Sustainable Water Resources Management (2020) 6:4
https://doi.org/10.1007/s40899-020-00373-z

ORIGINAL ARTICLE

Assessment of groundwater potential zones using multi-criteria decision-making technique: a micro-level case study from red and lateritic zone (RLZ) of West Bengal, India

Sabita Roy[1] · Sugata Hazra[1] · Abhra Chanda[1] · Sourav Das[1]

Received: 12 March 2019 / Accepted: 11 January 2020 / Published online: 25 January 2020

Abstract

Locating potential zones of ground water reservoir is a challenging task particularly in dry areas, mountaneous region or lateritic zones. In the present century, Satellite Remote sensing could offer a fresh promise to identify surface and sub-surface water resources with less time and cost. The present study was carried out in the drought-prone red and lateritic zones (RLZs) of West Bengal, India, to identify groundwater potential zones. Multi-criteria approach based on remote sensing and geographic information system utilizing six parameters, namely hydrogeomorphology, slope, drainage density, lineaments density, land use/land cover and fractional impervious surface were used in this analysis. Weightages were assigned to the parameters using Analytical Hierarchical Process (AHP) while different classes within each parameter were ranked according to their relative importance for groundwater potentiality. The study characterized different zones of groundwater prospects, viz. excellent (0.77%), good (35.20%), fair (61.80%), and poor (2.13%). During validation, 81% among the surveyed 180 dug wells of the area in the "good" potential zones were found to be perennial; while, ten among the ten dug wells surveyed in the 'poor' potential zone were found to be non-perennial in nature. The findings, thus, could establish that present methodology using AHP with enhanced parameterization has a better potential to identify and map the groundwater potential zones more realistically, and can be applied for drought risk reduction in wider RLZ zones.

Keywords Groundwater potential zone · Analytic hierarchical process (AHP) · Red and lateritic zone · RS and GIS technique

Introduction

Water is necessary to mankind; however, with dwindling surface water resources, groundwater is presently the principal source of fresh water for domestic and agricultural use. Forever increasing demand for water has accelerated the use of underground water. Especially, in the dry zone where the annual rainfall is low; groundwater (particularly from dug wells and tube wells) acts as the main source of water for agriculture, industry and household uses. Globally, 42% of the total groundwater is used for agricultural purposes (Taylor et al. 2013). Groundwater happens to be an important natural resource for reliable economic growth and drinking water in both urban and rural environment (Agarwal and Garg 2016). Groundwater is known to be a dynamic and renewable natural resource but in hard rock landscape like red and lateritic zones (RLZs), availability of groundwater is limited. In India, water resource improvement is needed as it plays a crucial role in developing the country's

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s40899-020-00373-z) contains supplementary material, which is available to authorized users.

✉ Sourav Das
sourav.biooptics@gmail.com

Sabita Roy
sabita21.roy@gmail.com

Sugata Hazra
sugata_hazra@yahoo.com

Abhra Chanda
abhrachanda1985@gmail.com

[1] School of Oceanographic Studies, Jadavpur University, 188, Raja S.C. Mallick Road, Kolkata 700032, India

agro-economy (Bhunia et al. 2012). Moreover, in India, more than 90% of the rural and nearly 30% of the urban populations depend on groundwater to meet their drinking and domestic requirements (Reddy et al. 1996).

RLZs of India experience a wide range of temperature and erratic rainfall (Mukherjee and Banerjee 2009). Agriculture in RLZs is mostly rainfed. Due to low water holding capacity, excessive drainage, surface runoff and high soil-erosion, red lateritic zones are highly susceptible to any change of weather parameter (Milly 1994; Milly and Dunne 1994; Sehgal 1998; Mukherjee and Banerjee 2009). Recent studies revealed that the RLZs of West Bengal (Purulia and Bankura districts) India, though experience sufficient but often irregular annual rainfall, are affected by recurrent droughts (Mukherjee and Patil 2013; Ghosh and Jana 2017). In years of below-normal rainfall, RLZs suffer from water stress. In summer months most of the surface water sources like ponds, streams, etc. dry up completely and groundwater stands as the only option for water supply (Nag 1998). Due to the variability of rainfall and lack of irrigational facility, cultivation becomes challenging and gets severely affected (Sehgal 1998; Mukherjee and Banerjee 2009; Mukherjee and Patil 2013). Groundwater resource identification and sustainable use in the RLZ are, therefore, extremely necessary to sustain productivity, remove poverty and to ensure food security in such areas.

The most reliable and standard methods for determining locations, the thickness of aquifers and other subsurface information require test drilling and stratigraphic analysis; however, these approaches are expensive, time-consuming and needs skilled manpower (Todd 1980; Roscoe Moss Company 1990). Numerous techniques for delineating groundwater potential zones (GWPZ) such as frequency ratio (Guru et al. 2017; Al-Abadi et al. 2015), random forest model (Naghibi et al. 2016) and logistic regression model (Pourtaghi and Pourghasemi 2014) have been adopted and implemented by various researchers. In this context, analytic hierarchy process (AHP) based on remote sensing and GIS is considered as a simple, effective, reliable and cost-effective technique (Machiwal et al. 2011; Ishizaka and Labib 2011; Maity and Mandal 2017).

Several studies have been conducted in the world for identifying the groundwater potential zones using remote sensing and GIS for the evaluation of groundwater resources in Central Eastern Desert, Egypt (Abdalla 2012), Burdur, Turkey (Sener et al. 2005), Ghana (Gumma and Pavelic 2013), Maknassy basin, Tunisia (Chenini et al. 2010) and Kurdistan region, Iran (Rahmati et al. 2015). Ferozu et al. (2019) also delineated the groundwater potentiality in the drought-prone area of Bangladesh using remote sensing and GIS approach.

Similar works were conducted in India by Jasrotia et al. (2016) in the sub-mountainous region, Mallick et al. (2015) in New Delhi, Madrucci et al. (2008) in Udaipur district, Rajasthan, Paschim Medinipur District, West Bengal (Bhunia et al. 2012), Theni district, Tamil Nadu (Magesh et al. 2012) and Unnao district Uttar Pradesh (Agarwal et al. 2013). Waikar and Nilawar (2014) used AHP for identification of GWPZ in the Parbhani district of Maharashtra. Ndatuwong et al. (2014) made hydrogeological factors coupled with remote sensing and GIS techniques for demarcation of GWPZs in the Vindhyan basin of Uttar Pradesh. Jaiswal et al. (2003) also emphasized on remote sensing and GIS techniques to define groundwater prospective zones for rural development. Prasad et al. (2008) have considered geomorphology and lineament density (Nalgonda District, Andhra Pradesh) for identification of ground water prospective zones. In India, micro-scale GWPZ evaluation using remote sensing and GIS technique was attempted with considerable success Ibrahim-Bathis and Ahmed (2016) used land use/land cover, geomorphology, drainage density, slope and lineament density for identification of GWPZs in Doddahalla watershed of Krishna basin. Similar parameters were used for GPWZ identification at Bairasagara Watershed, Kolar district, Karnataka by Chandra et al. (2006) and at Kattankulathur block Kancheepuram district of Tamil Nadu (Nagarajan and Singh 2009).

Micro-level GWPZ was also assessed in Purulia and Bankura District, West Bengal using integrated approach of remote sensing and GIS techniques in the hard rock terrain of Kashipur Block, (Nag and Kundu 2016), Baghmundi block in Purulia District (Nag 2005) Dwarakeswar watershed, Bankura district, (Nag and Lahiri 2011) and Chhatna Block, Bankura District (Nag and Ghosh 2012). They have mainly used three basic parameters (hydrogeomorphology, slope and lineament density) to identify the groundwater potentiality. However, recent studies (Patra et al. 2018; Nsiah et al. 2018; Magesh et al. 2012; Singh et al. 2018; Ferozu et al. 2019) indicate that drainage density, land use and fractional impervious surface (FIS) are very important parameters to effectively recognize GWPZ. The drainage pattern indicates runoff and infiltration capacity to recharge the groundwater (Yeh et al. 2016; Ferozu et al. 2019). FIS serves as an indicator of the availability of groundwater (Patra et al. 2018) and land use/land cover can influence the groundwater recharge (Leduc et al. 2001). Many studies have also integrated drainage density, land use/land cover and FIS to identify a potential groundwater recharge zone (Singh et al. 2019; Ferozu et al. 2019; Patra et al. 2018). Due to the paucity of studies involving an integrated approach to identifying GWPZs in the RLZ of West Bengal, India, the present study was conducted to delineate the GWPZs in the study area using the parameters like hydro-geomorphology, slope, lineament, drainage density, land use/land cover and FIS.

Study area

RLZ of West Bengal under National Agricultural Research Project (NARP) includes the districts of Purulia, Bankura, West Medinipur, Burdwan (part) and Birbhum (part). Kashipur block (~ 434 km^2) of Purulia district and Chhatna block (~ 449 km^2) of Bankura district were chosen as representatives of the RLZ (Fig. 1) which lie between 23°10′33.2″ (N)–23° 30′40.3″ (N) and 86°34′19.97″ (E)–87°00′55.59″ (E). The study area is largely a Pre-Cambrian gneissic terrain comprising crystalline gneiss, schist, intrusives and recently deposited alluvium (Nag and Ghosh 2012). The Dwarakeswar is the largest river in the area and flows from northwest to southeast. The area experiences subtropical climate and the average temperature ranges between a maximum 43–47 °C (summer) and minimum 7–12 °C (winter), respectively. The annual rainfall (1200–1400 mm) is distributed throughout the year as 100–150 mm during the pre-monsoon season, 900–1100 mm during the monsoon season and 80–110 mm during the post-monsoon season. The land surface of the area is characterized by hard rock uplands, undulating laterite and flat alluvial area (Nag and Kundu 2016). Elevation, in general, varies between 150 and 300 m in the area, the master slope being towards the east and south-east (Ray 1982).

Data used

Six different types of thematic maps, respectively, for geomorphology, lineament, slope, land use/land cover, drainage density and FIS, were prepared from analysis of satellite data and existing maps for the present study area. Elevation, slope and drainage density maps were prepared using ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) Digital elevation model (DEM) at 30-m spatial resolution downloaded from United States Geological Survey Earth Explorer (earthexplorer.usgs.gov). The geological map was acquired from the Geological Survey of India (GSI). Topographical maps (No. 73 I/11, 73I/12, 73 I/15 and 73I/16) were collected from the Survey of India. Land use/land cover and FIS maps were generated from LISS-IV (Linear image sensing sensor) images at 5.8-m spatial resolution.

Materials and methods

The processes of delineating the groundwater potential zones have been represented in Fig. 2. Six thematic layers (Hydrogeomorphology, Slope, Lineament Density, Drainage Density, Land Use/Land Cover and FIS) having significant control on groundwater availability (Mukherjee et al. 2012; Agarwal et al. 2013) were prepared. The GWPZs were acquired by superimposing all the thematic layers in terms of weighted overlay technique (Waikar and

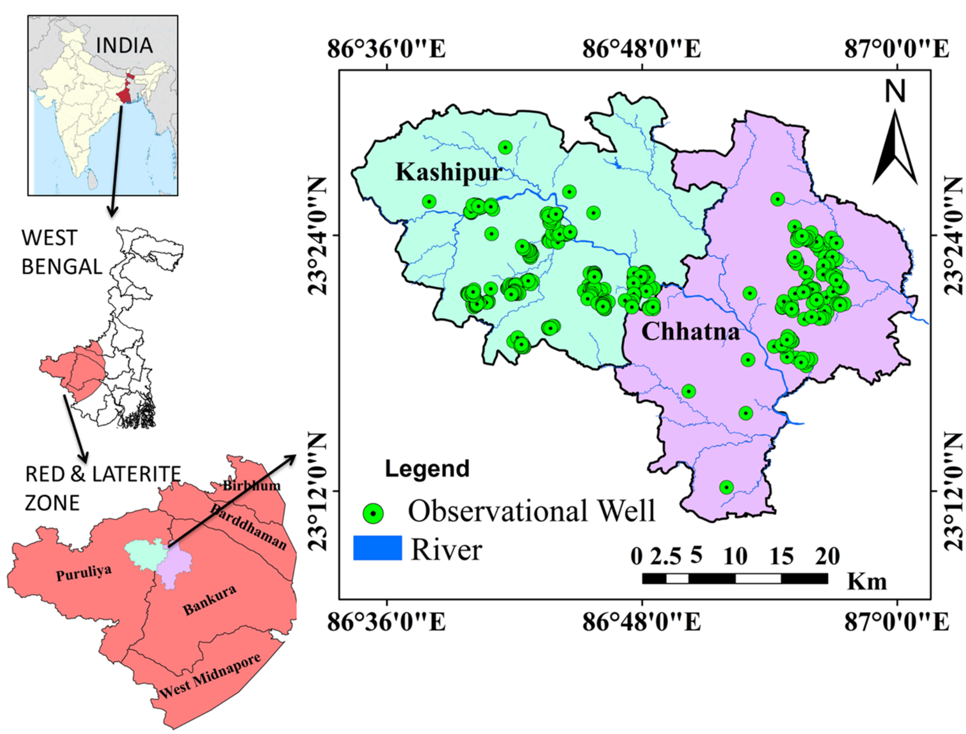


Fig. 1 Location map of the study area

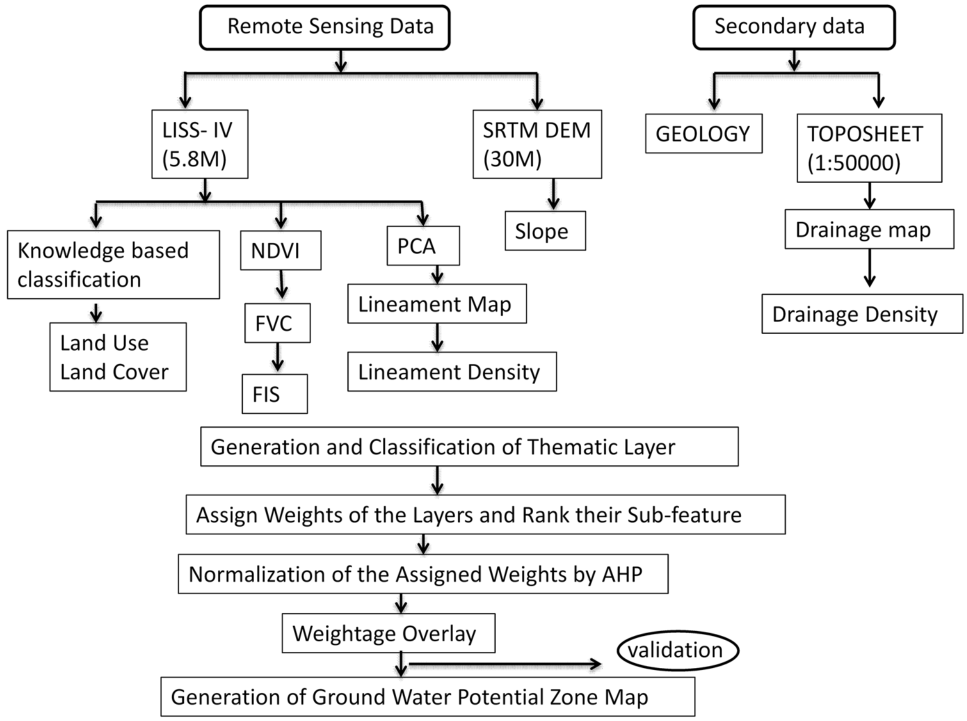


Fig. 2 Flow chart of methodology

Nilawar 2014) using the spatial analysis tool in ArcGIS 10.3 software.

Generation and classification of the thematic layers

Hydrogeomorphology

Collected hydro geomorphological map of the study area was scanned, rectified and digitized in ArcGIS 10.3 software.

Slope

The slope map was created from the digital elevation model (DEM) using the spatial analysis tool in ArcGIS10.3 software.

Lineament

Lineaments were interpreted from a high-resolution satellite image (LISS-IV). At first, Principal Component Analysis was conducted for image enhancement in ERDAS14, followed by automatic line extraction in PCI Geometica 9.1. Lineament density map (km/km^2) was prepared in ArcGIS10.3.

Drainage density

Drainage was derived using the DEM and toposheets. Using ArcGIS10.3 software, the drainage density map was composed taking into account length of drainage per sq km area.

Land use/land cover

Land use/land cover map for the year 2017 was composed using high-resolution (5.8 m) satellite image (LISS-IV) and knowledge-based classification technique using the ERDAS Imagine (14) platform.

Fractional impervious surface

Impervious surface indicates the environmental quality of any region. Satellite-derived NDVI data (from LISS-IV image) were used to derive fractional vegetation cover (FVC) (Kasperson 2015).

Ridd (1995) and Owen et al. (1998) showed the relation between the fractional vegetation cover (FVC) and fractional impervious surface area (FIS) flows as:

$$\mathrm{NDVI_S} = \mathrm{NDVI} - \mathrm{NDVI_{low}}/\mathrm{NDVI_{high}} - \mathrm{NDVI_{low}}, \quad (1)$$

where, $NDVI_{low}$ and $NDVI_{high}$ values were obtained from bare soil and dense vegetation, as proposed by Carlson and Ripley (1997).

$$FVC = (NDVI_S)^2, \quad (2)$$

$$FIS = 1 - FVC. \quad (3)$$

Assigning rank and weight

The groundwater potential zones were evaluated by integrating all the spatial layers using weighted overlay approach. Before the overlying operation, individual spatial layers were reclassified to a uniform rank of 1–4, where 1 represents poor groundwater potential and 4 represents excellent groundwater potential. Weights have been assigned through pairwise comparisons matrix based on AHP (Table 1).

Table 1 Normalized Pairwise comparison matrix (six layers) developed for AHP based groundwater potential zoning

Parameters	Hydrogeo-morphology	Slope	Lineament	Drainage	Land use/land cover	FIS	Weight
Hydrogeomorphology	6	5	4	3	2	1	0.41
Slope	6/2	5/2	4/2	3/2	2/2	1/2	0.2
Lineament	6/3	5/3	4/3	3/3	2/3	1/3	0.14
Drainage	6/4	5/4	4/4	3/4	2/4	1/4	0.1
Land use/land cover	6/5	5/5	4/5	3/5	2/5	1/5	0.08
FIS	6/6	5/6	4/6	3/6	2/6	1/6	0.07

FIS Fractional impervious surface

Table 2 Weights assigned for different ground water control parameters in the present study

Parameter	Classes	Weight	Influence (%)	Rank	Area (sq km)
Geomorphology	Valley fills	0.41	41	4	12.35
	Buried pediment moderate			3	260.55
	Buried pediment shallow			2	602.17
	Structural hills			1	7.71
	Inselberg			1	8.21
Slope (degree)	0–10	0.2	20	4	509.295
	10–20			3	192.723
	20–40			2	84.0744
	> 40			1	103.235
Lineament density (km/km^2)	0–0.5	0.14	14	1	459.104
	0.5–1.2			2	338.768
	1.5–2.5			3	75.1023
	2.5–3.5			4	18.5364
Drainage density (km/km^2)	0.00000104–0.000003555	0.1	10	4	35.27
	0.000003555–0.00005093			3	248.2
	0.00005093–0.00006191			2	380.56
	0.00006191–0.00008105			1	225.07
Land use/land cover	Vegetation	0.8	8	3	145.99
	Water body			3	11.49
	Pediment			1	98.87
	Fallow land			2	49.97
	Agricultural land			4	512.26
	Settlement			1	35.75
FIS	0.03–0.41	7	7	4	93.42
	0.41–0.50			3	135.26
	0.51–0.60			2	244.407
	0.61–0.70			1	347.518
	0.71–1.00			1	68.5066

The ranks were assigned to the respective parameters considering the field survey experiences, stakeholder consultation, and expert opinion surveys as well as consulting the existing literature (Krishnamurthy et al. 1996; Saraf and Choudhury 1998; Waikar and Nilawar 2014). Hydrogeomorphology was assigned the highest weight; whereas slope, lineament density and drainage density were assigned moderate weight and land use/land cover was assigned low weight (Table 2). After assigning weights to the respective parameters, individual ranks were given for sub-variables (Butler et al. 2002; Asadi et al. 2007; Yammani 2007). The maximum value was used to characterize the highest groundwater potentiality and vice versa.

Results and discussion

Hydrogeomorphology

Hydrogeomorphology, controlled by landform, lithology and underlying rock structure (Patra et al. 2018) in turn imparts a significant control over the groundwater potential and prospect (Kumar et al. 2008). The study area is characterized by dominant rocky terrain, undulating surfaces, erosional and depositional hydro-geomorphic features (Fig. 3).

Structural hills

These are rocky broad upland with a perceptible rise in elevation. Very shallow coarse loamy soil was observed. It is mostly covered by open to dense forest and plantation and is not suitable for agriculture or orchards. From the groundwater point of view, the structural hills serve as high run-off zones, leading to poor infiltration mainly due to moderately steep to very steep hill slopes.

Valley fills

These are accumulation zones of unconsolidated sediments and colluvium derived from surrounding uplands. Soil characteristics in this region are fine loamy to clayey soil with fine texture, and moderately well-drained having moderate wetness. Valley fills are suitable for single crop and that too for mainly terrace cultivation. This region has very good porosity and permeability but sometimes the presence of clay may make it impermeable.

Buried pediment (moderate)

The slope of moderate buried pediment is gentle. Moderately deep clay to fine loamy soil with fine texture was observed over this landform. Buried pediment (moderate) is suitable for a single crop with marginal Rabi crops. Groundwater prospects are also moderate in this region.

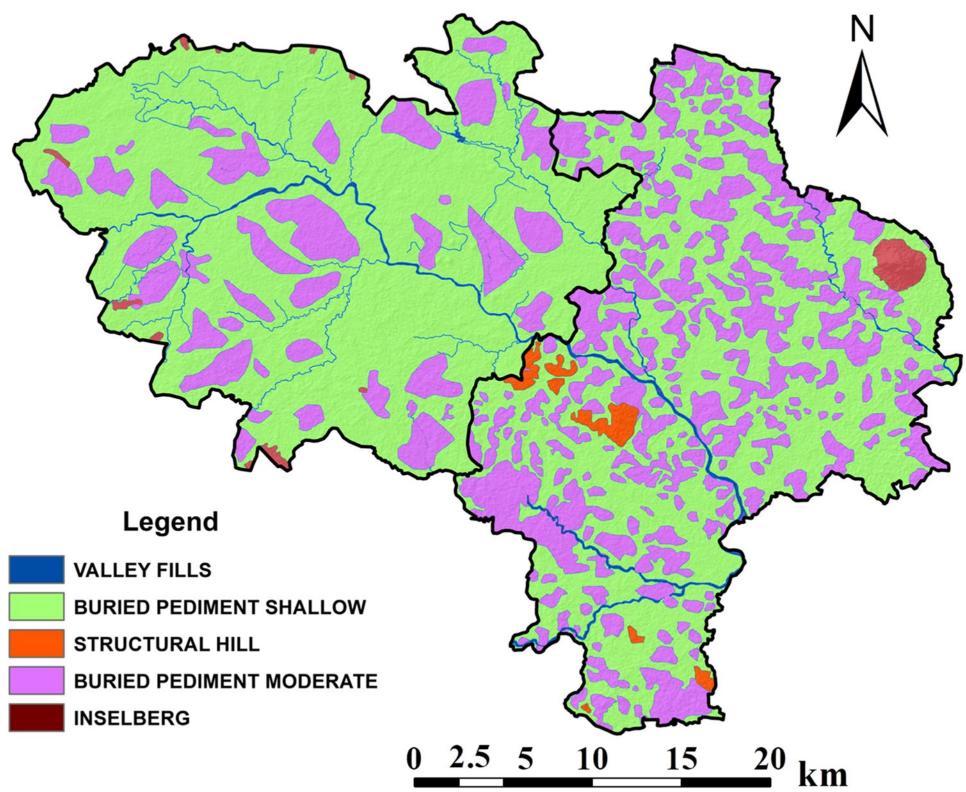


Fig. 3 Hydrogeomorphological map of Kashipur and Chhatna block

Buried pediment (shallow)

This region shows nearly flat to gently sloping topography. It is characterized by shallow to moderately deep loamy soil followed by weathered zone. Soil texture is coarse with the presence of weathered rocky outcrops. This region is also suitable for a single crop. The groundwater prospects in this region are moderate to poor.

Hydrogeomorphology provides information about the distribution of various landform and topography of an area and is one of the main factors used widely for the delineation of groundwater potential zones (Rajaveni et al. 2017; Thapa et al. 2017).

The structural hills and inselberg region of the study area are having sharp but with rugged tops depicting that the high surface runoff of the upper stretches of the hills is affected by erosion. Very shallow coarse loamy soil is originated. However, the lateritic lower plateau with valley fill occurs in midland and lowland areas of the Dwarakeswar river basin, with fine-textured, moderately well-drained loamy to clayey soil. Hence, valley fill is the best landform (highest rank) and structural hill is poor (lowest rank) for high groundwater potential.

Slope

Generally, flat and gently sloping areas have high infiltration and are capable of more groundwater recharge; whereas, steeply sloping grounds promote high run-off and little or no infiltration (Adiat et al. 2012; Rahman et al. 2012). The slope of the study area ranges between 0° and 54°, with maximum at Shusunia Hill area in Chhatna block, Bankura (Fig. 4). Gentle to moderate (0–10°) and steep (> 20°) slope covered 70% and 30% area of the blocks, respectively.

The class having less slope value is given the highest rank due to an almost flat or gentle slope which associated high infiltration and low runoff, while class having maximum slope value is given the lowest rank due to relatively high runoff and low infiltration.

Lineament

Geological linear features are mainly expected to be the fractured zone with good porosity and permeability (Das et al. 1997; Rao et al. 2001; Magowe and Carr 1999; Hardcastle 1995; Devi et al. 2001). The lineament disposition of the area gives important information about subsurface fractures that may influence the movement and storage of groundwater. Mainly ESE–WNW/E–W, NE–SW and NW–SE, N–S/NNE–SSW trending fractures, joints or lineaments were found in the study area. Areas with very high lineament

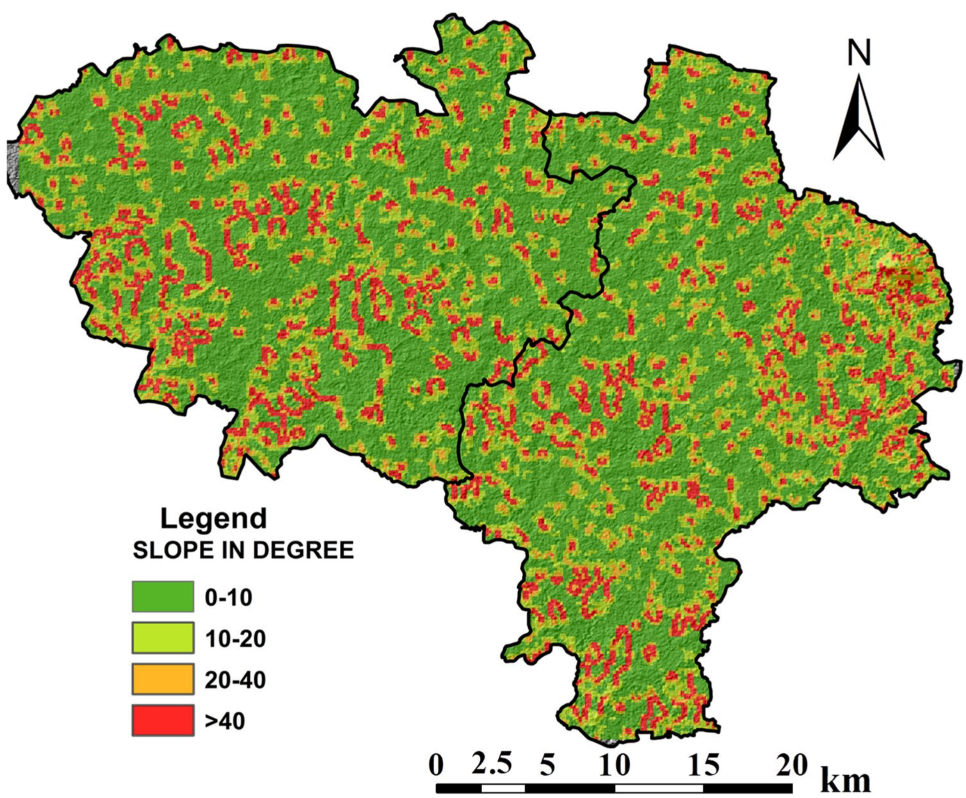


Fig. 4 Slope map of the study area

density (2.5–3.5 km/km^2) have good groundwater potentiality and assigned higher rank due to good porosity and infiltration; whereas, the areas with very low lineament density (0–0.5 km/km^2) are considered to have poor groundwater potentiality and assigned lower rank. The entire area is classified into four categories according to lineament density as shown in Fig. 5.

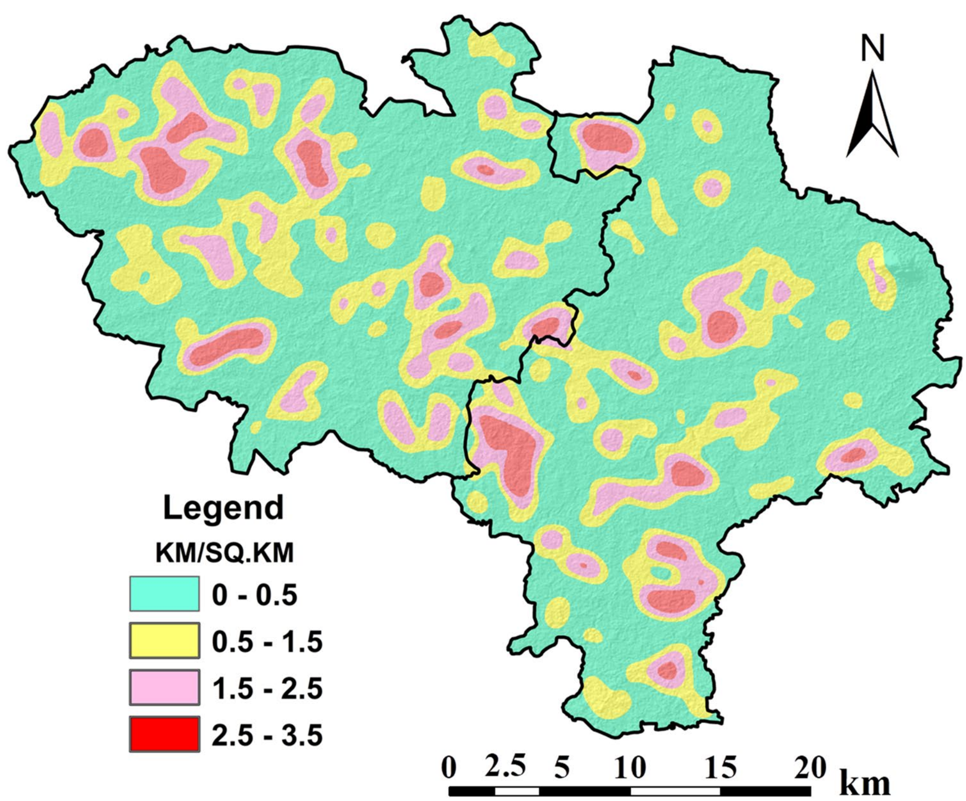
Drainage density

Drainage density reflects the proximity of spacing of channel as well as surface characteristics (Manap et al. 2013). Runoff, infiltration, relief and permeability-related information are acquired by quantifying drainage density and type of drainage. Drainage pattern gives information related to surface materials and subsurface formation, such as dendritic drainage mostly indicates homogenous rocks; the trellis, rectangular and parallel drainage patterns are indicative of structural and lithological controls (Horton 1945). Observations from various geologic and climatic zones indicate that low drainage density is more likely to occur in a flat region with highly permeable subsoil under dense vegetation. High drainage density is developed in mountainous relief, regions with sparse vegetation and impermeable subsurface. Low drainage density characterizes coarse drainage texture and high drainage density leads to fine drainage texture (Waikar and Nilawar 2014). A high drainage density region causes lower infiltration leading to poor GWPZs as compared to a low drainage density region (Murasingh 2014). River or water bodies are generally considered as the vital sources of recharge of the groundwater table. However, if too many rivers flow in an area increasing the drainage density, it means high surface runoff and eventually promotes limited infiltration and reduced groundwater recharge (Dinesh Kumar et al. 2007; Magesh et al. 2012). Drainage density has an inverse effect on permeability. Therefore, it is an important feature in evaluating groundwater potential zone. High drainage density value is favorable for runoff and low groundwater potential. Hence, high rank is given the low drainage density area. The highest drainage density was found to occur in the northern and south-western part; whereas, the lowest drainage density occurs in the eastern part of the study area (Fig. 6).

Land use/land cover

Land use/land cover of an area is largely governed by the groundwater resources and, at the same time, plays an important role in controlling the resources. It influences many hydrogeological processes in the water cycle like evapotranspiration, infiltration, surface runoff, etc. (Kaliraj et al. 2014). In the forest and agricultural land, runoff is generally less and infiltration is more, whereas, in pediment and settlement areas, the rate of infiltration usually

Fig. 5 Lineament density map of the study area



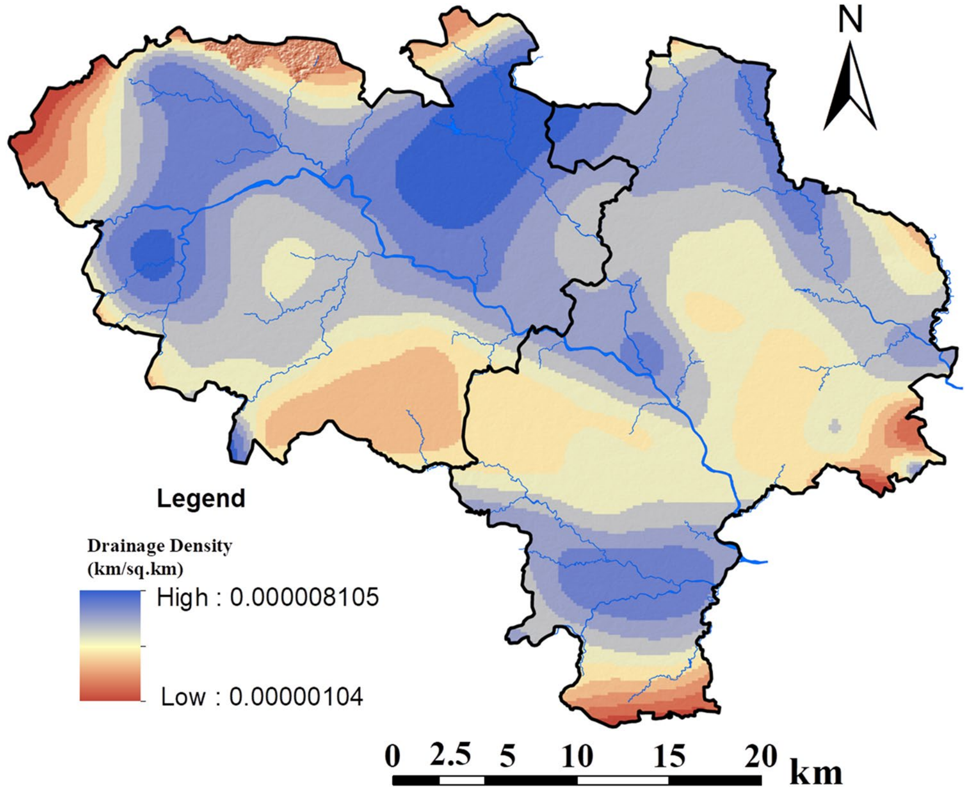


Fig. 6 Drainage density map of the study area

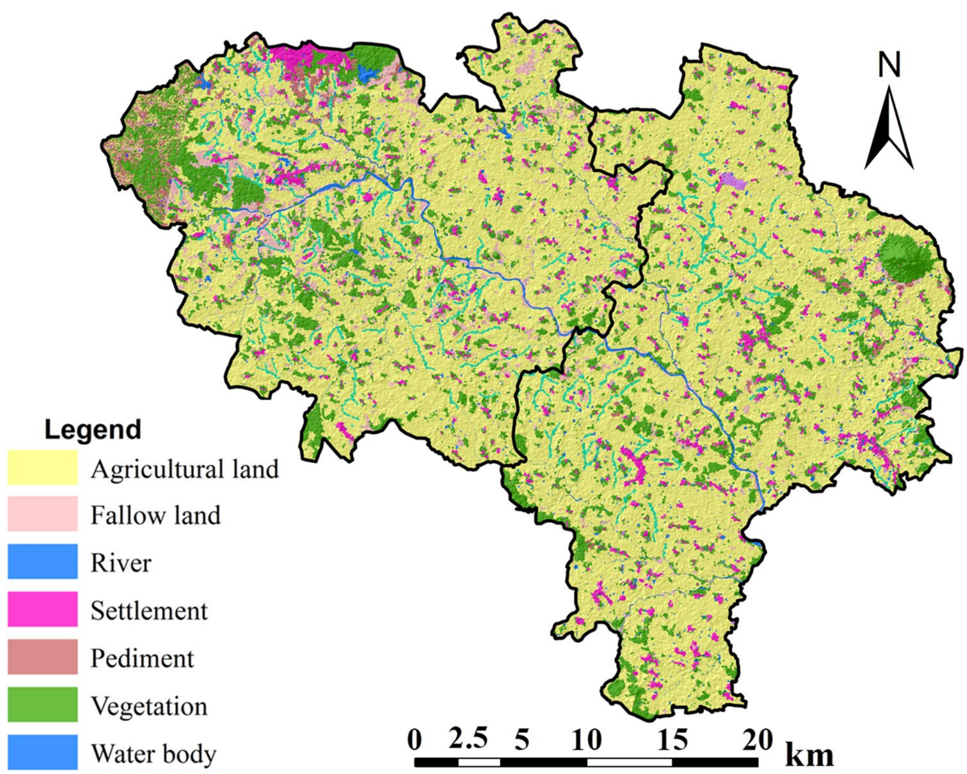


Fig. 7 Land use/land cover map of the study area

decreases. Therefore, agricultural land, vegetation cover area is assigned high rank, and pediment and settlement are assigned low rank. In the RLZ understudy, major portion in land use is cropland, covering 516.14 km^2 (59.99%) area, forest & vegetation covering 129.52 km^2 (15.05%), pediment covering 128.31 km^2 (14.91%), fallow land covering 50.33 km^2 (5.84%) and settlement covers 36.06 km^2 (4.19%) area (Fig. 7).

Fractional impervious surface

Impervious surfaces, either natural or manmade, are hard surfaces that prevent percolation of rainwater and groundwater recharge. Analysis of impervious surface, therefore, has an important contribution in the identification of GWPZ. Many researchers (Fohrer et al. 2001; Lee et al. 2003; Zhou et al. 2010; Weng 2012) have deliberated the effect of the impervious surface on hydrology and environment. Impervious surfaces impede percolation, infiltration, subsurface water availability and encourage overland flow, larger volumes of run-off and shorter time of absorption (Brun and Band 2000). Thus, a higher amount of impervious surface restricts groundwater potentiality in a region. Hence, low FIS area is considered as high groundwater potential zone. In the study area, the coverage of such an impervious surface is around 42% indicating low to poor groundwater potential (Fig. 8).

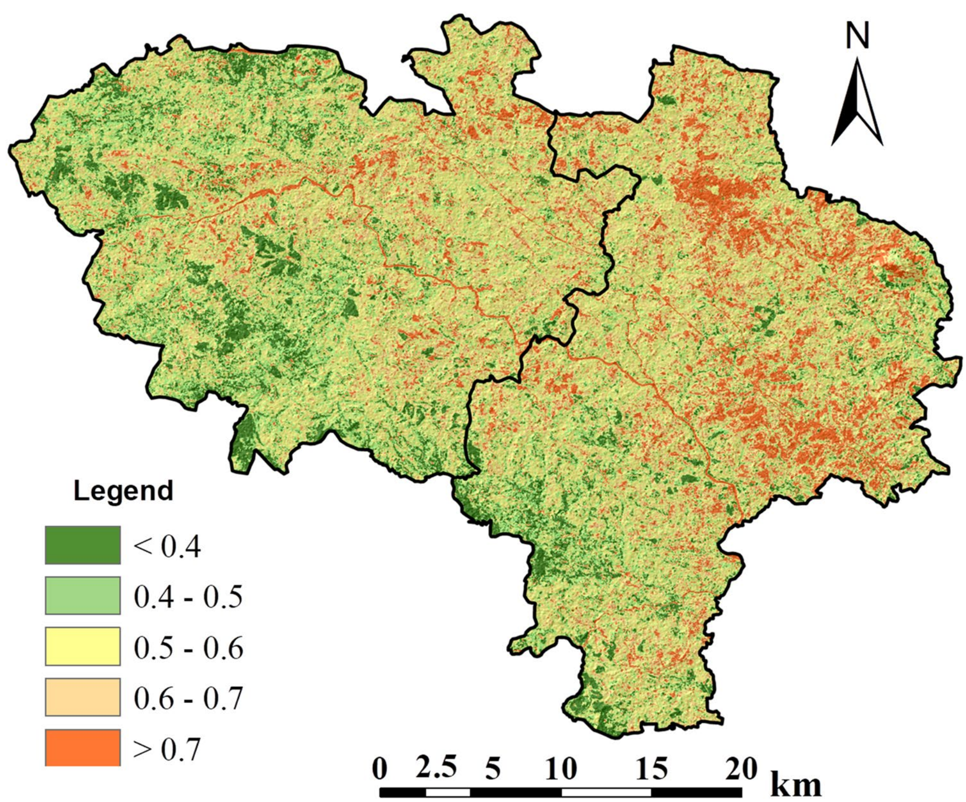
Ground water potential zones

All the six thematic layers (hydrogeomorphology, slope, lineament density, drainage density, land use/land cover and fractional impervious surface) were assimilated in a GIS platform and a single groundwater potential map was produced illustrating the favorable groundwater zones (Fig. 9). Four different classes, namely, 'Excellent', 'Good', 'Fair' and 'Poor' GWPZs were categorized in 1–4 scale (Table 3).

The 'Fair' areas of groundwater potential zones are found to be randomly distributed over the study area. It encompasses an area of 265 km^2 in Chhatna and 278 km^2 in Kashipur, which are about 56.72% and 59.81% of the total area of the administrative blocks in the RLZ, respectively. The north, north-eastern, south and south-western parts of the study area fell under the category of 'good' GWPZ of about 170 km^2 (38.45%) and 139 km^2 (31.81%) in Chhatna and Kashipur block, respectively. 'Good' GWPZ is characterized by a gentle slope, low drainage density, high lineament density and favorable hydro-geomorphological form. 'Poor' GWPZ has low recharge capacity and steeper slope as compared to good and moderate GWPZ (Patra et al. 2018). The southern part of the Kashipur covers an area of about 18.27 km^2 'poor' GWPZ zone because of its steep slope and unfavorable geomorphological condition.

Ground water potential zones have been identified with the help of remote sensing and GIS-based AHP process

Fig. 8 Fractional impervious surface of the study area



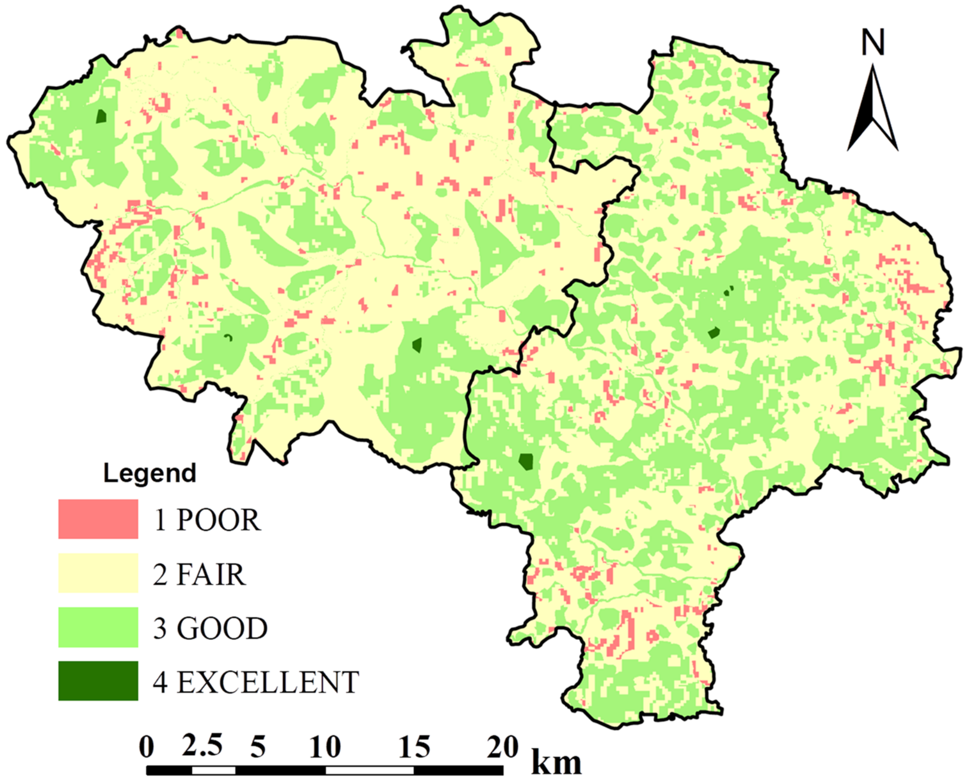


Fig. 9 Ground water potential zone of the present study area

Table 3 Groundwater potential zones of the study area

Sr. no.	Potential zones	Chhatna area (km^2)	Kashipur area (km^2)
4	Excellent	2.51	1.29
3	Good	170.79	139.08
2	Fair	265.41	278.61
1	Poor	4.32	18.27

in different parts of the world (Sener et al. 2005; Gumma and Pavelic 2013; Rahmati et al. 2015; Ferozu et al. 2019). Results of these studies indicated that out of the total study area, 30–40% have fair to good potentiality of groundwater, as in Bangladesh (Ferozu et al. 2019), in Iran (Rahmati et al. 2015) or in central Eastern desert Egypt (Abdalla 2012). Similar study at Ghana (Gumma and Pavelic 2013) could identify 50% of the total area to be of fair to good groundwater potentiality.

In contrast, GWPZ assessed using three parameters of hydrogeomorphology, slope and lineament density in the Kashipur Block, Purulia District (Nag and Kundu 2016) and Chhatna Block, Bankura District (Nag and Ghosh 2012) identified significantly larger area under ‘excellent’ and ‘good’ categories of GWPZ. These previous studies identified about 30–35% of the Chhatna block and 2% of the Kashipur under ‘excellent’ category, while 55–60% of the area of both the blocks under ‘good’ category of GWPZ. However, ground validation of GWPZ in the present study did not reveal such an encouraging proposition.

Recent studies (Patra et al. 2018; Nsiah et al. 2018; Magesh et al. 2012; Singh et al. 2018; Ferozu et al. 2019) indicate that drainage density, land use and fractional impervious surface (FIS) are most important parameters to effectively recognize GWPZ. The present study using six basic parameters namely hydrogeomorphology, slope, lineament density, drainage density, land use/land cover and FIS in an integrated remote sensing GIS framework appears to be more in tune with the state of the art method to delineate the GWPZs, particularly in the RLZ of West Bengal. Moreover, previous studies in this area did not offer any ground validation of the remote sensing-derived GPWZs. Thus, the findings from the present study are distinguished from the earlier ones in two aspects; firstly, in the total number of parameters employed for the analysis and secondly, in the better accuracy in ground water potential assessment as evidenced by the validation from field data discussed in the subsequent section.

Validation of groundwater potential zones

To validate the potentiality of the groundwater, the present status of several dugwells was considered as a proxy of groundwater availability. It was assumed that regions having good to fair GWPZ must be accompanied by perennial dugwells and the dugwells of poor GWPZ should show the characteristic of drying up, especially in summer. Field surveys were conducted and the majority of dugwells in good/fair GWPZs were found to be perennial indicating the existence of permeable reservoir with substantial water storage at subsurface. Conversely, majority of the wells in the poor zone was found to dry up during the summer season. Out of the total 180 perennial wells in the present RLZ, 81% were found in good GWPZ and 19% in fair GWPZ confirming the first part of the hypothesis. Conversely, among the 76 non-perennial wells, 62% falls in the fair category and all the surveyed wells (10 wells) in the poor GWPZ were found to be non-perennial. This observation not only proves the high accuracy of the assessment but also signifies that the approach taken in the present study to characterize the GWPZs was apt for such kind of RLZ.

Conclusion

Sustainable use of groundwater is necessary to promote long-term sustainability of agriculture as well as for socio-economic development in any area. In the present RLZ, groundwater is being extensively used to the domestic and agricultural needs of the people. The agriculture of the RLZ area under study depends largely on rainfall and rainwater harvesting, mostly through ponds and dugwells with limited river lift irrigation. As the onset of monsoon and quantum of rainfall in the month of July and August has become irregular in recent time, the demand of groundwater is increasing to fill up the water deficit not only in the Rabi (winter) season but also during the monsoon months. We have delineated the GWPZs in the RLZ of West Bengal (Kashipur and Chhatna blocks) by the integrated RS and GIS-based AHP methodology. The GWPZs were derived for the present RLZ and the results revealed that poor, fair and good potential zone covered 4.18%, 56.72% and 31.81% of the Kashipur and 1%, 59.81% and 38.45% of Chhatna, respectively. It was also observed from the study that good groundwater recharge zone is located only in the peneplained portion of the study area with favorable hydrogeomorphology, slope, lineament density, drainage density and land use/land cover. Rainwater is mainly responsible for the groundwater recharge. However, moderate to steep slope area is considered as fair zones for groundwater recharge processes. These areas can be selected for the construction of recharge structures such as check dam, water absorption trench and farm ponds to store the rainwater and to arrest excessive surface runoff. The GWPZ map as an outcome of the present study is envisaged to be useful for locating suitable locations for extraction of water, sustainable groundwater utilization, further land-use planning and water resource management in Bankura and Purulia region and can be extended to other RLZs of West Bengal, and India. This integrated remote sensing–GIS framework-based analysis has been used at the micro-scale in the present study but this method can further be scaled up in the RLZ of India and the world to facilitate better watershed management practices, which can be used for agricultural and drinking water purposes. The present research reaffirms the efficacy of integration of remote sensing with AHP in terms of being a cost-effective method requiring a reduced workforce and eliminating the time constraints of conventional methods for groundwater prospecting.

Acknowledgements The study was sponsored by the National Bank for Agriculture and Rural Development, India (NABARD) through the Development Research Communication and Services Centre (DRCSC), Kolkata from the Climate Adaptation Fund (AFB/PPRC15/12). The authors are grateful for these financial and logistic supports. The authors also express their gratitude to the Geological Survey of India and Survey of India for providing the secondary data. The author (S. Roy) is thankful to Jadavpur University, India for providing the State Fellowship.

References

Abdalla F (2012) Mapping of groundwater prospective zones using remote sensing and GIS techniques: a case study from the Central Eastern Desert, Egypt. J Afr Earth Sci 70:8–17

Adiat KAN, Nawawi MNM, Abdullah K (2012) Assessing the accuracy of GIS-based elementary multi-criteria decision analysis as a spatial prediction tool—a case of predicting potential zones of sustainable groundwater resources. J Hydrol 440:75–89

Agarwal R, Garg PK (2016) Remote sensing and GIS based groundwater potential & recharge zones mapping using multi-criteria decision making technique. Water Resour Manag 30(1):243–260

Agarwal E, Agarwal R, Garg RD, Garg PK (2013) Delineation of groundwater potential zone: an AHP/ANP approach. J Earth Syst Sci 122(3):887–898

Al-Abadi AM (2015) Groundwater potential mapping at northeastern Wasit and Missan governorates, Iraq using a data-driven weights of evidence technique in framework of GIS. Environ Earth Sci 74(2):1109–1124

Asadi SS, Vuppala P, Reddy MA (2007) Remote sensing and GIS techniques for evaluation of groundwater quality in municipal corporation of Hyderabad (Zone-V), India. Int J Environ Res Public Health 4(1):45–52

Bhunia GS, Samanta S, Pal DK, Pal B (2012) Assessment of groundwater potential zone in Paschim Medinipur District, West Bengal—a mesoscale study using GIS and remote sensing approach. J Environ Earth Sci 2(5):41–59

Brun SE, Band LE (2000) Simulating runoff behavior in an urbanizing watershed. Comput Environ Urban Syst 24(1):5–22

Butler M, Wallace J, Lowe M (2002) Groundwater quality classification using GIS contouring methods for cedar valley, Iron County, Utah. Digit Mapp Tech 2002:207

Carlson TN, Ripley DA (1997) On the relation between NDVI, fractional vegetation cover, and leaf area index. Remote Sens Environ 62(3):241–252

Chandra S, Rao VA, Krishnamurthy NS, Dutta S, Ahmed S (2006) Integrated studies for characterization of lineaments used to locate groundwater potential zones in a hard rock region of Karnataka, India. Hydrogeol J 14(6):1042–1051

Chenini I, Mammou AB, El May M (2010) Groundwater recharge zone mapping using GIS-based multi-criteria analysis: a case study in Central Tunisia (Maknassy Basin). Water Resour Manag 24(5):921–939
Das S, Behera SC, Kar A, Narendra P, Guha S (1997) Hydrogeomorphological mapping in groundwater exploration using remotely sensed data—a case study in keonjhar district, orissa. J Ind Soc Remote Sens 25(4):247–259
Devi SP, Srinivasulu S, Raju KK (2001) Delineation of groundwater potential zones and electrical resistivity studies for groundwater exploration. Environ Geol 40(10):1252–1264
Dinesh Kumar PK, Gopinath G, Seralathan P (2007) Application of remote sensing and GIS for the demarcation of groundwater potential zones of a river basin in Kerala, southwest coast of India. Int J Remote Sens 28(24):5583–5601
Ferozu RM, Jahan CS, Arefin R, Mazumder QH (2019) Groundwater potentiality study in drought prone barind tract, NW Bangladesh using remote sensing and GIS. Groundw Sustain Dev 8:205–215
Fohrer N, Haverkamp S, Eckhardt K, Frede HG (2001) Hydrologic response to land-use changes on the catchment scale. Phys Chem Earth Part B 26(7–8):577–582
Ghosh PK, Jana NC (2017) Groundwater potentiality of the Kumari River Basin in drought-prone Purulia upland, Eastern India: a combined approach using quantitative geomorphology and GIS. Sustain Water Resour Manag 4(3):583–599
Gumma MK, Pavelic P (2013) Mapping of groundwater potential zones across Ghana using remote sensing, geographic information systems, and spatial modeling. Environ Monit Assess 185(4):3561–3579
Guru B, Seshan K, Bera S (2017) Frequency ratio model for groundwater potential mapping and its sustainable management in cold desert, India. J King Saud Univ Sci 29(3):333–347
Hardcastle KC (1995) Photolineament factor: a new computer-aided method for remotely sensing the degree to which bedrock is fractured. Photogramm Eng Remote Sens 61(6):739–746
Horton RE (1945) Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geol Soc Am Bull 56(3):275–370
Ibrahim-Bathis K, Ahmed SA (2016) Geospatial technology for delineating groundwater potential zones in Doddahalla watershed of Chitradurga district, India. Egypt J Remote Sens Space Sci 19(2):223–234
Ishizaka A, Labib A (2011) Review of the main developments in the analytic hierarchy process. Expert Syst Appl 38:14336–14345
Jaiswal RK, Mukherjee S, Krishnamurthy J, Saxena R (2003) Role of remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development—an approach. Int J Remote Sens 24(5):993–1008
Jasrotia AS, Kumar A, Singh R (2016) Integrated remote sensing and GIS approach for delineation of groundwater potential zones using aquifer parameters in Devak and Rui watershed of Jammu and Kashmir, India. Arab J Geosci 9(4):304
Kaliraj S, Chandrasekar N, Magesh NS (2014) Identification of potential groundwater recharge zones in Vaigai upper basin, Tamil Nadu, using GIS-based analytical hierarchical process (AHP) technique. Arab J Geosci 7(4):1385–1401
Kasperson RE (2015) Risk governance and the social amplification of risk: a commentary. In: Risk governance. Springer, Dordrecht, pp 485–487
Krishnamurthy J, Venkatesa Kumar N, Jayaraman V, Manivel M (1996) An approach to demarcate ground water potential zones through remote sensing and a geographical information system. Int J Remote Sens 17(10):1867–1884
Kumar MG, Agarwal AK, Bali R (2008) Delineation of potential sites for water harvesting structures using remote sensing and GIS. J Indian Soc Remote Sens 36(4):323–334
Leduc C, Favreau G, Schroeter P (2001) Long-term rise in a Sahelian water-table: the Continental Terminal in south-west Niger. J Hydrol 243(1–2):43–54
Lee JG, Heaney JP (2003) Estimation of urban imperviousness and its impacts on stormwater systems. J Water Resourc Plan Manag 129(5):419–426
Machiwal D, Jha MK, Mal BC (2011) Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. Water Resour Manag 25(5):1359–1386
Madrucci V, Taioli F, de Araújo CC (2008) Groundwater favorability map using GIS multicriteria data analysis on crystalline terrain, Sao Paulo State, Brazil. J Hydrol 357(3–4):153–173
Magesh NS, Chandrasekar N, Soundranayagam JP (2012) Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geosci Front 3(2):189–196
Magowe M, Carr JR (1999) Relationship between lineaments and groundwater occurrence in western Botswana. Groundwater 37(2):282–286
Maity DK, Mandal S (2017) Identification of groundwater potential zones of the Kumari river basin, India: an RS & GIS based semi-quantitative approach. Environ Dev Sustain. https://doi.org/10.1007/s10668-017-0072-0
Mallick J, Singh CK, Al-Wadi H, Ahmed M, Rahman A, Shashtri S, Mukherjee S (2015) Geospatial and geostatistical approach for groundwater potential zone delineation. Hydrol Process 29(3):395–418
Manap MA, Sulaiman WNA, Ramli MF, Pradhan B, Surip N (2013) A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia. Arab J Geosci 6(5):1621–1637
Milly PCD (1994) Climate, soil water storage, and the average annual water balance. Water Resour Res 30(7):2143–2156
Milly PCD, Dunne KA (1994) Sensitivity of the global water cycle to the water-holding capacity of land. J Clim 7(4):506–526
Mukherjee A, Banerjee S (2009) Rainfall and temperature trend analysis in the red and lateritic zone of West Bengal. J Agrometeorol 11(2):196–200
Mukherjee A, Patil D (2013) Appraisal of Use Pattern in Wetalnds of Bankura, a drought prone region from eastern India. J Appl Technol Environ Sanit 3(4):141–146
Mukherjee P, Singh CK, Mukherjee S (2012) Delineation of groundwater potential zones in arid region of India—a remote sensing and GIS approach. Water Resour Manag 26(9):2643–2672
Murasingh S (2014) Analysis of groundwater potential zones using electrical resistivity, rs & gis techniques in a typical mine area of Odisha (Doctoral dissertation)
Nag SK (1998) Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. J Indian Soc Remote Sens 26(1–2):69–76
Nag SK (2005) Application of lineament density and hydrogeomorphology to delineate groundwater potential zones of Baghmundi block in Purulia district, West Bengal. J Indian Soc Remote Sens 33(4):521
Nag SK, Ghosh P (2012) Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques. Environ Earth Sci 70(5):2115–2127
Nag SK, Kundu A (2016) Application of remote sensing, GIS and MCA techniques for delineating groundwater prospect zones in Kashipur block, Purulia district, West Bengal. Appl Water Sci 8(1):38
Nag SK, Lahiri A (2011) Integrated approach using Remote Sensing and GIS techniques for delineating groundwater potential zones in Dwarakeswar watershed, Bankura district, West Bengal. Int J Geomat Geosci 2(2):430

Nagarajan M, Singh S (2009) Assessment of groundwater potential zones using GIS technique. J Indian Soc Remote Sens 37(1):69–77
Naghibi SA, Pourghasemi HR, Dixon B (2016) GIS-based groundwater potential mapping using boosted regression tree, classification and regression tree, and random forest machine learning models in Iran. Environ Monit Assess 188(1):44
Ndatuwong LG, Yadav GS (2014) Integration of hydrogeological factors for identification of groundwater potential zones using remote sensing and GIS techniques. J Geosci Geomat 2(1):11–16
Nsiah E, Appiah-Adjei EK, Adjei KA (2018) Hydrogeological delineation of groundwater potential zones in the Nabogo basin, Ghana. J Afr Earth Sc 143:1–9
Owen SM, Boissard C, Hagenlocher B, Hewitt CN (1998) Field studies of isoprene emissions from vegetation in the Northwest Mediterranean region. J Geophys Res-Atmos 103(D19):25499–25511
Patra S, Mishra P, Mahapatra SC (2018) Delineation of groundwater potential zone for sustainable development: a case study from Ganga Alluvial Plain covering Hooghly district of India using remote sensing, geographic information system and analytic hierarchy process. J Clean Prod 172:2485–2502
Pourtaghi ZS, Pourghasemi HR (2014) GIS-based groundwater spring potential assessment and mapping in the Birjand Township, southern Khorasan Province, Iran. Hydrogeol J 22(3):643–662
Prasad RK, Mondal NC, Banerjee P, Nandakumar MV, Singh VS (2008) Deciphering potential groundwater zone in the hard rock through the application of GIS. Environ Geol 55(3):467–475
Rahman MA, Rusteberg B, Gogu RC, Ferreira JL, Sauter M (2012) A new spatial multi-criteria decision support tool for site selection for implementation of managed aquifer recharge. J Environ Manag 99:61–75
Rahmati O, Samani AN, Mahdavi M, Pourghasemi HR, Zeinivand H (2015) Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS. Arab J Geosci 8(9):7059–7071
Rajaveni SP, Brindha K, Elango L (2017) Geological and geomorphological controls on groundwater occurrence in a hard rock region. Appl Water Sci 7(3):1377–1389
Rao NS, Chakradhar GKJ, Srinivas V (2001) Identification of groundwater potential zones using remote sensing techniques in and around Guntur town, Andhra Pradesh, India. J Indian Soc Remote Sens 29(1–2):69
Ray A (1982) Indus trial potential of Purulia West Bengal A study in Economic Geography (Ph.D. thesis)
Reddy PR, Kumar KV, Seshadri K (1996) Use of IRS-1C data in groundwater studies. Curr Sci 70:600–605
Ridd MK (1995) Exploring a VIS (vegetation-impervious surface-soil) model for urban ecosystem analysis through remote sensing: comparative anatomy for cities. Int J Remote Sens 16(12):2165–2185
Roscoe Moss Company (1990) Handbook of groundwater development. Wiley, Hoboken
Saraf AK, Choudhury PR (1998) Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. Int J Remote Sens 19(10):1825–1841
Sehgal J (1998) Red and lateritic soils: an overview. Red Lateritic Soils 1:3–10
Sener E, Davraz A, Ozcelik M (2005) Integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. Hydrogeol J 13(5–6):826–834
Singh LK, Jha MK, Chowdary VM (2018) Assessing the accuracy of GIS-based multi-criteria decision analysis approaches for mapping groundwater potential. Ecol Ind 91:4–37
Singh SK, Zeddies M, Shankar U, Griffiths GA (2019) Potential groundwater recharge zones within New Zealand. Geosci Front. https://doi.org/10.1016/j.gsf.2018.05.018
Taylor RG, Scanlon B, Doll P, Rodell M, Van Beek R, Wada Y, Longuevergne L, Leblanc M, Famiglietti JS, Edmunds M, Konikow L (2013) Groundwater and climate change. Nat Clim Change 3(4):322–329
Thapa R, Gupta S, Guin S, Kaur H (2017) Assessment of groundwater potential zones using multi-influencing factor (MIF) and GIS: a case study from Birbhum district, West Bengal. Appl Water Sci 7(7):4117–4131
Todd DK (1980) Groundwater hydrology, 2nd edn. Wiley, New York, pp 111–163
Waikar ML, Nilawar AP (2014) Identification of groundwater potential zone using remote sensing and GIS technique. Int J Innov Res Sci Eng Technol 3(5):12163–12174
Weng Q (2012) Remote sensing of impervious surfaces in the urban areas: requirements, methods, and trends. Remote Sens Environ 117:34–49
Yammani S (2007) Groundwater quality suitable zones identification: application of GIS, Chittoor area, Andhra Pradesh, India. Environ Geol 53(1):201–210
Yeh HF, Cheng YS, Lin HI, Lee CH (2016) Mapping groundwater recharge potential zone using a GIS approach in Hualian River, Taiwan. Sustain Environ Res 26(1):33–43
Zhou Y, Wang Y, Gold AJ, August PV (2010) Modeling watershed rainfall-runoff relations using impervious surface-area data with high spatial resolution. Hydrogeol J 18(6):1413–1423