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Investigation for potential groundwater recharge area over the Kunur river basin, Eastern India: An integrated approach with geosciences

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Abstract: Present work prepared a linear model to identify the potential area of groundwater recharge over the Kunur river basin, using six factors (e.g. drainage density, surface slope, ruggedness index, lineament density, Bouguer gravity anomaly and potential maximum water retention capacity) from different fields of geosciences (e.g. geomorphology, geotectonic, geophysics, and hydrology) with the help of geoinformatics. To integrate all these factors, grid (6.25km^2) wise weights have been assigned based on their level of importance on groundwater development. Using interpolation (Inverse Distance Weighted) method on the cumulative weights of 176 grids, the basin has been divided into five grades (excellent, good, moderate, low and poor) of recharge potential zones, where the excellent recharge zones are mainly concentrated in the downstream area and dense *sal* forest areas. Extended urbanization and intensive paddy cultivation have reduced the recharge capacity over the southeastern part of upper basin area and the northern part of the middle basin area respectively. The derived result has been calibrated by twenty four observed wells based average groundwater depth data for the pre-monsoon and post-monsoon seasons over the last eleven years (2000-2010) and the rate of seasonal fluctuation in water table over the basin. It is concluded that the study helps to demarcate those palaces, which area should be preserved as the pathway of refilling groundwater resource for future utilization.

Keywords: Linear Model, Geosciences, Inverse distance weighted method, Recharge potentiality, Urbanization, Seasonal fluctuation

1. Introduction

People of West Bengal face a serious problem of groundwater availability related to its quality and quantity. According to Central Groundwater Board or CGWB (2014), with the advent of energized pumping system as well as groundwater intensive agricultural irrigation such as "Boro" cultivation, average water level has gone down up to 5-10 m bgl (below ground level) during pre-monsoon season and 2-5 m bgl during post-monsoon season. The study also shows that due to the excessive exploitation of groundwater than recharge, fall in post-monsoon water level is increasing at a much higher rate than that of pre-monsoon depth of water level. Nevertheless, over the state quality of groundwater is also degrading very rapidly, out of the 341 administrative blocks within 19 districts of West Bengal, 79 administrative blocks covering eight districts are facing arsenic problem (CGWB, 2014). Flouride contamination also is a recent phenomenon in the state. As per the sample survey conducted in this regard by Public Health Engineering Department or PHED (2010) of Govt. of West Bengal, 225 villages in 43 blocks of 7 districts were found to contain fluoride in groundwater beyond permissible limit (>1.5 mg/L). Coastal salinity has also been reported from 59 blocks in four districts (CGWB, 2014). Overall, 39 blocks have been categorized as semi-critical in senses of fresh drinking water availability from groundwater resource.

In an experimental work with 140150 water samples for arsenic from 7823 villages of 241 blocks from all 19 districts of the state since 1988, Chakraborti et al. (2009) observed that 48.1% had arsenic above 10 lg/L (WHO guideline value), 23.8% above 50 lg/L (Indian Standard) and 3.3% above 300 lg/L (concentration predicting overt arsenical skin lesions). The study has also concluded that in West Bengal alone, 26 million people are potentially at risk from drinking arsenic-contaminated water (> 10 lg/L). In an another experimental work on fluoride contamination in groundwater over the Bankura district with the help of PHED, Chakrabarti and Bhattacharya (2013) observed that out of 8500 water sample from different tube wells, 3617 tube wells were found to contain fluoride above 0.5 mg/L., 612 sites have fluoride more than 1 mg/L., out of which 247 sites have high fluoride above 1.5 mg/L.

In India also, long-term over exploitation of groundwater resources poses a challenge to water resource management (Vijay Shankar et al., 2011). India is now the biggest user of groundwater for agriculture in the world and during 2000–01 to 2006–07, about 61% of irrigation in the country was sourced from groundwater (Shah, 2011). Groundwater irrigation has been expanding at a very rapid pace in India since the 1970s. The data from the Minor Irrigation Census (2001) shows the evidence of growing numbers of groundwater irrigation structures (wells and tube wells) in the country. According to Kumar and Raj (2013), since 1951, per capita availability of water in India has declined from ~3000 m^3/year to ~1800 m^3/year in 2010. The share of surface water has also declined from 60% in the 1950s to 30% in the first decade of the 21st century (CGWB, 2010). Now, it is very essential to indentify suitable area for groundwater recharge and increased this valuable resource to meet increasing demand of irrigation and at the same time to bring up the requirement of uncontaminated drinking and domestic usable water for the country's vast rural and urban populations.

In recent days, the detection of groundwater recharge potential zone draws more attention from researchers as well as scientists from different field of study. In India, therefore, basin-scale groundwater resource development is becoming a major issue due to acute shortage of water resource (Rao, 2009). During the last two decades, so many research works have been published based on the potential application of remote sensing on hydrological data extraction, where, thermal bands and multispectral imageries of different sensors have been extensively used to collect the information about groundwater potential and deficit regions (Meijerink, 1996; Mukherjee, 2008). Ringrose et al., (1998) attempted to study on possible association of near-surface groundwater and vegetation characteristics using a combination of remote sensing data and geographic information systems (GIS) techniques. De Alwis et al. (2007) reported on the application of Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) techniques on saturated surface area and hydrological active areas (HAA) delineation for water resource planning.

As a most fascinating technology in water resource monitoring, Gravity Recovery and Climate Experiment (GRACE) makes a leading position to estimate the fluctuation of total water storage (TWS) with an integrated change of surface water storage (SWS), soil moisture storage (SMS) and groundwater storage (GWS) by calculating the changes of earth's gravity field, which is primarily controlled by changes in total water storage (TWS) (Long et al., 2013). It is a twin satellite includes most innovative technology to calculate absolute variation of earth's water storage at regional level (minimum footprint 200,000 km^2) within the monitoring interval of 10 days to longer time scale (Longuevergne et al., 2010; Long et al., 2014). The application of GRACE data helps to start a new decade for geo-hydrological research with eliminating the limitation and questions about the level of accuracy. Application of GRACE also reduces the dependency of traditional monitoring systems on site measurements or model simulations, which are costly and time-consuming (Jiang et al., 2014). Since the beginning of twenty first century, GRACE is an excellent option for terrestrial hydrology research, but it is suitable only for continental scale estimation rather than a smaller region. In this circumstance, multispectral images are still being used as key technology in the micro level hydrological modeling (e.g. Kunur river basin) for its better spatial resolution (30m × 30m) and direct observation of emitted electromagnetic radiation from the earth surface. Although, GRACE data are freely and publicly available from a number of sources, but precise estimation for a given area requires significant training and time commitment, which may be difficult for groundwater managers in some developing nations (Morre, 2012).

Present study integrated four fields of geosciences e.g., geomorphology, geotectonic, geophysics and hydrology with the help of geoinformatics technology to investigate the recharge potential area over the Kunur river basin (KRB). These four fields help to summarize the influencing factors on groundwater recharge from over the surface, above the surface and beneath the surface of earth crust. In India, several studies have been carried out based sub-basin scale prioritization for groundwater potentiality mapping using morphometric analysis, geomorphology and sediment yield index (SYI) and remote sensing-GIS (Krishnamurthy et al., 1996; Biswas et al., 1999; Khan et al., 2001; Suresh et al., 2004; Nookaratnam et al., 2005; Srinivasa et al., 2008; Avinash et al., 2011). Ramlingam and Santhakumar (2002) have explored the suitable recharge areas and structures to augment an aquifer system in Tamil Nadu, India using remote sensing and GIS with the integration of thematic maps of geomorphology, geology, soil, slope, land use, drainage density, lineament density, runoff isolines, depth to weathered zone, depth to basement, groundwater level fluctuations and the water quality.

But none of this work has integrated the factors of geophysical parameters e.g. underlying rock density, gravity anomaly of the basin in the research work and also sub-basin scale analysis makes some generalization in these findings. In the current study, Bouguer gravity data have been introduced to specify the zone of low rock density and high rock density for their importance on surface water infiltration. Lineament density values are also integrated here with the combination of drainage density, ruggedness index and slope characteristic of the KRB. Types of land cover and hydrological soil groups of KRB have been also applied here to incorporate the influencing factors from over and above the surface, which are playing crucial role on rainwater retention capacity (Ringrose et al., 1998). To integrate all these factors, grid (6.25km^2) wise weightage values have been assigned based on their level of importance on groundwater development. The generated potentiality map has also been calibrated with the observed groundwater level data of pre-monsoon and post-monsoon seasons collected from the State Water Investigation Director (SWID), Kolkata. The primary objective of this paper is to investigate the groundwater recharge potentiality over the KRB using applied fields of geosciences with the help of geoinformatics.

2. Material and methods

2.1 Study area

The present study has been conducted over the northeastern part of Barddhaman district, West Bengal, Eastern India. KRB has been selected within the interfluve of the Ajay and Damodar rivers (Figure 1a), which is a major right bank tributary of Ajay river. KRB covers almost 33% area of the lower Ajay river

Journal of Geomatics Vol 9 No. 2 October 2015

basin. The area of the study basin is about 916.40 km^2. The river originates near Jhanjira village of Ukhra Gram Panchayate on the western upland of the Barddhaman district at an altitude of 125 metres. It runs for a distance of 114 km towards east direction. The elevation ranges from 131 metres to 20 metres throughout the basin (Roy and Mistri, 2013). It has a forest cover, spreading over almost 31.35% area, water body holds around 10.35% area, 13.82% area is for human settlement, 41.74% for agricultural land, and 2.73% area comes under barren land or unsuitable areas for agriculture (Figure 1b) [based on Landsat 8 Image, dated on 26th April, 2013; processing by Q-GIS v.2.4, at 97.56 % of accuracy on Kappa coefficient]. Geographically this basin is tropical; the Tropic of Cancer (23°30′E) is passing over the basin from West to East.

Over the region, annual average rainfall observed is 1380 mm and mean temperature is 25.8^{o} C during last 100 years (IMD, 2014). Over the 1901-2003 periods, National Climate Centre (2006) of India Meteorological Department, has observed that in the South Bengal sub-division the total amount of rainfall during the September month has increased (56.50 mm) at 5% significance level, whereas, 91 mm, 26 mm, and 95 mm of rainfall has increased during the monsoon, post-monsoon and annual respectively, at 10% level of significance

The study area consists of six major aquifer systems with varying characteristic of bed thickness, groundwater depth, and water yield capacity (Table 1 and Figure 1c) (CGWB, 2014). The 58% of the basin area covers by Laterite aquifer and extends from middle to top of the basin with least yield capacity (20-60 m^3/day). The downstream area of the basin covers by alluvial aquifer (37.88%) with high yield capacity and the upper edge of the basin consists with patches of sandstone, shale, and fine-grained siltstone with coal seams. An eastward sub-surface flow of groundwater is present with the ranging electric conductivity from 500 to 2000 micro-Siemens/cm (CGWB, 2014).

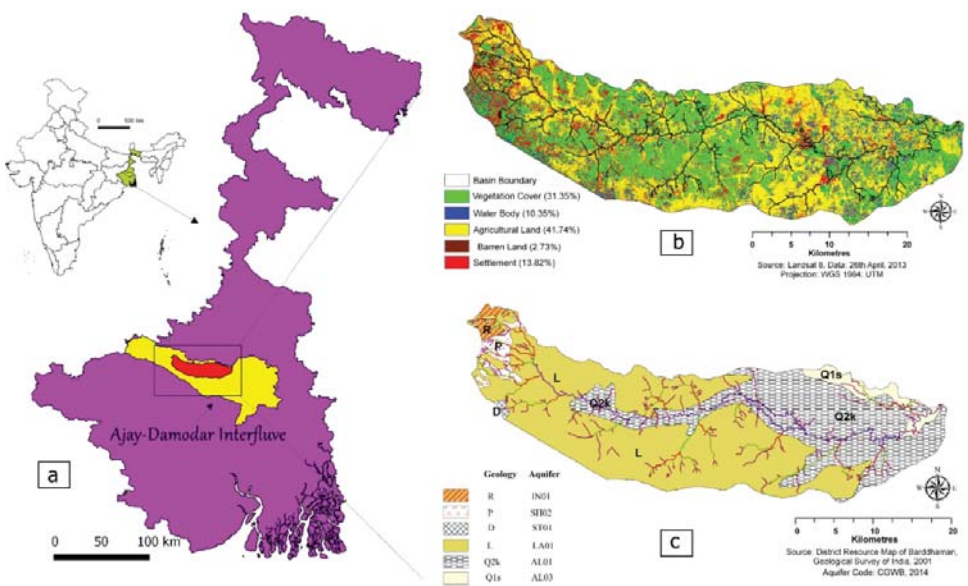

Figure 1: (a) Regional location map of the study area; (b) land cover types; and (c) surface geology and condition of aquifers

2.2 Geoscientific factors related to groundwater recharge

The entire KRB has been investigated to examine the potentiality of groundwater recharge by applying an integrated study on fluvial geomorphology, morphotectonics, geophysical parameters, hydrological models and digital topography using topographic maps (1:50,000), ASTER DEM (30 m), multi-spectral imagery (Landsat 8) and field mapping. The boundary of KRB has been delineated using Survey of India (SoI) topographical maps (73 M/6, M/7, M/10, M/11, M/14, and M/15 of 1:50,000) and Landsat 8 images. All topographical maps were geo-referenced [into a Universal Transverse Mercator (UTM) projection, WGS 84, Zone 45 North] using 16 ground control points (GCPs) distributed all the corners for each maps with <0.002 root mean square (RMS) error.

Applied six different techniques from four fields of geosciences in the purpose of groundwater recharge potentiality mapping have been categorized in the table 2 with proper data sources and their role on groundwater development. In the table 2, positive sign (+ive) indicates with the increasing morphometric value of a particular parameter, groundwater recharge potentiality also increases and vice-versa. If the relationship shows negative sign (–ive), it means with the increasing morphometric value of a particular parameter groundwater recharge capacity will be deceased and vice-versa.

Journal of Geomatics Vol 9 No. 2 October 2015

Table 1: The major aquifers and geological units within the study area and their geo-hydrological characteristic with period of formation and covering area (Source: CGWB, 2014)

Code		Rock types	Depth of water level (Decadal Average in m bgl)	Thickness of aquifer / weathered zone (m)	Yield (m3/ day)	Age	% of the total KRB
Aquifers	Geology						
AL01	Q_2k	Younger Alluvium (Clay/Silt/Sand/ Calcareous concretions)	5-10	50-700	200-1500	Quarternary	3.81
AL03	Q_1s	Older Alluvium (Silt/Sand/Gravel/ Lithomargic clay)					34.07
LA01	L	Laterite / Ferruginous concretions	5-10	8-20	20-60		58.00
ST01	D	Sandstone/ Conglomerate	5-10	5-40	5-2000	Upper Palaeozoic to Cenozoic	0.28
SH02	P	Shale with Sandstone	5-15	10-30	20-80		2.67
IN01	R	Basic Rocks (Dolerite, Anorthosite etc.)	5-15	5-25	Low Yield	Proterozoic to Cenozoic	1.17

Geomorphological features related to morphometric indices and all streams have been digitized from topographical maps at 1:50,000 scales produced by the SoI between 1967 and 1972. In addition, online mapping using 'Plug-in layer tool in Q-GIS software' with 'Google Satellite Image' becomes a useful technique in this study for the extraction and to upgrade of linear features related to relief and linear geomorphology. ASTER DEM (2009) has been used to prepare the maps of surface slope condition (in degree) and ruggedness index of the KRB. A web based mapping technique has been applied through the 'Layer from WM(T)S server' mapping tools in Q-GIS to get the arrangement of lineaments from the recently uploaded web version (http://bhuvan5.nrsc.gov.in/bhuvan/wms) in thematic map services of National Remote Sensing Centre (NRSC), India. According to NRSC (2014), it is a collaborative work of GIS cell of ISRO and Standing Committee on Geology, to prepare a national level geomorphological and lineament map on 1:50,000 scale using three level classification system based on the origin of landforms. To prepare the density maps of digitized stream lines and lineaments, Kernel Function in Arc GIS v.9.3 has been run with the cell size of 30m × 30m. Bouguer gravity data have been integrated to emphasize underlying rock density and its impact on groundwater recharge. The map of Bouguer gravity anomaly was prepared by the National Geophysical Research Institute or NGRI (1978), Hyderabad, India with 5 mGal contour interval, which has been converted into raster data using Q-GIS to extract the data in the current study.

Rate of infiltration and amount of direct runoff generation are the prime controller of basin hydrology (Wagener et al., 2004). Therefore, to incorporate the effects of land cover types (Ringrose et al., 1998) and hydrological soil groups (Anbazhagan et al., 2005) on the rate of infiltration and rainwater retention, the Soil Conservation Services (SCS) curve number (CN) method has been applied to estimate grid wise potential maximum water retention capacity of soil during heavy rainfall throughout the basin area. The SCS curve number method is a simple, widely used and efficient method for determining the approximate amount of runoff and water loss from a rainfall event over an area of interest, in which the effect of land use and land cover, various soil cover and antecedent moisture condition were also considered (Chow, 1964; USDA, 1999; Anbazhagan et al., 2005). According to USDA (1999), this technique helps to generate the water retention capacity of soil in any particular region, which is a vital indicator for groundwater development. The SCS curve number method was originally developed by the Soil Conservation Service (1964, 1972) for the development of agricultural sector in the United States (Chow, 1964). The CN values of different land cover within the each grid have been derived from the referenced table of CN calculation followed by Chow (1964). For this, grid-level land cover types have been extracted from the direct observation using recent Google Earth Image (2015) after superimposing the grids over the image through Q-GIS. Once the curve numbers were identified for different land units, the weighted curve numbers were calculated for each grids using eq. 1.

$$\mathrm{WCN} = \frac{\sum(\mathrm{CN_1} \times \mathrm{a_1} + \mathrm{CN_2} \times \mathrm{a_2} + \mathrm{CN_n} \times \mathrm{a_n})}{\sum \mathrm{a}} \quad (1)$$

where, WCN is weighted curve number, CN_1 is curve number for particular land unit 1, a_1 area for that particular land unit 1, $\sum a$ is the sum of total area ($6.25 km^2$). Next the derived WCN has been used to calculate the value of S, using eq. 2.

$$S = \frac{25400}{WCN} - 254$$ (water depth expressed in mm) (2)

2.3 Assessment of potential groundwater recharge zone

In the current study, for the purpose of calculating potential groundwater recharge zone, the above mentioned factors have been used for the evaluation and also weightage accumulation was applied to get the recharge potential score. To accumulate all the data in a single framework, 176 grids (~6.25km^2) and their representing points at regular interval (X: 2500m; Y: 2500m) have been placed over the KRB to extract the data from all six input maps. Quartile technique has been followed to make four equal groups of all individual map wise extracted data based on their quartile ($Q_{1, 2, 3}$) values. The weightage value (W_v) has been also provided to each group within the range of 1, 2, 3, and 4 and where 'W_v 1' represents very low potential zone for groundwater recharge and 'W_v 4' indicates optimal potentiality to recharge, whereas, W_v 2 and W_v 3 represent low and medium potential zones, respectively (Table 2).

Table 2: Techniques of different morphometric indices and their relationship with groundwater development

Applied techniques	Sources	Role on groundwater development (References)	Weightage values (W_v)
Drainage Density (DD) (in km^2)	Topographical Maps, 1967-72 (1: 50,000)	(–ive) (Todd and Mays, 2005)	<0 = 4 0-0.130 = 3 0.131-0.990 = 2 >0.990 = 1
Surface Slope (SS) (in degree)	ASTER Dem, 2009 (30m)	(–ive) (Biswas et al., 1999; Avinash et al., 2011)	<1.7 = 4 1.71-3.397 = 3 3.398-5.430 = 2 >5.430 = 1
Ruggedness Index (RI) (in km^2)	ASTER Dem, 2009 (30m)	(–ive) (Biswas et al., 1999; Rao, 1999)	<4.580 = 4 4.581-6.930 = 3 6.931-9.510 = 2 >9.510 = 1
Lineament Density (LD) (in km^2)	(NRSC, 2014)	(+ive) (Yen et al.,, 2014)	<0.000075 = 1 0.000076-0.0840 = 2 0.0841-0.200 = 3 >0.200 = 4
Bouguer Gravity Anomaly (BGA) (mGal)	(Chow, 1964)	(–ive) (Long and Kaufmann, 2013)	<0 = 4 0-5 = 3 5-10 = 2 >10 = 1
Maximum Water Retention Capacity (S) (mm)	SCS Curve Number Method, (USDA, 1999; Chow, 1964)	(+ive) (Chow, 1964)	<55.76 = 1 55.76-63.50 = 2 63.51-108.85 = 3 >108.85 = 4

The total weights of each point (1-176) in the integrated layer are computed using a weighted linear combination method as follows:

$$\mathbf{P_{r\,(1\text{-}176)} = DD_{wr} + SS_{wr} + RI_{wr} + LD_{wr} + BGA_{wr} + S_{wr}} \quad (3)$$

where, $P_{r\ (1\text{-}176)}$ is the groundwater recharge potential index of respective grids and/or points; DD, SS, RI, LD, BGA and S are the score of drainage density (km/km^2), surface slope (in degree), ruggedness index (RI/km^2), lineament density (km/km^2), Bouguer gravity anomaly (mGal) and potential maximum water retention capacity (mm), respectively. The subscripts w and r refer to the weight of a theme and the reference number of individual points of the same theme, respectively. The generated vector file with points of cumulative weightage data has been then interpolated using the inverse distance weighted (IDW) method at the second power, with a variable search radius and considering the 12 closest points to get ready the final version of groundwater recharge potential map of the KRB. The potential groundwater recharge zone in this basin has been divided into five grades, namely excellent, good, moderate, low and poor.

3. Results and discussion

In the current study, six most promising indices have been used to delineate the zones of optimal groundwater recharge. These six techniques have been selected for their success in groundwater investigation throughout the world. These indices are also helping to integrate the field of geomorphology (Drainage Density, Slope, Ruggedness Index), geotectonic (Lineament), geophysics (Bouguer Gravity Anomaly) and applied hydrology (SCS Curve Number) for the research on groundwater investigation.

3.1 Drainage density and groundwater recharge

Stream lines based drainage density map of the KRB helps to summarize the results of classical methods of drainage density (D_d), stream frequency (S_f) and drainage texture (D_t) map. According to Horton (1945), a lower value of D_d is an indicator of the presence of highly permeable strata under dense vegetation and low relief, whereas, the higher value of D_d generates over the weak/impermeable rocks under sparse vegetation and mountainous relief regions. The high value of stream frequency indicates greater surface run-off and a steep ground surface (Horton, 1945). Drainage texture (D_t) is also a vital parameter to understand the basin character. It helps to correlate vegetation cover, soil texture and structure, and channel spacing (Horton, 1945; Smith, 1950; Schumm, 1956). Smith (1950) also classified it as coarse (<4 per km), intermediate (4–10 per km), fine (10–15 per km) and ultra-fine (>15 per km). In the KRB, the value drainage density (DD) ranges from 0.08 km/km^2 to 1.17 km/km^2, with an average 0.48 km/km^2 (Figure 2a). Overall, the values indicate the permeable nature of the basin surface strata associated with coarse-drainage density (Avinash et al., 2011). Predominantly, the edges of the basin are characterized with very low drainage density, which is the indicator of higher permeability and infiltration capacity than the middle portion of the basin.

3.2 Ruggedness index and groundwater recharge

Ruggedness Index (RI) is a combined result of basin relief (R) and drainage density (D_d) that indicates the structural complexity of the terrain (Schumm, 1956). Higher value of RI indicates a zone of high relief area with steep slopping ground and high drainage density (Ramalingam and Santhakumar, 2001). As a factor in groundwater development, RI plays inverse relation with infiltration, where a high value of RI indicates the maximum runoff and very low infiltration capacity and vice-versa. Over the KRB, the RI value ranges from 2.55 /km^2 to 16.07 /km^2 with an average of 7.03 /km^2 (Figure 2b). Maximum RI has been observed over the extreme northwest part and southeast part of the basin. Part of the middle basin again comes under medium to high RI value.

3.3 Surface slope and groundwater recharge

Slope analysis is an important parameter in geomorphic studies which is controlled by climato-morphogenic processes in the area underlying the rocks of varying resistance (Ramalingam and Santhakumar, 2001). In case of groundwater research of any area, the understanding of slope properties is very essential to indentify the spatial variation of water runoff capacity and its travel time (Sreedevi et al., 2005). Flat and gently sloping ground promotes maximum capacity of water infiltration and groundwater development, whereas, a steeply sloping ground encourage to speedy runoff and no infiltration (Rao et al., 2001). In the present investigated area, the slope amount ranges from 1.22˚ to 7.75˚, with an average 3.90˚(Figure 2c), where the maximum portion of land comes under the gentle slopping ground, it suggests the good capacity of water infiltration. The basin has also steep sloping land over the extreme upstream area with some patches throughout the basin. The steep sloping ground promotes to immediate runoff of rainwater without much infiltration (Rao, 1999).

3.4 Lineaments and groundwater recharge

Lineaments provide the pathways for groundwater movement and are hydrogeologicaly very important (Sankar, 2002). Lineament density map is a measure of quantitative length of linear feature expressed in a grid. Lineament density of an area can indirectly reveal the groundwater potentiality of that area since the presence of lineaments usually denotes a permeable zone (Gopinath and Seralathan, 2004). Areas with high lineament density are good for groundwater development (Haridas et al., 1994). In the KRB, total 20 lineaments have been traced and the length varies from 2.33 km to 15.33 km, with an average 6.75 km (Figure 2d). The general trends of majority lineaments are in the SW-NE and NW-SE direction. Over the basin, these are mainly concentrated in the middle part with some in the upper catchment area. Zones of lineament intersection have high suitability of groundwater recharge (Gopinath and Seralathan, 2004), but unfortunately over the basin there is no such intersection point. In the lineament density map (Figure 2d) value ranges from 0.013km/km^2 to 0.250km/km^2, where the average density is 0.114km/km^2. Higher density areas have been observed over the middle part, northeast part of downstream area and northwest part of the upstream region.

3.5 Bouguer gravity anomaly and groundwater recharge

Understanding of underlying rock density is a key tool for the mapping of groundwater recharge area (Smith et al., 2004). According to Reddy (2010), the rate of infiltration is very much control by the fundamental properties of geological materials, mainly its density. Infiltration takes place due to the combine influence of gravity and capillary forces. Raghunath (2013) stated that the force of gravity helps to move the excess water by deep percolation and builds up the groundwater table. There is an inverse relation between rock density and permeability of rock, and a positive relation with porosity of rock (Reddy, 2010). Nevertheless, the groundwater recharge capacity also has a positive relation with the permeability of rock. Therefore, if any area covers by high density rock, the infiltration capacity of that area will be low and vice-versa. To know the spatial variation of rock density beneath the earth, gravity data are widely used to estimate that (Prasad et al., 2005). According to Smith et al, (2004), gravity has the potential to become a new source of important remote sensing data for catchment-scale hydrological modelling. However, the usefulness of this data has not yet been demonstrated. Among the all

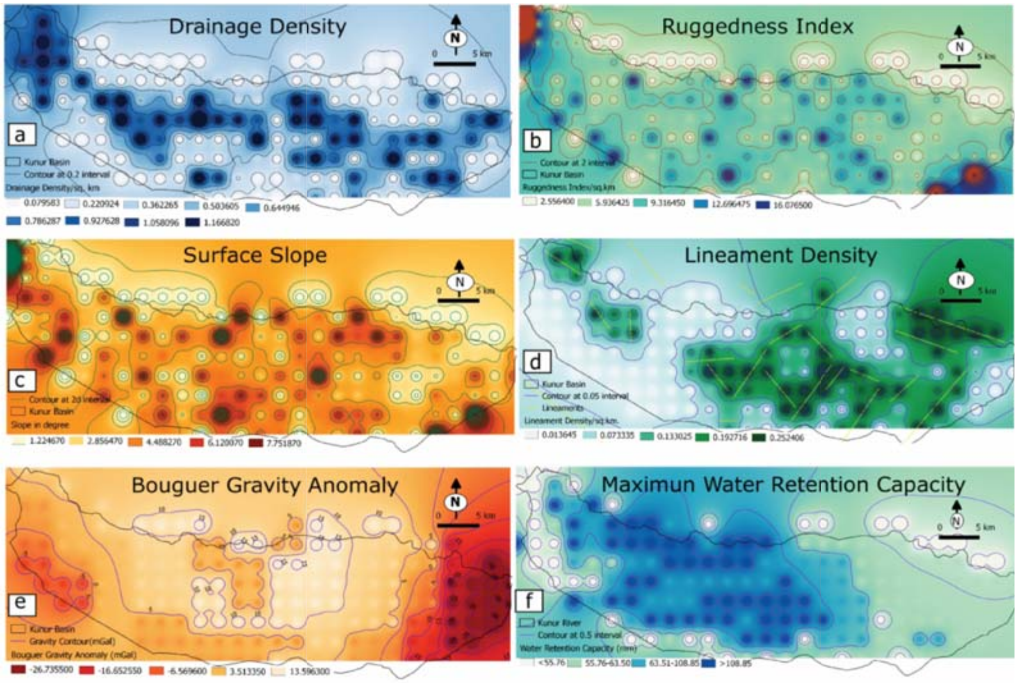

Figure 2 (a-f): Various indices to identify the groundwater recharge potential area over the Kunur river basin

obtained gravity data from geophysical estimation, the Bouguer gravity data is more corrected and is a standard used in geologic interpretation on land (USGS, 1997). According to Verma (1985), any areas underlying by masses with relatively higher density, Bouguer anomalies are reflected as higher gravity and vice-versa. Bouguer anomalies are giving negative values over the elevated region and showing inverse relationship with topography (USGS, 1997). The most important unknown source of gravitational anomaly is the effect of the irregular underground distribution of rocks having different densities. According to Long and Kaufmann (2013), if the gravity anomaly is well defined, the excess or missing mass can be computed directly from the gravity data.

Spacing of contour lines over the chorochromatic map of Bouguer gravity anomaly shows the sharp variation of gravity over the KRB with a range of -35 mGal to +15 mGal (Figure 2e). In the study area minimum value of gravity (-35 mGal) has been observed over the extreme eastern part of the basin with a concentrated elliptical depression near the confluence zone with Ajay river. Geophysically, the downstream area is consisting with low density rock, mainly young to old alluvium. According to Dobrin (1976), the average density of alluvium is varies from 1.50 g/cm^3 to 2.0 g/cm^3. In the downstream area spacing of contour lines of Bouguer gravity are showing a very rapid fall of underlying rock density, within the distance of ten kilometers gravity falls from +10 mGal to -30 mGal. Maximum gravity is found over the middle of the basin, which suggested that in this part underlying rock consist with heavy dense. Lithological condition of this track has been revealed from the panel diagram based on the 12 exploratory boreholes (Figure 3). Depth of the bed rock is increased rapidly towards the downstream of the Kunur river and percentage of granular material also increased towards the downstream, particularly at 'Tikuri' (87.78581E; 23.54674N) 86.50 per cent of layer constructed by sandy material within 185 metres of drilling (Niyogi, 1985).

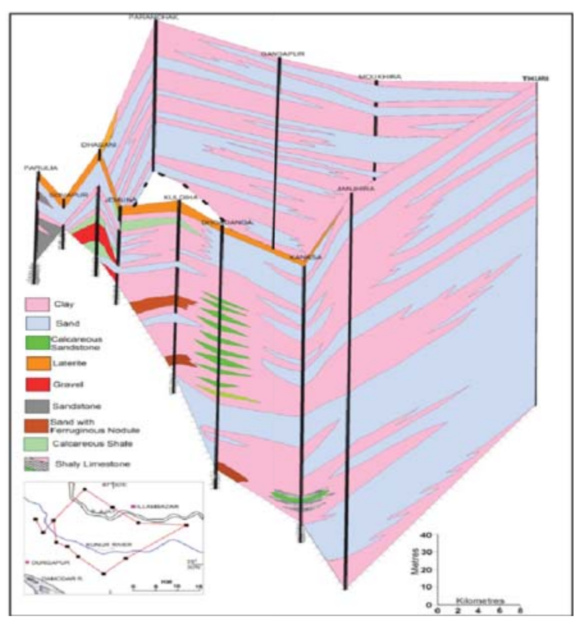

Figure 3: Panel diagram showing the lithological condition in the Interfluve region of Ajay and Kunur rivers (Source: modified of Niyogi, 1985).

3.6 SCS curve number method and groundwater recharge

This widely used hydrological model derived result shows that there is a close relationship between the land cover characteristic and water infiltration capacity on different hydrological soil groups. In the KRB, over the forest dominated area maximum soil retention capacity (>108.85mm) has been identified and the lowest retention capacity (<55.76mm) is observed over the murrum quarrying area in the upper catchment and rapidly expanded urban area i.e. Durgapur Municipal Corporation (Figure 2f). Figure 1b shows most of the basin area is covered by dense sal (shorea robusta) forest (~31.35%) and agricultural land (~41.47%). Sal forests have great influence on hydrological behaviors of any basin area. As per the report of National Institute of Hydrology (NIH), Roorkee (1996-97) if any part of land, cover with sal forest, this area experienced with high water retention capacity and less runoff. They calculated the rate of infiltration in different land cover area (Table 3), where it is clear to notice that in the forested area there is a very high infiltration rate than other. The study has also identified that particularly within the sal forest area 25.30 percent of total rainfall is intercepted by forest cover and there is a low evapotranpiration rate in the sal forest. These entire hydrological characteristic helps to maximum water retention of sub-soil and minimum runoff on that area.

Table 3: Role of land cover type on soil surface infiltration (NIH, 1996-97)

Land use	Infiltration rate (cmhr^{-1})
Forest	26.0
Grassland	12.0
Cropland	09.0
Grazed grassland	5.13
Cultivated land	7.20

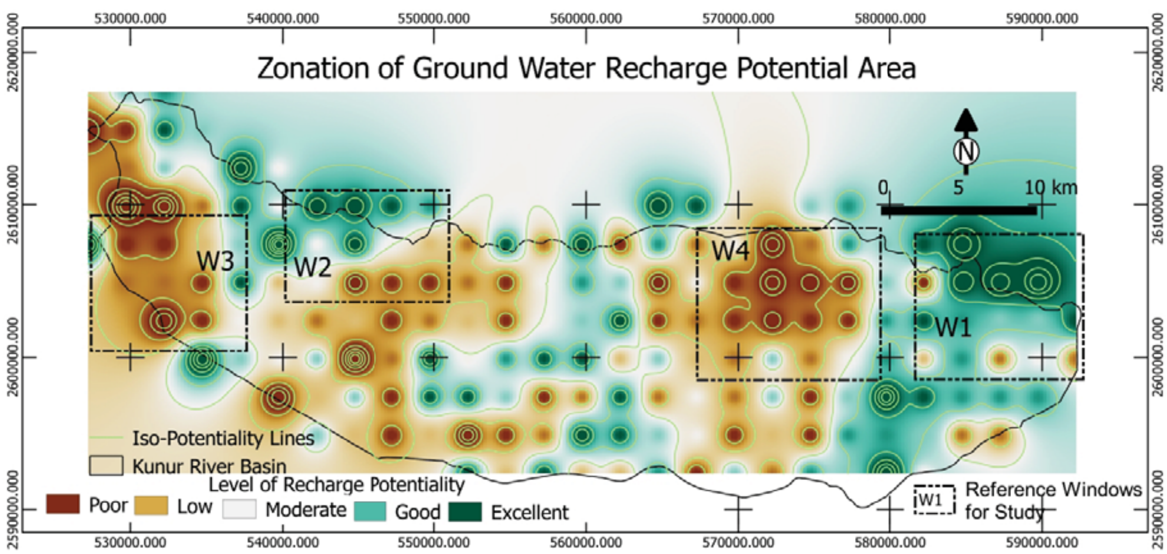

Figure 4: Groundwater recharge potentiality map of the Kunur river basin

3.7 Groundwater recharge potentiality zoning

The fusion derived map shows the regional variability of groundwater recharge potentiality over the KRB (Figure 4). Four windows (W_{1-4}) have been selected for the better understanding of causes behind the present scenario. Five potential zones have been categorized for the KRB, where excellent zones for groundwater recharge have been found only over the northeast part of the downstream area and northern part of upper catchment area. The major causes behind the development of excellent zone for groundwater recharge in the northeastern part of lower basin area (Window I in Figure 4) is presence of series of palaeochannels within the interfluve of Ajay and Kunur rivers (Figure 5a).

Landsat ETM+ images have been used to identify the location of palaeochannels with the band combination of 574 (Figure 5a). This combination involves no visible bands. It provides the best atmospheric penetration and have better absorption rate in water body. It may be used to find textural and moisture characteristics of soils. During field survey near Guskara (87.73952E; 23.49121N), a scratch of palaeo channel has been identified over the floodplain area of Ajay-Kunur Interfluve region (Window I; Figure 5a-inset). Palaeochannels are the one of the excellent option over the earth surface to refill the groundwater for its very high infiltration capacity and working as sub-surface pathways and processes related to groundwater transportation (Kolker et al., 2013). Due to its important for groundwater recharge, a comprehensive development of palaeohydrology in India has also been observed from the recent works on palaeo discharge estimation (Sridhar et al., 2013), palaeochannel mapping (Zankhna and Thakkar, 2014), and reconstruction of palaeochannel morphology with palaeo hydrological attributes (Khan and Tewari, 2013). Samadder et al. (2011) have been mapped the location of palaeochannels over the western Ganga plains to detect the potential zone of artificial groundwater research. Another zone of excellent capacity for groundwater recharge in KRB is developed in the northern part of upper basin area (Window II; Figure 5b) due to the presence of dense sal forest cover and its higher infiltration capacity (26.0 cmhr¯1) with high rainwater intercepted capacity (25.30%). Over the basin a very sharp relation between forest cover and groundwater recharge capacity has been observed. Similar to the Window II, the zones for moderate to good recharge capacity over the middle basin area is the result of dense to open sal forest cover.

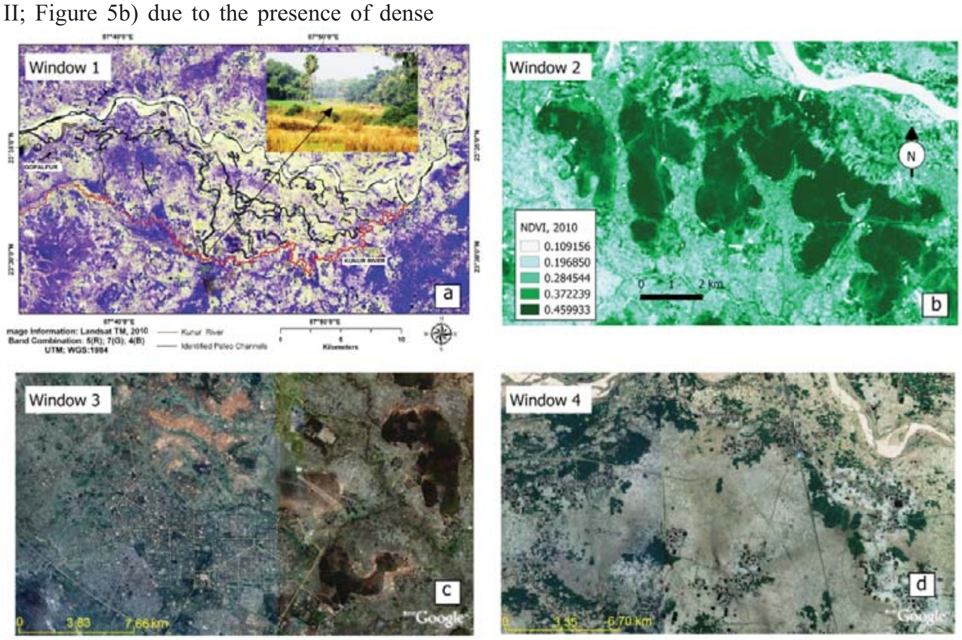

Figure 5: Selected windows for case studies (a) represents the most potential zone for groundwater recharge due to presence of numerous palaeochannels; (b) shows another excellent zone for groundwater recharge due to dense and healthy sal (shorea robusta) forest cover with high NDVI values; (c) shows the extended urban area (DMC) acting as a impervious land for recharge; and (d) is the zone of intensive agricultural field of paddy cultivation and poor zone for groundwater recharge

Major portion of the basin comes under the poor to low category zone due to the alternative causes of natural and human induced. Tow windows are identified as poorest area for groundwater recharge (Window III and IV in Figure 4). Window III shows the area of Durgapur Municipal Corporation (DMC) and its rapid rate of urbanization and increasing impervious area are the major causes for low infiltration capacity (Figure 5c). Causes behind the Window IV (Figure 5d), is extensive agriculture practice and its very low capacity of water infiltration (7.20 $cmhr^{-1}$). Due to the presence of high positive values in Bouguer gravity anomaly in here, density of rock also plays important role to developed poor to low categories recharge zone (Figure 2e).

3.8 Model validation

To calibrates the obtained result from the above analysis, twenty four observed wells wise groundwater depth data for the pre-monsoon and post-monsoon of the last decade (2000-2010), have been used to calculate the level of seasonal fluctuation of water table over the basin (Figure 6). In order to generate a water table map, the average depths to water level data of pre-monsoon and post-monsoon dates for last eleven years (2000 to 2010) have been interpolated using the kriging method. According to Saraf and Choudhury (1998), the seasonal fluctuation of the water table is directly related to groundwater recharge. Subtraction of the pre-monsoon water table from the post-monsoon water table image yields a water level fluctuation scenario. Maximum fluctuation (-3.5m to -4.0m) has been observed over the zone of W1 and W2 and in the middle of the basin, which are also demarked as having excellent potentiality to groundwater recharge in figure 4. Iso-fluctuation lines of this area are showing that post-monsoon depth of groundwater table (bgl) has raise up to 3.5m to 4.0m from the pre-monsoon level. As monsoon-fed rainfall is the major source of recharge in this region, maximum infiltration of rainwater in these zones promote to achieve this development of groundwater level in the KRB. Once again, the identified poor zones for groundwater recharge (W3 and W4) experienced with very low seasonal groundwater table fluctuation (<2.0m) due to the extensive impervious land cover within the window 3 and agricultural field over the window 4. Overall, the relationship between figure 4 and figure 6 defines the acceptable success of this work on the potential groundwater recharge zone identification.

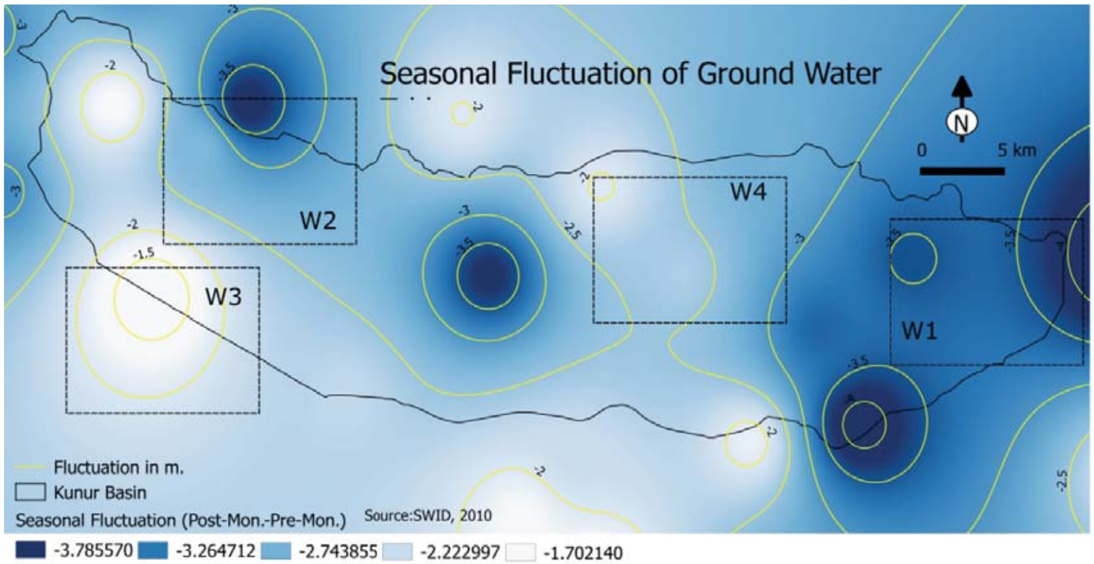

Figure 6: Average seasonal fluctuation [post monsoon ─ pre monsoon] of groundwater table over the Kunur river basin for the last decade (2000-2010), $W_{1\text{-}4}$ showing the reference windows used in recharge potential map

4. Conclusion

In this study, an integrated approach has been applied for the Kunur river basin for assessing the characteristics of groundwater recharge using GIS techniques. The result indicates that the most effective groundwater recharge potential zone is located in downstream and within the forest belt of this basin. Role of forest cover on the development of groundwater table has also been proved here. Negative impact of surface concretization on the development of this valuable natural resource has been found over the DMC. This study has also enabled to integrate four important fields of geosciences to enhance the acceptability of derived result in groundwater research using geoinformatics. Positive role of palaeochannels on groundwater development has been pointed here. Application of Bouguer gravity data and lineament density help to include the effect of sub-surface condition on the rate infiltration from surface water. Overall, this study helps to demarcate those palaces, which area should be preserved as the pathways of refilling groundwater resource for future utilization.

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