4
		14.05–23.31	3.18	5
Curvature	0.05	(−1.58) – (−0.23)	10.27	1
		(−0.23) – 0.00	53.62	2
		0.00–0.23	24.45	4
		0.23–2.38	11.66	6

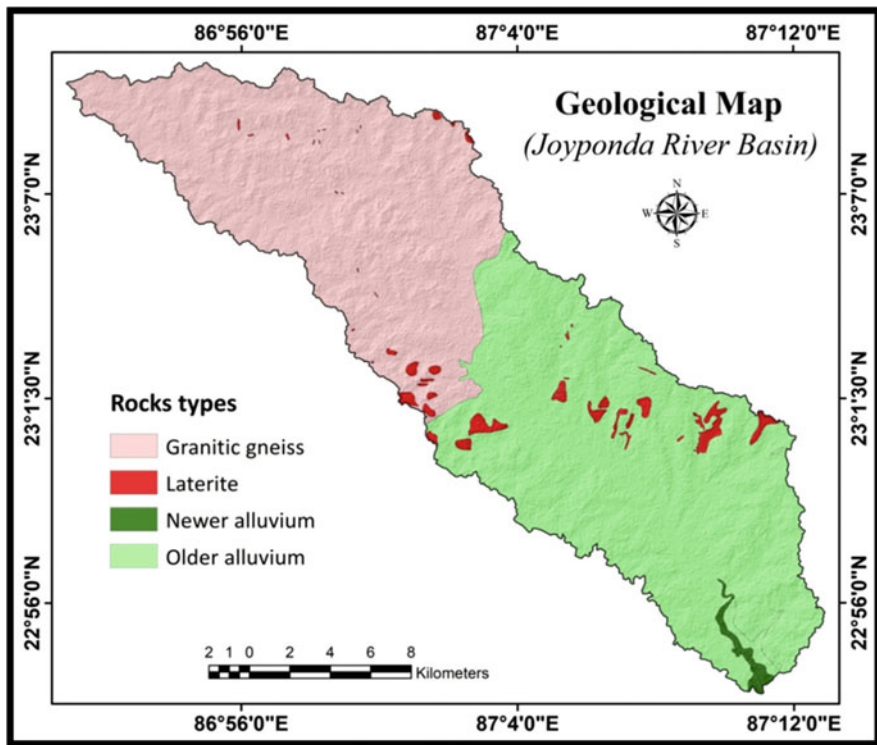


Fig. 9.3 Geological setting of the study area

alluviums are considered as the major water bearing aquifers in the basin area followed by the laterite and granitic gneiss (Groundwater Estimation Committee 2017) (Fig. 9.4).



Fig. 9.4 Field photographs of the Joyponda river basin

9.4.2 Lineament Density

The groundwater potentiality in hard rocks terrain is largely controlled by the discontinuity of rock surface, such as joints, fractures, faults and shear zones. These linear or curvilinear tectonically deformed features create favourable conditions for downward movement of water through the hard rocks surface and ultimately that gives rise to the development of pocket aquifers (Chandra et al. 2006; Acharya and Malik 2012; Shailaja et al. 2019). The permeability and secondary porosity are highly influenced by the areas of high lineaments (Arulbalaji et al. 2019; Ghosh et al. 2020). The high lineament density zones are observed in different pockets of the basin in circular, semi-circular and elongated patterns covering an area of 28.38% of the total basin (Fig. 9.5). The moderate type of lineament density is seen along the basin almost from source to sink of the river, while some portion of the basin boundary (24.84%) shares low amount of lineament density (Table 9.2).

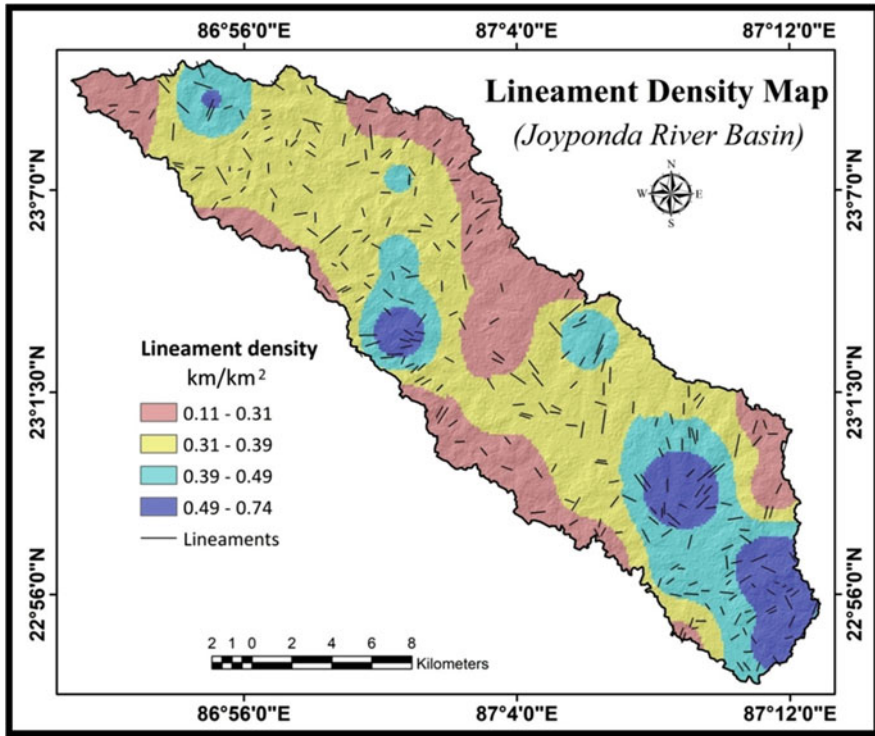


Fig. 9.5 Lineament density of the study area

9.4.3 Geomorphology

Geomorphology is the science which tries to understand the evolution of landforms of complex diversity and different geomorphic processes acting upon them (Summerfield 1999; Goudie 2004; Huggett 2007). It also provides details about the distribution of weathered zones, processes of water movement and characteristics of underlying lithology (Murmu et al. 2019). The geomorphic features of the area are divided into four distinct categories. The upper portion of the basin, which is pediment-piedplain complex, occupies 34.79% area of the total basin, and this complex is considered as less favourable for groundwater recharge due to its undulating topographical characteristics. The upland plain (60.61%) mainly dominates the entire basin from upper-middle course of the Joyponda river up to the confluence point (Table 9.2). There are plenty numbers of small water bodies observed across the river basin randomly. A small proportion of flood plain area is contributed by the river Joyponda from its middle reach to sink (Fig. 9.6). The weathered and loose materials of upland plain and alluvium of flood plain are more suitable in the movement and occurrence of groundwater (Krishnamurthy et al. 1996).

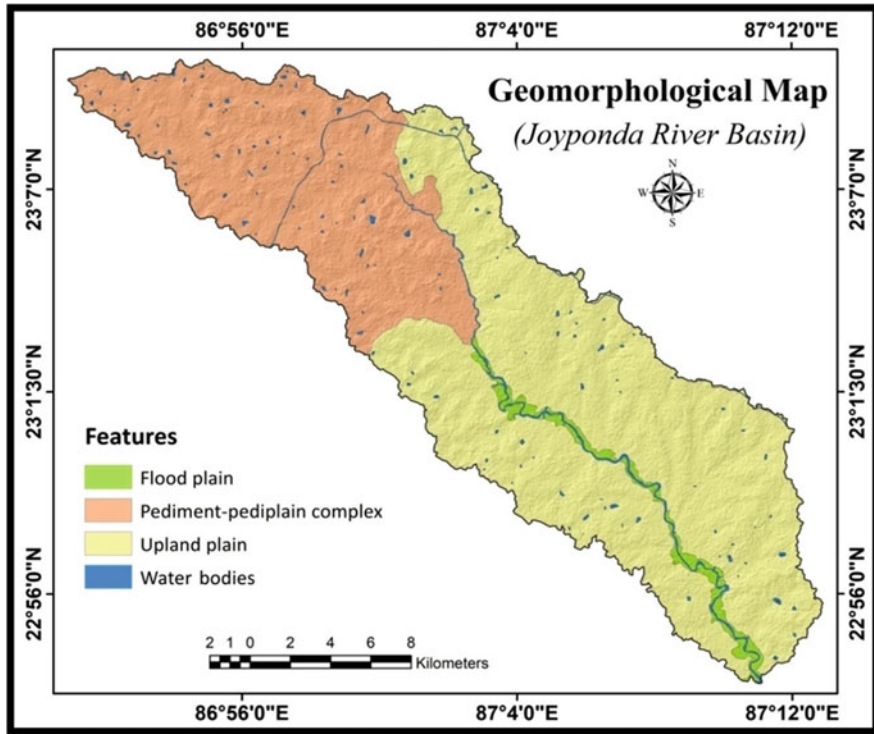


Fig. 9.6 Geomorphological map of the study area

9.4.4 Slope

The steepness of topography is a very crucial factor in groundwater development of an area. The degree of slope is directly proportional to the surface runoff and inverse to the infiltration rate (Siva et al. 2017). The higher amount of slope reduces the chance of water percolation into the soil and resulting less amount of groundwater recharge (Singh et al. 2013). The high degree of slope covering an area of 6.72% is observed across the basin due to concentration of low dissected residual hills (Fig. 9.7). The low degree of slope (i.e. less than 1.04 degree) is mainly found in the riverine areas of lower course sharing an area of 29.86% of the total basin. This area is most favourable for groundwater recharge due to loose sediments. A significant proportion of the basin area (63.42%) experiences moderate type of slope varying from 1.04 to 3.78 degree (Table 9.2).

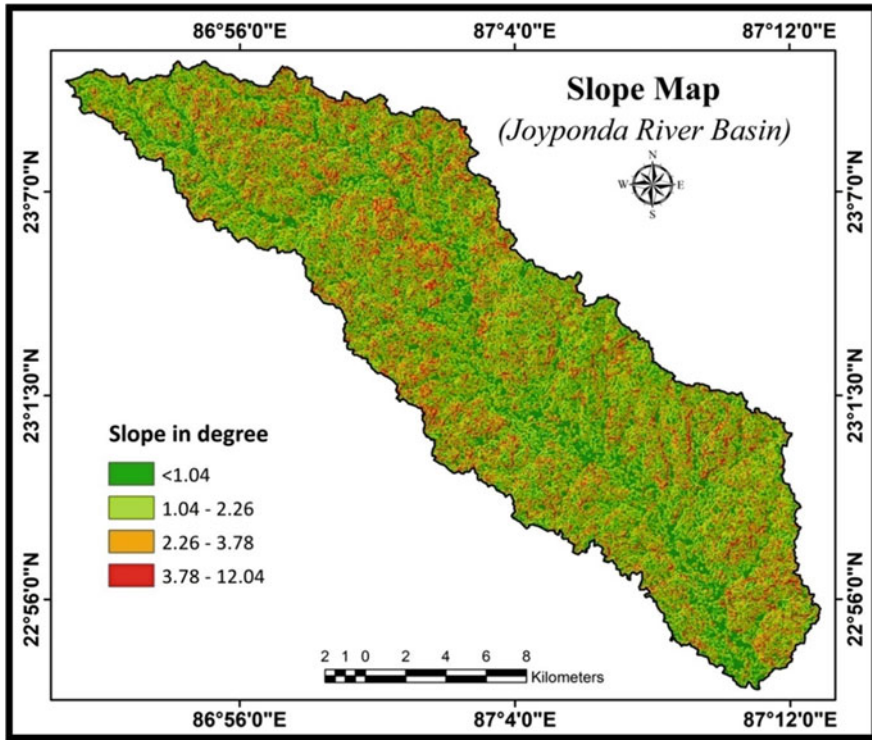


Fig. 9.7 Slope map of the study area

9.4.5 Curvature

Curvature refers to the amount of bend of topographic surface from being a horizontal plain. The shapes of bend or curve of topography are considered as convex profile, when it is curved upward, and concave profile, when it is curved downward (Benjmel et al. 2020). The concave upward profile has the highest potentiality in groundwater recharge (Arulbalaji et al. 2019). High curvature value represents the deceleration of runoff and enhancement in water infiltration rate. The curvature values of the study area lie in between -0.23 and 2.38 . The concave surface occupies around 36.11% of the total basin area (Table 9.2), and it reflects a good signature of high amount of water accumulation though most part of the river basin area experiences convex surface (Fig. 9.8).

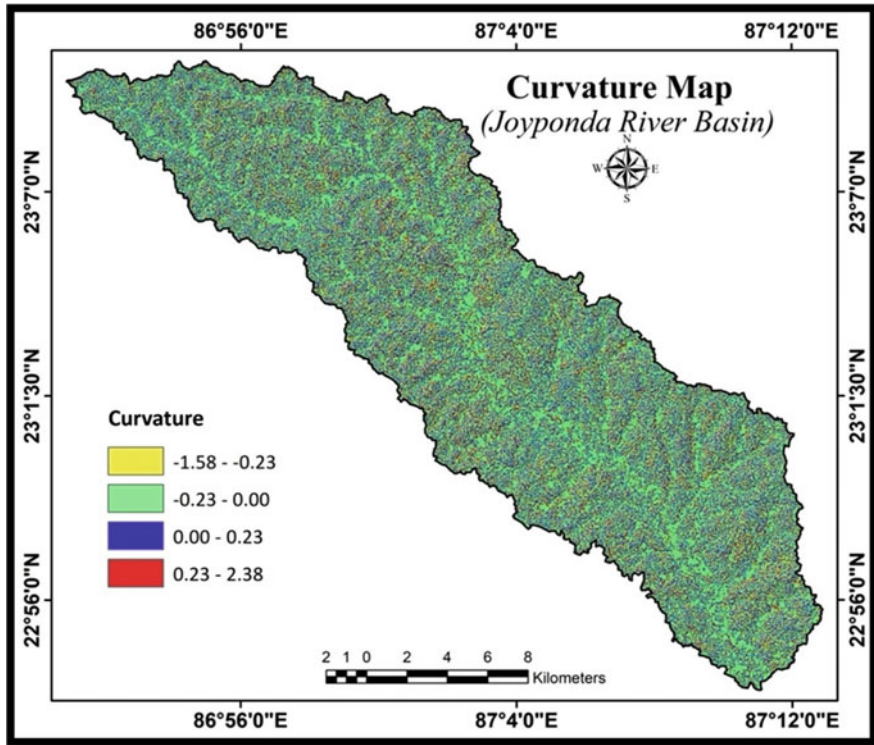


Fig. 9.8 Curvature map of the study area

9.4.6 Drainage Density

Drainage density of an area is expressed as a ratio between sum of the total stream lengths considering all stream orders of a unit to the total unit area (Horton 1932; Kale and Gupta 2001). There is a positive relation of drainage density with slope, altitude and rainfall, while negative relation exists with vegetation cover and infiltration rate (Chorley and Morgan 1962; Morisawa 1962; Hugget 2007). The higher drainage density is an indicator of high runoff and less groundwater recharge. In contrast, the lower drainage density areas are suitable for groundwater recharge (Magesh et al. 2012). The drainage density of the river basin is classified into four distinct categories. Most of the drainage basin (60.97%) enjoys almost low drainage density, i.e. less than 1.09 km/km² (Table 9.2), and it is mainly found in the entire middle portion of the basin. The higher degree of drainage density is observed either in elongated pattern or circular pattern over the river basin, and the lower order streams are mainly incipient ephemeral in nature along with short life span in terms of their perennial character (Fig. 9.9).

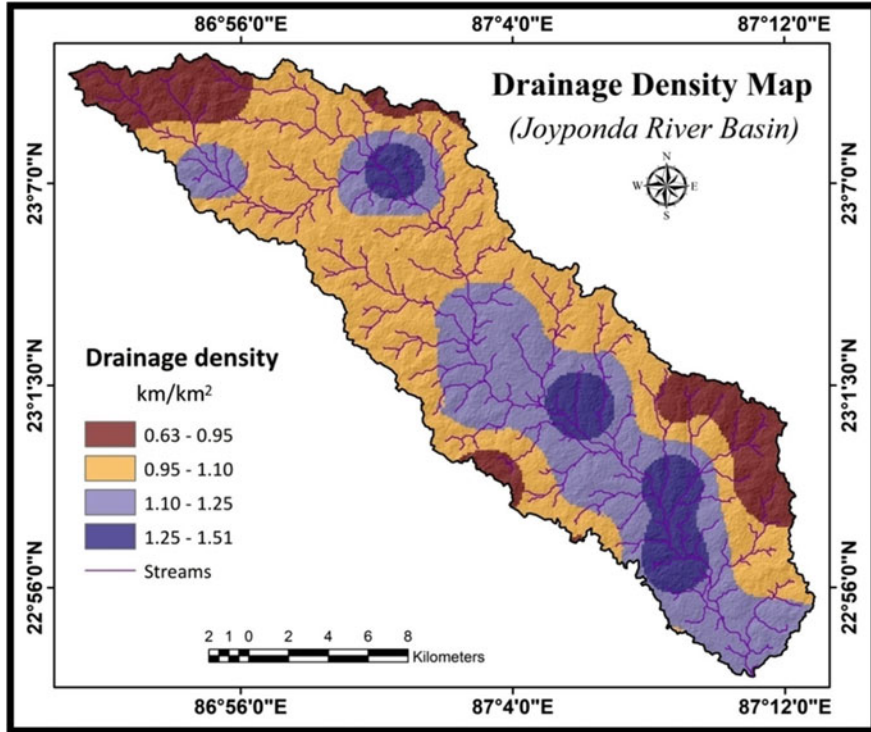


Fig. 9.9 Drainage density map of the study area

9.4.7 Rainfall

Rainfall is the main source of groundwater recharge in this area. The maximum rainfall is received in between June to September by the entire area due to advent of Monsoon (Nag and Ray 2015). According to the CGWB more than 80% of precipitation flows away as runoff of this hard rocks terrain due to low rate of permeability and topographical irregularities (CGWB 2017). Thus, the low intensity rainfall of longer duration is more preferable in groundwater recharge compared to the high intensity rainfall of short period (Nasir et al. 2018). The annual average rainfall of the basin varies from 1147 mm to 1241 mm as per the CWC database. The entire river basin has divided itself into four distinct rainfall categories from north-west to south-east direction like a stair case (Fig. 9.10). The higher amount of rainfall is enjoyed by the upper portion of the basin, whereas the amount of rainfall decreases gradually towards the lower catchment area of the basin. Most of the basin area (69.98%) enjoys more than 1201 mm rainfall (Table 9.2).

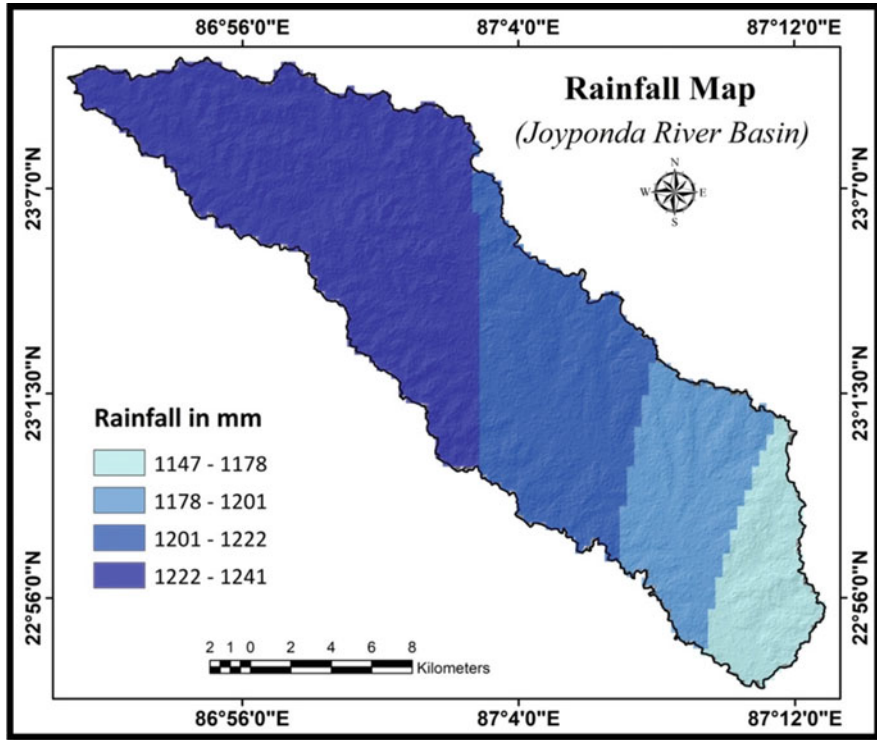


Fig. 9.10 Rainfall distribution map of the study area

9.4.8 Soil

The groundwater recharge is determined by a number of properties of soil, such as soil type, texture, water infiltration, percolation, permeability and water holding capacity (Shekhar and Pandey 2014; Murmu et al. 2019). The coarse texture of soil is more favourable for groundwater recharge followed by fine texture (Maity and Mandal 2017; Ghosh et al. 2020). There are five types of soils found in the study area (Fig. 9.11), and the coarse loamy soil covers an area of 23.78% of the Joyponda river basin, followed by fine loamy soil (28.65%) and fine-fine silty soil (38.29%). The clayey skeletal soil and loamy skeletal soil account for 6.29% and 2.99% of the basin area, respectively (Table 9.2).

9.4.9 Infiltration Number

The infiltration number is used to understand the potential infiltration capacity of an area, and it is the result of stream frequency and drainage density (Prabhakaran and

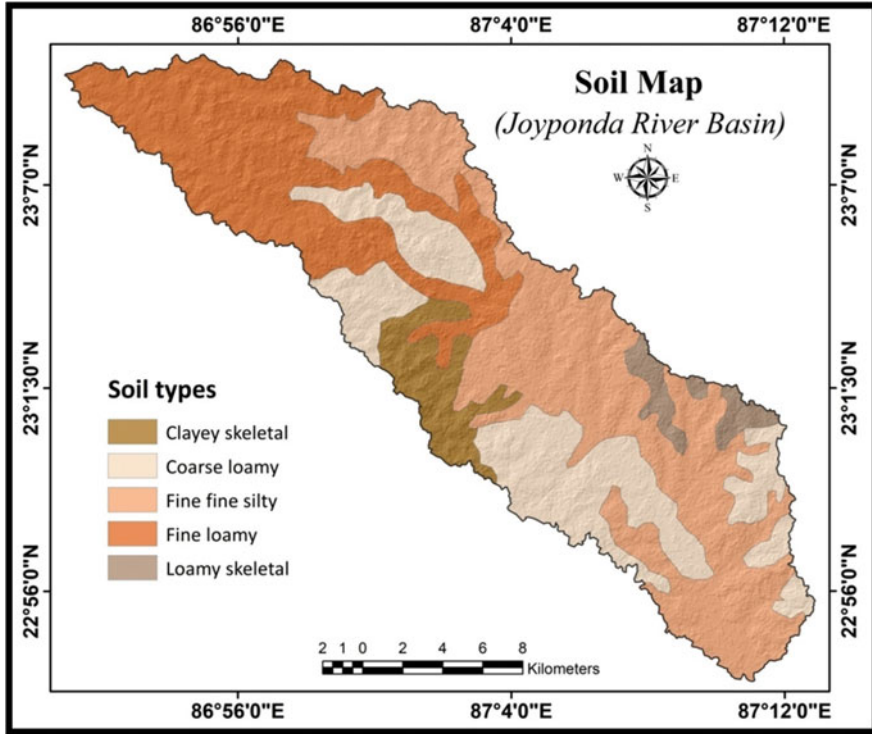


Fig. 9.11 Soil map of the study area

Raj 2018). There is an inverse relation between infiltration number and groundwater recharge. The higher infiltration number is unfavourable for groundwater recharge and leads to high runoff. Less infiltration number increases the chances of high groundwater recharge (Joji et al. 2013; Ghosh and Jana 2018; Prabhakaran and Raj 2018). Infiltration number of the basin varies from 0.11 to 2.14. Most of the basin area (63.44%) comes under the less infiltration number, i.e. less than 1.06 (Table 9.2). Areas of higher infiltration number of more than 1.42 are mainly found in circular pattern from middle to lower reach of the basin, while medium infiltration number is highly concentrated in elongated pattern almost in the middle of the basin (Fig. 9.12).

9.4.10 Topographic Wetness Index

Topographic wetness index helps to perceive the role of topography in controlling the potential groundwater infiltration. It is computed considering the propensity of water to be stored up at any point of the basin and the propensity of water to move

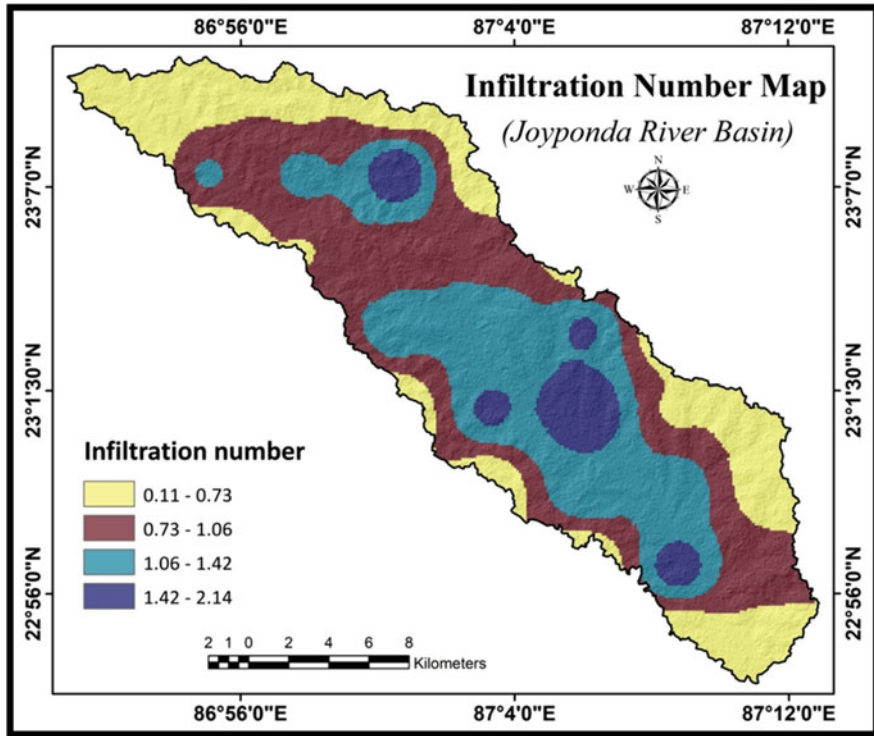


Fig. 9.12 Infiltration number map of the study area

down due to gravitational force (Nampak et al. 2014; Arulbalaji et al. 2019). This index of the basin varies from 5.01 to 23.31. The higher index value of an area over the river basin indicates good potentiality of groundwater, and vice-versa. An area of 17.61% of the river basin enjoys higher topographic wetness index, i.e. more than 10.39 (Table 9.2). The rest of the basin area experiences low to moderate topographic wetness index (Fig. 9.13).

9.4.11 Land Use Land Cover

In the process of groundwater development, the role of land use land cover is indisputable, and it also portrays the details about the surface water, groundwater, infiltration, soil moisture, water holding capacity and runoff rate (Singh et al. 2017). The entire basin area is categorized into six classes based on land use land cover. Most of the basin area (62.12%) is utilized for agricultural practices, which bear good potentiality of groundwater recharge. Forest cover and shrub land share 28.84% of total basin area (Table 9.2). This vegetation cover is found to be good

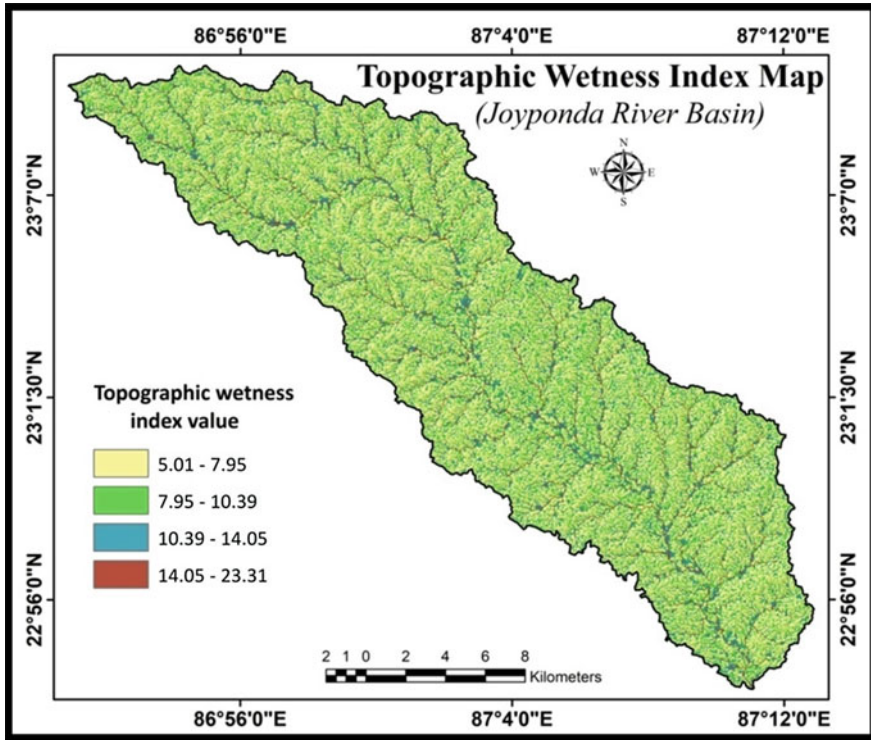


Fig. 9.13 Topographic wetness index map of the study area

transmitter of water into the ground creating routes for water percolation unfastening the soils and rocks by their roots (Murmu et al. 2019). There is a very small amount of water bodies (1.00%) existing over the basin. The main concentration of barren land is located at the top of the river basin, and a few numbers of patches of barren land are observed in small semi-circular pattern scattering over the basin (Fig. 9.14)

9.4.12 GPZ of the Joyponda River Basin

The prospect zones of groundwater of Joyponda river basin are delineated using the integrated approach of AHP and geospatial techniques considering a total number of eleven hydro-geological factors. It is estimated that the basin enjoys 12.62% of area as very good GPZ followed by good (24.47%). The moderate prospect zone of groundwater is recorded as 28.93%. Only 10.97% area of the river basin experiences very poor groundwater potentiality followed by poor potential zones (Table 9.3). The prospect zones of good to very good lie mainly in between middle to lower reach of the river basin (Fig. 9.15).

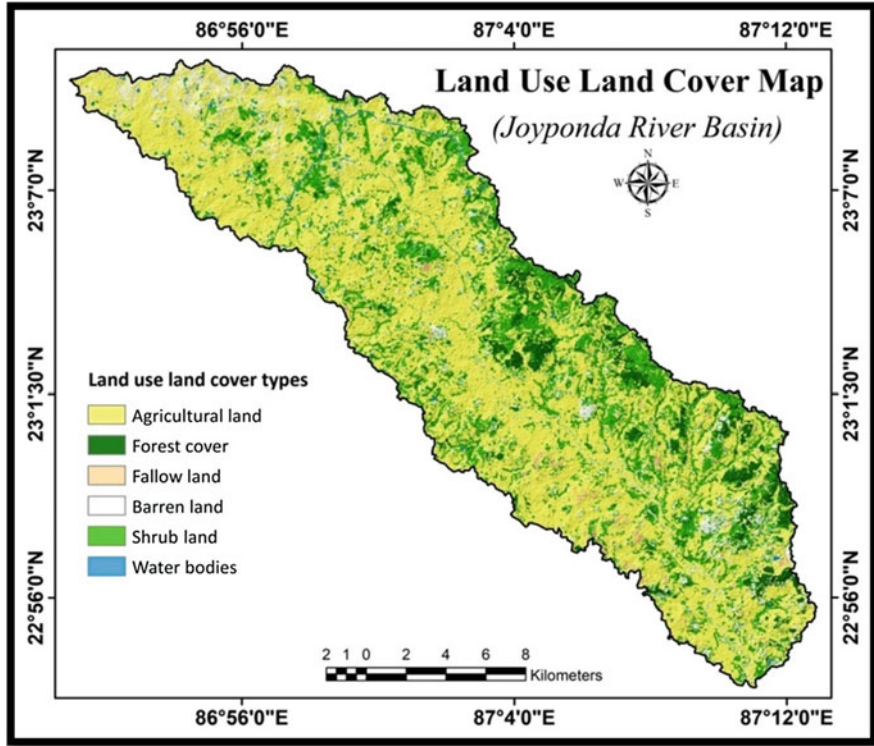


Fig. 9.14 Land use land cover map of the study area

Table 9.3 Descriptive statistics of groundwater potential zones

Groundwater potential zones	Area (km ²)	Area (%)	No. of reference dug wells
Very poor	43.5	10.97	4
Poor	89.69	22.61	4
Moderate	114.78	28.93	7
Good	98.67	24.87	4
Very good	50.05	12.62	8

9.4.13 Accuracy Assessment of GPZ Map

Before the judicious use of the GPZ map, it is a prerequisite condition to assess the accuracy level and validity of the applied model. To do the same, the Pre-Monsoon groundwater level data of 27 dug wells distributed over the river basin are taken into account. These individual dug wells are considered as reference points to investigate groundwater prospect. The range of the groundwater level data lies in between 0.90 mbgl and 9.97 mbgl, and the data are classified into five different categories in ArcGIS software adopting natural break classify system, namely, very poor (7.25

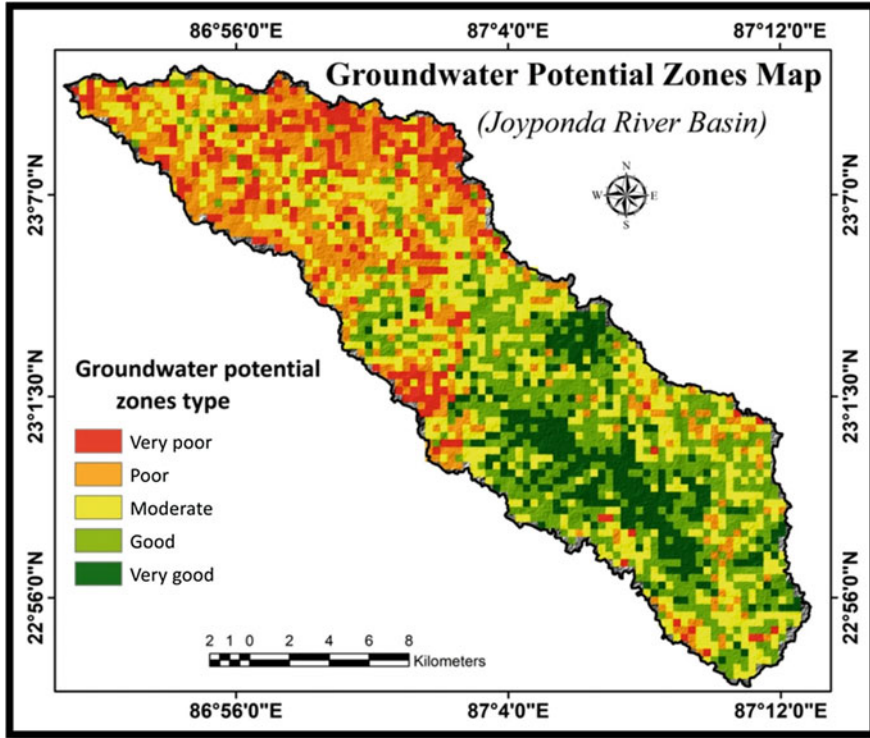


Fig. 9.15 Groundwater potential zones map of the study area

mbgl to 9.97 mbgl), poor (6.39 mbgl to 7.25 mbgl), moderate (4.39 mbgl to 6.39 mbgl), good (2.89 mbgl to 4.39 mbgl) and very good (0.90 mbgl to 2.89 mbgl). The calculated value of the overall accuracy assessment of the study is found to be 85%, which certainly upholds the implication of the used model. The study shows that the higher depth of water level of dug wells is found at the upper part of the basin, while the lower depth of water level of dug wells is observed at the lower part of the river basin. Here, the Kappa co-efficient is also computed to understand the level of agreement between simulated GPZ map and reference points of dug wells. Generally, the value of the Kappa co-efficient belongs to 0 to 1, where 1 represents almost perfect agreement and 0 denotes less than chance of agreement (Viera and Garrett 2005). The Kappa co-efficient value of the present study is computed as 0.81, which indicates towards the almost perfect agreement between simulated model and observed value of reference points.

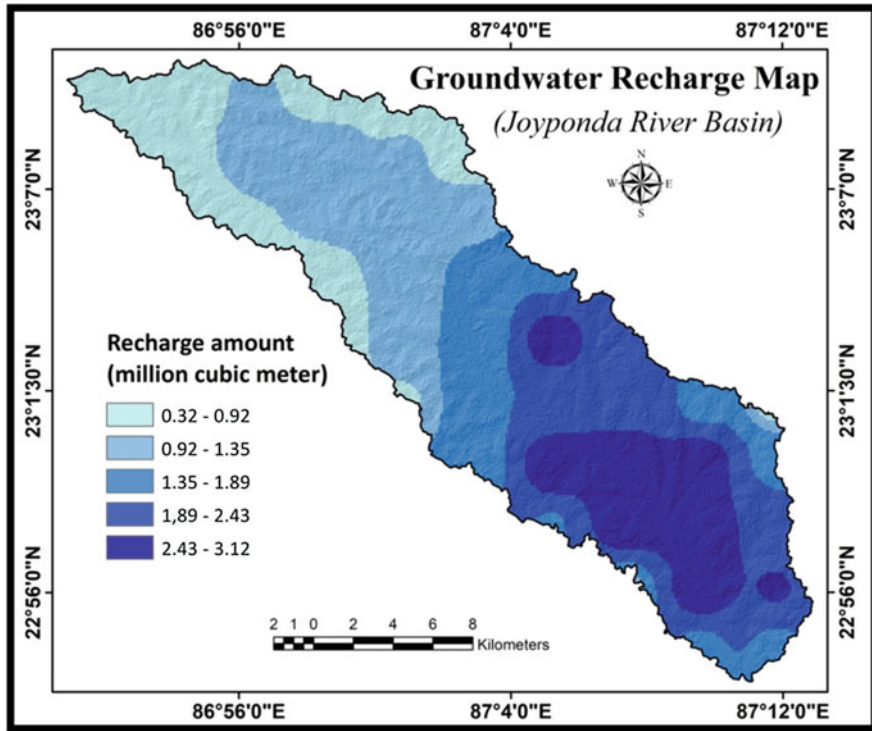


Fig. 9.16 Spatial distribution of natural groundwater recharge amount

9.4.14 Estimation of Natural Groundwater Recharge

In the present day, identification of groundwater recharge zones emerges with great importance to quantify the amount of infiltrated water into the ground for amplification of groundwater storage (Oke et al. 2015). The amount of recharge highly depends on the characteristics of hydro-geological unit. The duration and intensity of rainfall amount, pore space of soil, permeability, slope, etc. are primarily key determinants of groundwater recharge. The average annual rainfall of the study area varies from 1147 mm to 1241 mm. To calculate the amount of groundwater recharge from rainfall, the specified method of GEC 2015 is applied using raster calculator in ArcGIS software. It is estimated that the whole basin area receives average annual rainfall of $4.77 \times 10^8 \text{ m}^3$. Of the total volume of obtained rainfall, only 13.78% water, i.e. $6.5 \times 10^7 \text{ m}^3$, is credited to groundwater storage. The lower river basin area provides more rainfall for groundwater recharge compared to the upper catchment area (Fig. 9.16), which receives highest amount of rainfall in the basin. It is the topography which influences the variation of groundwater recharge by its inherent characteristics.

9.5 Conclusion

The study reveals that an area of 148.73 km² (37.49%) of the total Joyponda river basin enjoys good to very good potentiality of groundwater. These zones are mainly observed at lower basin areas, where older alluvium, gentle slope and high lineament density coexist. The areas of very poor to poor groundwater prospect occupy 133.19 km² (36.03%) area of the total basin. This area is mainly situated at the upper reach of the basin, which is characterized by high drainage density, high degree of slope, less lineament density, hard granitic gneiss rocks and high runoff. To meet the demands for water of populations of the basin mainly during the scorching dry summer, the groundwater exploration is required to be made when there is no such option left. Many a time, it was witnessed that the people of this region were discouraged due to the failing of borehole drillings in search of groundwater. Only the delineated GPZ are required to explore to minimize the risk of failures. This work may also help in disclosing many ways of new researches related to estimation of groundwater storage, rate of recharge, nature of aquifers, etc.

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