Bulletin of Department of Geology, Tribhuvan University, Kathmandu, Nepal, vol. 20-21, 2018, pp. 7-20.

Review on practices and state of the art methods on delineation of ground water potential using GIS and remote sensing

*Champak Babu Silwal[1] and Dinesh Pathak[2]

[1]*Central Campus of Technology, Tribhuvan University, Dharan, Sunsari, Nepal*
[2]*Central Department of Geology, Tribhuvan University, Kathmandu, Nepal*

ABSTRACT

Due to global increase in human population, the groundwater has been extensively used to meet the water demand for domestic as well as agricultural purpose. The number of deep and shallow wells has increased exponentially. For these purpose the groundwater potential area has to be delineated so as to delineate the area for intervention for groundwater abstraction. The determination of groundwater potential with the aquifer characteristics is not always possible due to unavailability of secondary data and from financial aspect. The delineation of groundwater potential with the integration of GIS and Remote Sensing (RS) as well as with the aid of geophysical data could be an effective approach. Groundwater delineation in mountainous region uses different hydrogeologic parameters like rainfall, slope, elevation, drainage density, lineament density, lithology/geology, land use/land cover (LULC), soil, etc., whereas in case of alluvial basins, parameters like aquifer material, soil, LULC, water table, specific yield, storage coefficient, transmissivity, etc. are used. The assignment of weight for the factors and rank for their classes are important steps in the Groundwater Potential Mapping (GPM) using GIS overlay. The weights for the different parameters have to be assigned as per their role in groundwater occurrences. Different methods like Analytical Hierarchy Process (AHP), expert's knowledge, probability weight approach, bivariate analysis, etc. have been used for assigning weights and ranks and the predicted potential need to be validated. Generally in mountainous aquifer, spring inventory forms the basic data for the verification. In addition, the aquifer characteristics like water table, yield, transmissivity can be used for the validation in flat lands. This method of delineation of groundwater potential is found to be appropriate with acceptable accuracy. Globally, there is increasing trend in the use of GIS and Remote Sensing for the identification of groundwater potential in recent time.

Key words: Factor maps, lineament, mountain aquifer, GIS analysis, groundwater potential

Received: 20 May 2018 **Accepted:** 13 June 2018

INTRODUCTION

Groundwater is an extensive, concealed and inaccessible resource and changes in quality and quantity are often very slow processes occurring below the large land areas. These changes cannot be determined directly and immediately. It is generally too late when the damages to the system becomes noticeable. Therefore, the protection and conservation of the resource with sustainable use is the major aspect of the groundwater management. For the management of groundwater resources, assessment of this precious natural resource is most essential part. The delineation of groundwater potential zone is equally important to further develop irrigation system and sustainable utilization of the resource (Pathak 2017). It is very difficult to meet the increasing demand of water supply induced by increasing population and urbanization through the existing usage pattern and resources (Vaux 2011). This implies to many parts of the world where the management of water resource is not under consideration and protection. In the present scenario of scarcity of water, the area potential to groundwater, should be identified and well assessed by means of groundwater exploration. As of the groundwater exploration standpoint, the term groundwater potential can be defined as the possibility of groundwater occurrence in the area (Jha et al. 2010). Groundwater availability in an area is indicated by the geology, geomorphology and structural set-up of that area. Delineation of groundwater potential zones with the help of drilling, hydrogeological, geological and geophysical methods is expensive and time consuming and also demands the involvement of experienced people (Fetter 1994). Geospatial technology is a rapid and cost-effective tool in producing valuable data on geology, geomorphology, lineaments slope, etc. that helps in deciphering groundwater potential zone. A systematic integration of these data with follow-up of hydrogeological investigation provides rapid and cost effective delineation of the groundwater potential zones. Geographic Information System (GIS) has the ability to easily and effectively handle huge amount of spatial data, which can be used in various environmental studies including water resources. It has been realized that delineation of groundwater potential zones by using GIS is convenient and time saving as large number of data can be handled in the GIS (Pathak 2017). GIS has also been applied for processing and interpretation of groundwater quality data (Rao and Jugran 2003). This technique has been used to solve problems related to groundwater by integrating various data. These data, in the form of thematic layers in GIS, are spatially integrated using mathematical and Boolean operators to develop a model depending on the objective of the problems (Mayilvaganan et al. 2011).

*Corresponding author
Email: geologistbabu@gmail.com (C.B. Silwal)

Integration of remote sensing data and GIS for the exploration of groundwater resources has become a breakthrough in the field of groundwater research, which assists in assessing, monitoring, and conserving groundwater resources. Sustainable development and management of groundwater resources necessitates assessment of availability of groundwater, its existing utilization and balance resources for future utilization. Water policy adopted by the nation defines the exploitable quantity of water resources, mostly based on safe yield, sustainable yield and planned depletion approach (Chatterjee and Ray 2014). This article aims to review the various factors responsible for the occurrence of groundwater in mountainous region and plain areas with tools and techniques to acquire required data as well as methods to delineate the groundwater potential in an area. The objective of the study is to review the literatures related to the delineation of groundwater potential using RS and GIS to provide a broader outlook on the topic and integrating the existing knowledge in different parts of the world, so as to apply the method in full efficiency in future. The review is also important to understand the development, present trend and recent progress on the research of groundwater potential using GIS and RS.

MATERIAL AND METHODS

For the reviews of the literatures on the topics, different article published in international and national journals were identified and more than 60 research articles have been collected and around 42 have been critically reviewed. The review generally focus on the area (mountainous or alluvial plain), parameters used for analysis, method for assigning the weightage for different parameters and its validation process.

OVERVIEW

Overview of Groundwater Potential Mapping

Delineating the groundwater potential zones using GIS and RS is an effective tool and is very useful in identifying the potential zone also in the arid to semi-arid region (Murthy 2000; Leblanc et al. 2003; Ganapuramet al. 2009; Abdalla 2012; Al-Abadi and Al-Shamma 2014; Rahmati et al. 2014 etc.). Pathak (2016) stated that establishment of the baseline database for groundwater potential zones has been easier by the extensive use of satellite data along with conventional maps rectified with ground truth data. Using remote sensing data provides a wide range scale of the space-time distribution of observations and also save time and money (Murthy 2000). In addition, it is widely used to characterize the earth surface (such as lineaments, drainage patterns and lithology) as well as to examine the groundwater recharge zones (Sener et al. 2005). Applications of GIS and RS for the exploration of groundwater potential zones are carried out by a number of researchers around the world, the factors involved in determining the groundwater potential zones are different according to the geographical regions, and hence the results vary accordingly (Teeuw 1995; Krishnamurthy et al. 1996; Tiwari and Rai 1996; Das et al. 1997; Thomas et al. 1999; Pratap et al. 2000; Murthy 2000; Sahid et al. 2000; Jaiswal et al. 2003; Leblanc et al. 2003; Rao and Jugran 2003; Sener et al. 2005; Yeh et al. 2009; Ganapuram et al. 2009; Varade et al. 2011; Mayilvaganan et al. 2011; Magesh et al. 2012; Abdalla 2012; Bera and Bandyopadhyay 2012; Manap et al. 2013; Suganthi et al. 2013; Al-Abadi and Al-Shamma 2014; Rahmati et al. 2014; Naveenkumar et al. 2015; Pathak and Shrestha 2016; Bashe 2017; Hussein et al. 2017; Pathak 2017 and Saha 2017).)

International practice

Rahmati et al. (2014) integrated Analytical Hierarchy Process (AHP), GIS and RS technique for mapping groundwater potential at Kurdistan region of Iran. In the study, different thematic layers like rainfall, lithology, drainage density, lineament density and slope percent has been used. The weight for the thematic layers were assigned by eigen vector technique. In the study, rainfall gained the maximum weight, whereas slope percent gained the minimum weight. The validation was done using Receiver Operating Curve (ROC) and found to be fairly good prediction (73.66%). The study concluded that accurate knowledge on the resources can be obtained from geospatial data analysis in the area suffering scarcity of data. Bashe (2017) used RS and GIS for groundwater potential mapping in Rift Valley lakes basin of Weito sub basin, Ethiopia. The author used the thematic layers like rainfall, land use, slope, soil, lithology, drainage, lineaments and geomorphic features. Land use and lineaments were extracted from the Landsat 8 OLI/TIRS multispectral images. The weights for the factors were assigned using AHP. The author suggests to use remotely sensed data of higher spatial and spectral resolution for the development of more realistic potential map. Manap et al. (2013) for the first time, used knowledge driven expert based GIS modelling for ground water potential mapping at the Upper Langat Basin in Malaysia. Nine dependent factors such as lithology, slope, lineament, land use, soil, rainfall, drainage density, elevation and geomorphology were considered as factor maps. The weightage for lineament density, lithology, rainfall and geomorphology were assigned high whereas soil, drainage density and landuse has been assigned minimum. The potential map was analysed for validation with 76% prediction accuracy using the data of bore wells. In the study, statistical analysis indicated that potential in hard rock is governed by secondary porosity like lineaments and lineament density. The area having very high potential includes the flat land, very low drainage density and high lineament density.

Al-Abadi and Al-Shamma (2014) used AHP and GIS for groundwater potential mapping of the major aquifer in Northeast Missan Governorate, South Iraq. Due to scarcity of data, only four groundwater dependent factors such as geological setting, geomorphological features, soil and hydrogeological setting were used. The potential map was verified using the available abstraction rate of existing wells and found the prediction accuracy of 72%.

Abdalla (2012) used RS and GIS for mapping groundwater prospective zones in Central Eastern Desert, Egypt. The parameters for the indication of groundwater potential such as slope, stream networks, lineaments, lithology and topography were used. The wadi filling and Quaternary deposit and also the Precambrian basement rocks were identified as very good prospecting zones and the steeply sloping hilly terrain of limestone and younger hard rocks were recognized as moderately to poor prospecting zones. The potential map (Fig. 1) and factor maps (Fig. 2) when compared shows very high potential zone has a strong impression of low topography and low slope angle. The control of wadi fill on groundwater potential can be visualized when compared with lithological map (Figs. 2e and 2f). The potential map has been verified with respect to the existing well clusters revealing that most of the wells are located in very good to moderate potential zone.

Practices in south Asia

There is the increasing trend of using RS and GIS for the delineation of groundwater potential and other groundwater related issues mainly in India and other south Asian countries. The National Remote Sensing Agency in India was the first to integrate information from remote sensing and GIS for delineating the groundwater recharge potential zone in India at 1987. Krishnamurthy et al. (1996) used Geographical Information System to demarcate groundwater potential zones of Marudaiyar basin using different thematic maps such as lithology, landforms, lineaments, surface water bodies, drainage density, slope classes and soil map. The authors compared the potential map with the bore well yield data collected in the field that showed a good agreement between the two, thus validating the potential map. They concluded that the GIS based ground water demarcation developed in their work was built with the relevant logical conditions and reasoning, hence the same method can be used with appropriate modifications elsewhere. Jaiswal et al. (2003) studied the role of remote sensing and GIS for generation of groundwater potential zone for rural development. The thematic layers on lithology, geological structures, landforms, land use/land cover were extracted from remotely sensed data, while drainage networks, soil characteristics and slope of the terrain were extracted using conventional methods. These thematic layers were then integrated into the GIS environment to depict village-wise groundwater prospect zones.

Ganapuram et al. (2009) used RS data and GIS for mapping of groundwater potential in the Musi basin of Andhra Pradesh (India) which is regarded as the most important agricultural production centre in the state with fast growing population and increasing urbanization. Various factor maps like base map, hydrogeomorphological, geological, structural, drainage, slope and land use/land cover were used for preparing potential map. The hydrogeomorphological units such as flood plain, valley fill and deeply buried pediplain are prospective zones

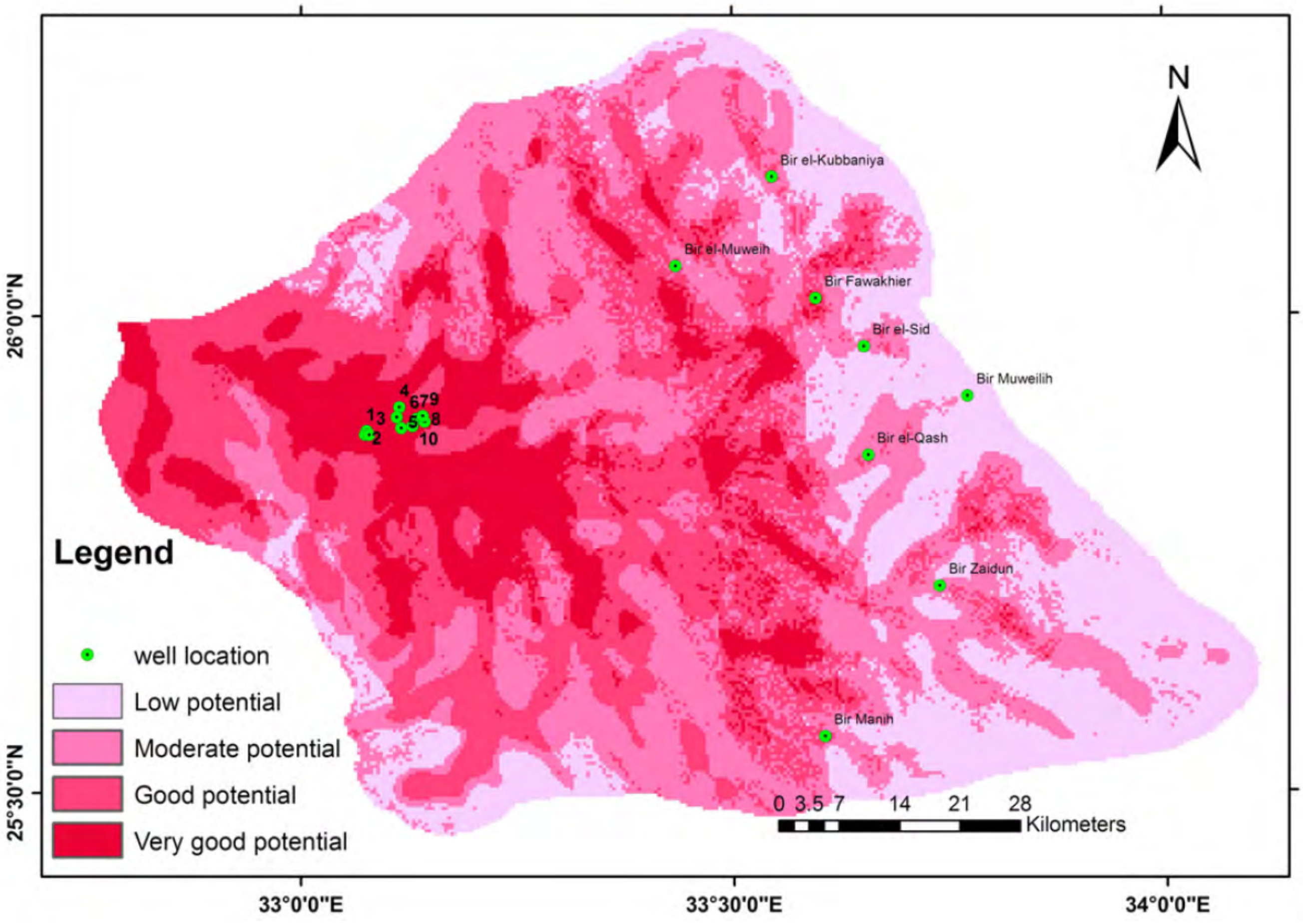

Fig. 1: Groundwater potential map of central eastern desert, Egypt (Abdalla 2012).

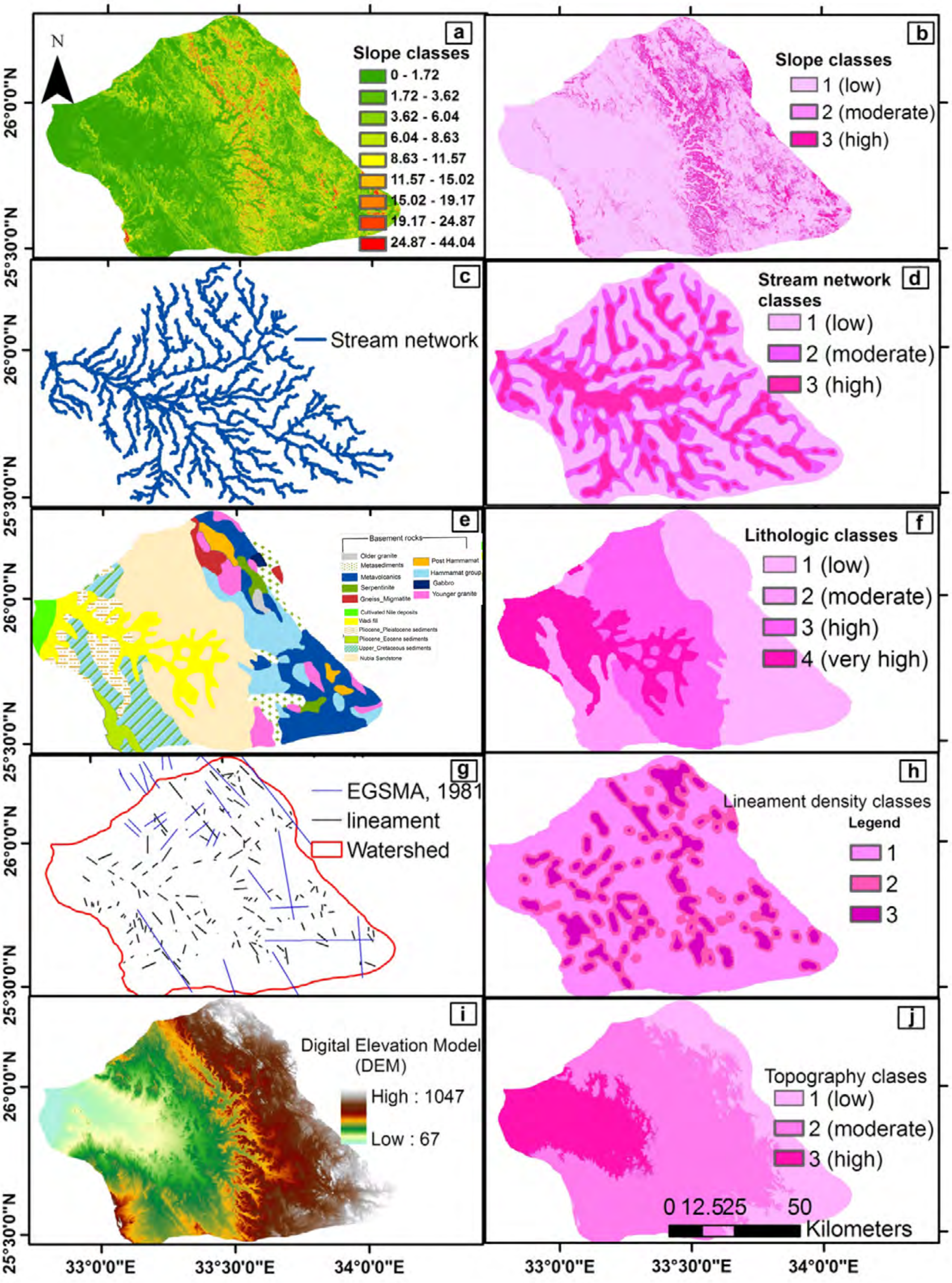

Fig. 2: Thematic maps (a). slope map derived from SRTM, (b). slope classes map, (c). stream network map, (d). stream density map, (e). simplified geology map modified after EGSMA (1981), (f). geologic map assigned weight factor depending on capability for holding water, (g). lineament map, (h). lineament density map, (i). Digital Elevation Model of the study area and (j). DEM classified map assigned weight factor depending on water infiltration (Abdalla 2012).

for groundwater exploration and development in the study area whereas the presence of faults and lineaments enhances the potential of the units. RS and GIS has been used for groundwater prospect zoning also in Ranebannur Taluk, Karnataka, India (Shivakumar et al. 2011). The study aimed at investigating the role of landforms and lineaments for the occurrence of groundwater availability. The thematic layers of geology, geomorphology, soil and land use/land cover were used as an indicator for the occurrence of groundwater. The validation was done using the well discharge data of hand pump in the area. They further suggest that, in hard rock terrain lineaments are very important for high yield as compared to medium yield from weathered rock.

Mayilvaganan et al. (2011) used RS and GIS for the delineation of groundwater potential on Thurinjapuram block of Thiruvannamalai District of Tamilnadu, India. The study incorporated the thematic layers such as lithology, geomorphology, drainage, soil, lineaments, land use and surface waterbody extracted from the satellite imageries and soil and drainage maps were digitized from published map. The potential map was validated using the groundwater depth data collected from other sources. Geomorphological map when compared with groundwater potential shows good control on groundwater occurrences showing good groundwater potential in the shallow buried pediplain (Fig. 3). Varade et al. (2011) used the integrated approach using RS and GIS for assessment of groundwater potential in Chandrapur and Gadchiroli district of Maharashtra, India. Different weight were assigned for the thematic layers like lithology, geomorphology, lineaments and land use/land cover as per their characteristics and the result was validated in the field as well. The inventory map revealed that the potential map thus prepared exhibit a good correlation with one another.

Bera and Bandyopadhyay (2012) used RS and GIS for mapping groundwater potential in Dulung watershed, West Bengal, India. Satellite data, other data set, existing maps and field observation data were utilized to extract information on the hydrogeomorphic features of the watershed. Six dependent factors such as drainage, land use/land cover, soil, rainfall, geology/geomorphology and slope steepness were used for the analysis. The probability weightage approach has been applied for assigning the weightage for the factors.

Saha (2017) used Analytical Hierarchy Process (AHP) for the groundwater potential mapping on Md. Bazar Block of

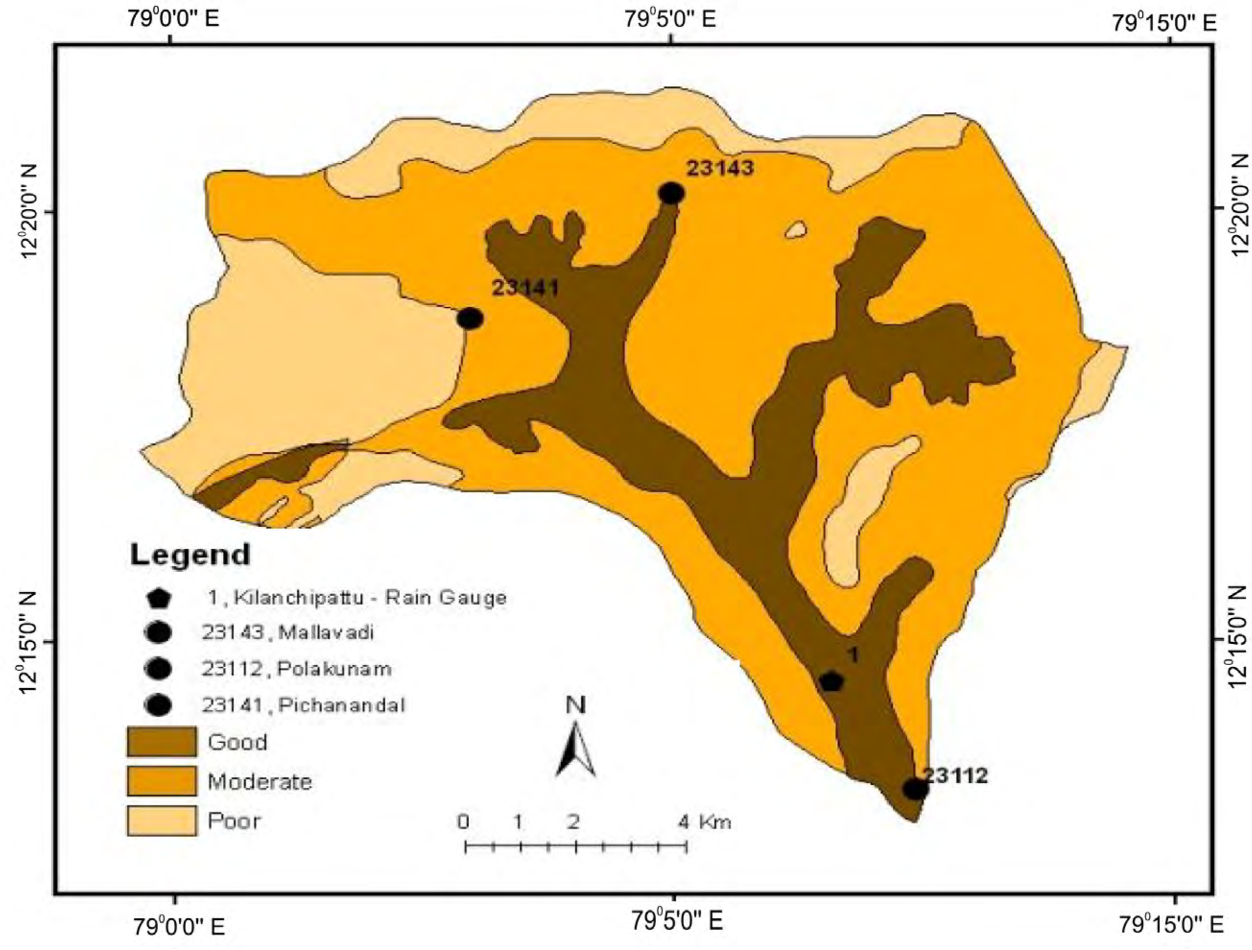

Fig. 3: Groundwater potential map validated with water table (Mayilvaganan et al. 2011).

Birbhum District, west Bengal. Thematic layers like geology, soil texture, elevation, land use/land cover, slope, rainfall, lineament density, drainage density, stream junction frequency, pond density, geomorphology and topographic wetness index were used. The lithology, hydrogeomorphology, drainage and lineaments were extracted from Landsat-8 image and ASTER DEM was used. The weightage for the different factors are assigned using expert knowledge on the AHP. The output map shows very low groundwater potential in the area of high slope, high drainage density and impermeable rocks. The validation was done statistically using Receiver Operating Curve (ROC) as well as comparing the groundwater depth data collected from different sources. In these studies, the commonly used thematic layers are lithology, geomorphology, drainage pattern, lineament density, soil and topographic slope. The majority of the studies focus on hard-rock terrains of India.

Nepalese context

Groundwater potential mapping works are very few in the Nepalese case and hence the publications are limited. The increasing trend in the use of GIS and RS and the growing number of professionals using this technique for groundwater potential assessment indicates that there will be more publications in Nepal in the coming days.

Pathak (2016) conducted the study on water availability and hydrogeological condition in siwalik foothill of east Nepal. In the study the author used geological and hydrogeological data to delineate the groundwater potential. Multispectral satellite image was used in the study to generate different data like recharge zone, settlement distribution, river morphology, source and availability of water and terrain characteristics. Factors like drainage and land use/land cover were extracted from topographical maps. Digital database of the collected data was prepared in GIS and relevant maps were prepared. Pathak and Shrestha (2016) prepared groundwater potential map in the mountainous area of Melamchi watershed in Sindhupalchowk District (Fig. 4), through overlay analysis in GIS assigning the weight and ranks for different thematic layers such as lithology, drainage density, land use/land cover, lineament density, slope, and precipitation along with their respective classes (Table 1). The different thematic layers were then combined and classified to produce the groundwater potential map. Most of the springs fall in the moderate and high potential classes. The authors concluded that the mapping method can be useful at the watershed/basin level study in the mountainous area of Nepal Himalaya. Similarly, Pathak (2017) used GIS to delineate groundwater potential zones in the Indo-Gangetic Plain of Rupandehi district by using the primary and secondary data. The GIS database was prepared with the well location and aquifer characteristics for shallow tube wells. The aquifer lying within the depth of 25m below ground level

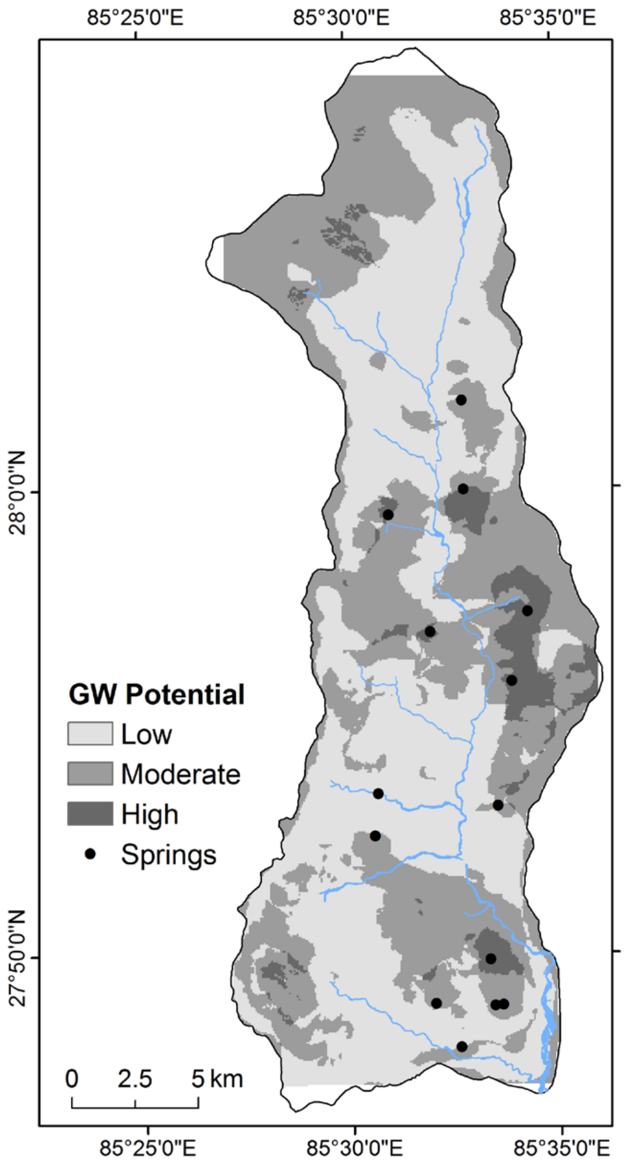

Fig. 4: Groundwater potential map of the Melamchi watershed (Pathak and Shrestha 2016).

was considered as shallow aquifer. The thematic layers like percentage of aquifer material, yield and water table data were used to prepare groundwater potential map (Fig. 5). The author also discussed the importance of thickness of aquifer material, well yield, hydraulic conductivity, water table for delineating the groundwater potential in the Indo-Gangetic Plain. However, in case if all these parameters are not available, the analysis performed with the thickness of aquifer material and yield of the well are fairly acceptable. The method adopted for Rupandehi district can be applied in other parts of the country, which would better serve for effective development planning and providing irrigation service to the farmers. The author emphasizes on the preparation of GIS database consisting of lithologic and hydrogeologic parameters as far as available for the preparation of more realistic groundwater potential map.

Table 1: Weight and rank assigned to different thematic layers (Pathak and Shrestha 2016).

S.N.	Parameters	Classes	Weight	Rank
1	Geology	Himal Group	10	3
		Gneiss		2
		Maksang and Siprin Khola Fm		1
2	Drainage Density	Low	5	3
		Moderate		2
		High		1
3	Lineament Density	Low	30	1
		Moderate		2
		High		3
4	Slope	Gentle (0-10°)	30	3
		Moderate (10-35°)		2
		Steep (>35°)		1
5	Land Use	Cultivation	10	3
		Forest		2
		Bush		2
		Grass		2
		Barren Land		1
		Water Body		3
6	Precipitation	Low	15	1
		Moderate		2
		High		3
		Total	100	

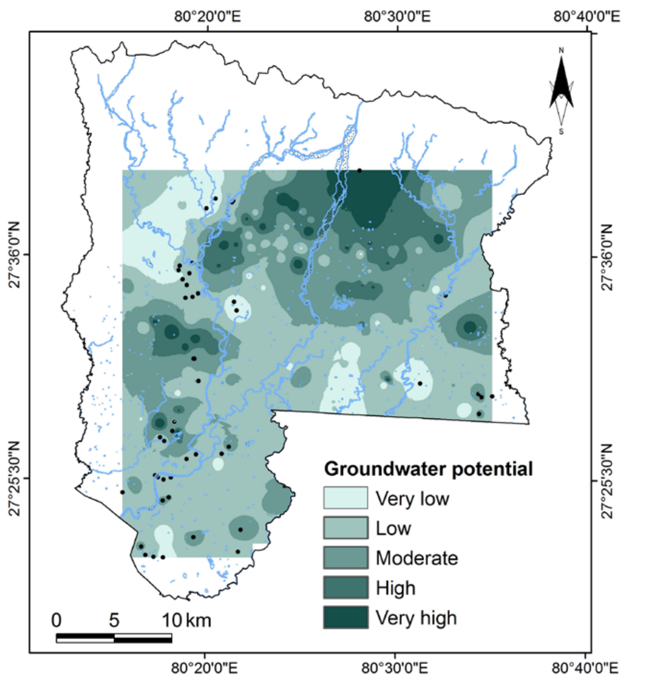

Fig. 5: Shallow groundwater potential map of Rupandehi District (Pathak 2017).

METHODOLOGY

Data Extraction from Remote Sensing to form GIS Database

In the mountainous area, the occurrence of groundwater is controlled by rock type, lineaments, topographical features and landforms as revealed from various studies. Use of Remote Sensing and GIS technology is very useful for the preparation of groundwater prospective areas mapping and to implement groundwater management plan on a scientific basis. Remote sensing provides data with various options of spatial, radiometric and temporal resolution that saves great time, efforts and resources in collecting data from the field. Remote sensing can effectively identify the characteristics of the surface of the earth (such as lineaments and geology) and can also be used to examine groundwater recharge (Sener et al. 2005). GIS is used to manage, utilize, and classify the results through the extraction of relevant information from remote sensing data to explore sites, combine the factors of groundwater recharge potential, and to provide appropriate weight relationships (Yeh et al. 2009).

Methods to Analyse the Data for Groundwater Potential Mapping

The type and number of themes used for the assessment of groundwater resources by geoinformatics techniques varies considerably from one study area to another. In most studies, local experience has been used for assigning weights to different thematic layers and their features depending upon the geology, terrain characteristics and climatic condition. The methodology proposed in the literatures (Krishnamurthy and Srinivas 1995, Krishnamurthy et al. 1996, Saraf and Choudhury 1998, Sahid et al. 2000, Jaiswal et al. 2003, Rao and Jugran 2003, Sikdar et al. 2004, Sener et al. 2005, Ganapuram et al. 2009, Yeh et al. 2009, Manap et al. 2013, Al-Abadi and Al-Shamma 2014, and Pathak and Shrestha 2016) to demarcate groundwater potential zone of an area is illustrated in Fig. 6. Selected thematic maps from different sources such as remote sensing data, geophysical data, and conventional data are integrated in the GIS environment to generate Groundwater Potential Index (GWPI).

Analytical hierarchy process (AHP) method

Analytical Hierarchy Process (AHP) proposed by Saaty (1990) is the frequently used method for groundwater potential mapping. It provides a flexible and easily understandable way of analysis of complicated problems. It is a multiple criteria decision making technique that allows subjective as well as objective features to be considered in decision making process (Al-Abadi and Al-Shamma 2014). AHP is the theory of measurement using pair-wise comparisons and depends on the judgment of experts to rank the factors. The comparisons are made using a scale of absolute judgments that represents, how much more, one element dominates another with respect to a given attribute. The comparison can be done using a

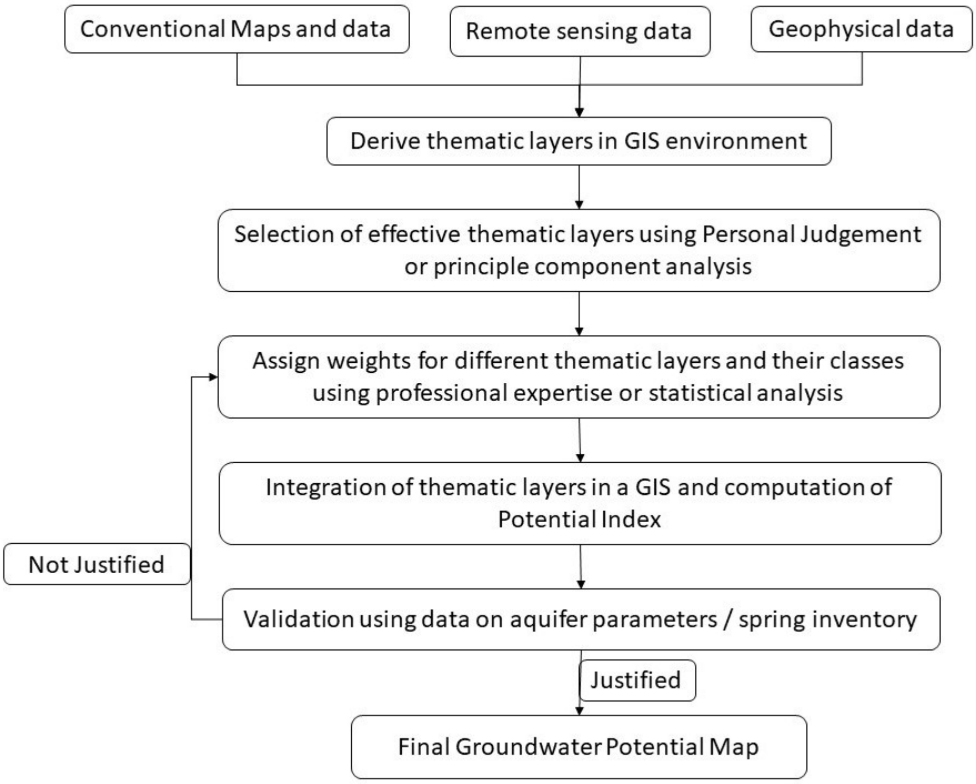

Fig. 6: Methodological flow chart for groundwater potential mapping.

comparison matrix of n by n order, of which n is the number of parameters to be compared. The scaling from 1 to 9 is used, in which 1 determines least favored and 9 indicates extremely favored, whereas for unfavorable factor reciprocal scale is assigned. From the matrix, the priority vector calculated, which is called normalized eigen vector. Each element of the matrix is divided by the column total to get normalized relative weight vector, the column sum of which is equal to 1. The row average of the matrix gives the normalized principle eigen vector also called priority vector. For checking the consistency of assigned weight, the principal eigen value (λ_{max}) is obtained from the summation of products between each element of eigen vector and the sum of columns of the comparison matrix.

The Consistency Index C.I.=(λ_{max}-n)/(n-1) and the Random Consistency Index, R.I. (theoretical value, which depends on the number of parameters under comparison) are compared to calculate the Consistency Ratio C.R.=C.I./R.I. whose value determines the acceptability of inconsistency (Fig. 7). The value less than 10% is considered as acceptable inconsistency. The advantage AHP over other method is that the statistical analysis for the consistency of weightage assigned can be measured and corrected when necessary.

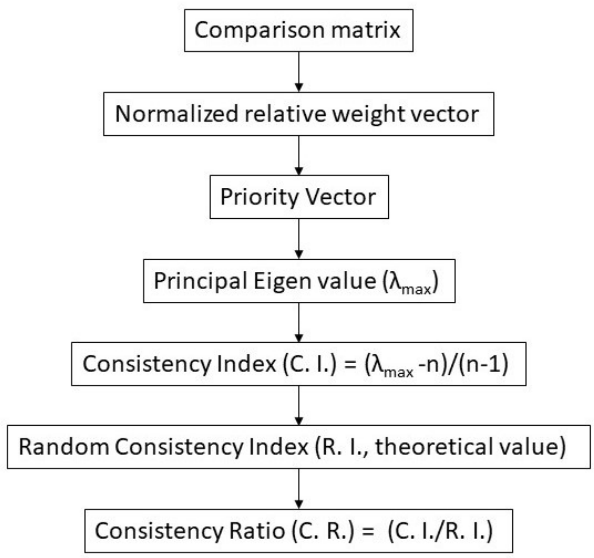

Fig. 7: Flowchart for the analysis of consistency ratio for assigned weight in AHP.

Weighted overlay method

Weighted overlay method has also been used in which the weights are given for each individual factors and ratings to the classes of each factors according to the Multi Influencing Factor (MIF) of that particular feature on the hydrogeological environment of the area. An example of assigning the weights and rating for the watershed in Nepal Himalaya is presented in Table 1. The weights for factor map and rating for the individual classes should be reviewed with respect to the physiographic region, watershed condition and the climatic factor. These values could be different in the watershed belonging to the Siwalik region and that in the Lesser Himalayan region.

Selection of Factors for Groundwater Potential Mapping in Mountainous Area

There are several difficulties in developing groundwater resources in mountainous area consisting of hard rock aquifer. Groundwater regime is characterized by wide and differing variations of aquifer parameters. Spatial variation of these parameters also adds up with the tectonic set-up and degree of weathering of near surface rocks. The tectonic set-up and weathering directly or indirectly influence the secondary porosity in the hard rock. As a result, the groundwater potential also varies spatially, sometimes within a few meters even within the same indicating factors. Low rainfall, high evaporation and run-off limit recharge to the groundwater systems (Rangarajan and Athavale 2000). The various factors responsible for the occurrence of groundwater is described briefly below:

Rainfall

Rainfall also called precipitation is very important part of the water cycle, which circulates the water from low lands to the highlands. Rainfall is a most important hydrological factor and duration and magnitude of the rainfall are the main determinants of groundwater recharge. Adiat et al. (2012) proved that the rainfall has a significant effect on percolation and GPM accuracy. Low rainfall, high evaporation and run-off limit recharge to the groundwater systems (Rangarajan and Athavale 2000). Generally, more the rainfall, higher is the groundwater potential of the area. Data on rainfall can be collected from the meteorological stations in and nearby the study area.

Geology and drainage pattern

Drainage pattern is one of the most important indicators of hydrogeological features. Drainage pattern, texture and density are controlled in a fundamental way by the underlying lithology. In addition, the creek pattern is a reflection of the rate that precipitation infiltrates compared to the surface runoff. The infiltration-runoff relationship is controlled largely by permeability, which is in turn, a function of the rock type and fracturing of the underlying rock or bedrock surface. The alluvial, lacustrine and aeolian sediments also have their own properties that controls the groundwater.

Geological structures

Secondary geological structures enhance the secondary porosity as well as permeability which directly influence the infiltration, thus controlling the groundwater. The foliation/ bedding plane also act as the passage for water into the surface. The joints, faults, thrusts, fold axis, etc. is known to influence the groundwater.

Drainage density

Drainage density can be defined as the ratio of total length of the stream and river in the drainage basin and total area of the drainage basin. It is the measure of how a drainage basin is drained by stream channel. The low drainage density is the reflection of high infiltration in groundwater system. An area of high drainage density increases surface runoff compared to a low drainage density area. Thus the area with low drainage density has the higher probability of groundwater recharge and higher potential for groundwater (Prasad et al. 2008).

Land use/land cover (LULC)

Land use is the description of how the land is being used by the people with respect to its suitability for particular use, whereas land cover is the description of physical material that covers the earth's surface irrespective of its suitability for specific use. Land use gives the better indication about the potentiality of groundwater as water availability is the major factor that determines the land use pattern. In addition, surface water bodies, like rivers, ponds, etc., can act as recharge zones, enhancing the groundwater potential in the neighborhood. Vegetation cover benefits groundwater recharge by loosening the top soil, prevents direct evaporation of water and sometimes prevent water loss by absorbing the water by roots. Paul (2006) assessed the impact of land use pattern on groundwater recharge and discharge. In his study, the author interestingly concludes that many areas are in the verge of desertification due to over abstraction of water for agricultural use. Land cover determines the amount of water for infiltration. Highly permeable land cover favors the groundwater potential whereas low permeable land cover increases runoff thus limiting the percolation to subsurface. The data on land use/ land cover can be extracted from satellite images (Fig. 8) and published topographic map (Choudhary and Pathak 2016).

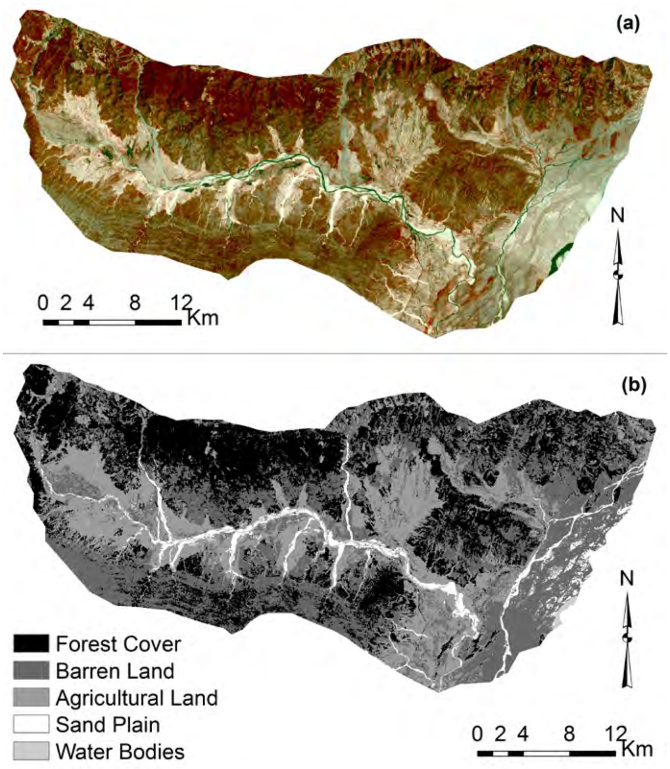

Fig. 8: (a) Satellite image and (b) Land use/land cover map of the Trijuga Watershed (Choudhary and Pathak 2016).

Geomorphology

Geomorphology reflects various landforms and structural features, many of which favor the occurrence of groundwater. The different units of geomorphological features can be extracted from remote sensing data (Prasad et al. 2008 and Saha 2017). Geomorphology of an area determines the runoff, flooding, groundwater recharge and rainfall to some extent. The topography of the area also determines the occurrence of groundwater. Different geomorphic features like hill and hill slopes, river valley, terraces, piedmont zones (fan and flood plain), river bed and plain area are important from groundwater perspective (e.g. Pathak 2016). Valley fill and moderately weathered pediplain has high ranking followed by shallow weathered pediplain, whereas the denudational hills, residual hills and rocky pediment has the least ranking (Prasad et al. 2008).

Slope

Slope is one of the important parameters that strongly determine the ground water recharge process (Prasad et al. 2008). Gentle slope reduces the velocity of surface runoff, thus increasing the time for infiltration into the ground. Steep slope does not allow water to percolate into the ground. Therefore, spatial analysis of slope is essential for the prediction of groundwater availability (Fig. 9).

Lineaments

Lineaments are linear expression of discontinuities on earth's surface such as, fault, cleavage, fractures, surface discontinuity and dykes. These features can be mapped at various scales from local to regional and can be utilized in mineral, oil and gas, and groundwater exploration studies. Lineaments are an important structural characteristic of the earth's surface that controls the movement of water between surface and subsurface and are of great relevance to the storage. Lineaments play significant role in groundwater exploration particularly in hard rock terrain (Bahuguna et al. 2003). The lineaments can be identified through the interpretation of the satellite imageries and aerial photographs as shown in Fig. 10 (Pathak and Shrestha 2016).

Areas with high lineament density infer high secondary porosity thus is referred as better groundwater potential zones. Lineaments have been used as the indicator for the potentiality of groundwater in mountainous terrain, therefore, characterization of the lineament becomes essential to ensure the possibility of locating potential groundwater zones. Lineament mapping has also been used with high accuracy to guide a drilling site for groundwater exploration (Teeuw 1995).

Soil

Soil is the disintegrated part of the rocks. It is also a complex biogeochemical material on which plant may grow. Information on the soil is important for the hydrologic evaluation. The infiltration and runoff relation depends on the soil properties and its texture. It has been observed from the GPM that the soil in alluvial plains (poorly sorted and coarse texture) and the agricultural land (high permeability and porosity) serves positively for the higher groundwater potential zones due to their high rate of infiltration. This indicates that, soil type plays a vital role in groundwater augmentation. The data on soil can be extracted from the remote sensing data (Murthy 2000).

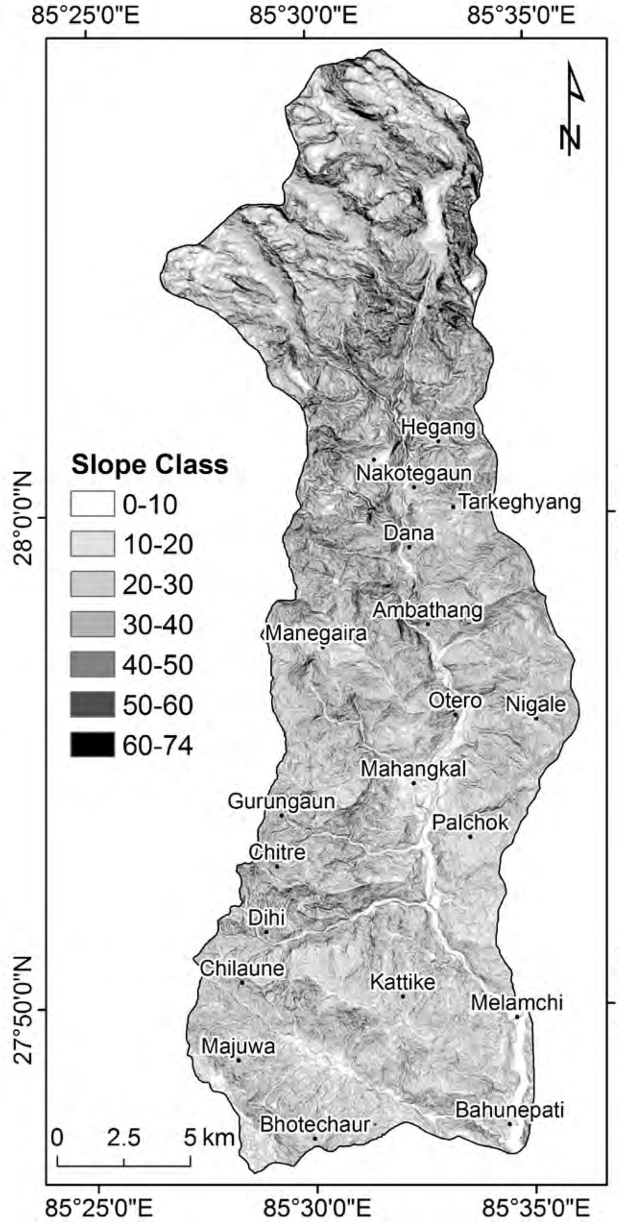

Fig. 9: Slope map (values in degree) of the Melamchi watershed (Pathak and Shrestha 2016).

Topographic wetness index (TWI)

The TWI has been widely used to explain the impact of topography conditions on the location and size of saturated source zones. TWI has been used for the identification of potential groundwater zone, describing spatial wetness patterns (Saha 2017). It is defined by Prasad et al. (2008) as, TWI=(As/tanβ).

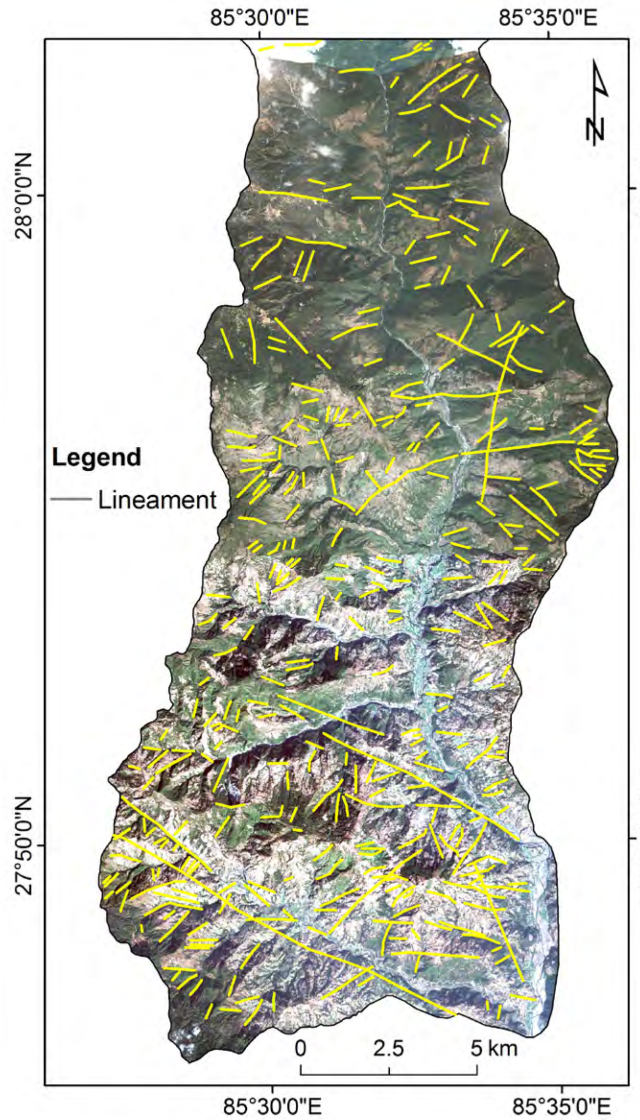

Fig. 10: Lineaments extraction from the satellite image (Pathak and Shrestha 2017).

Where As is the cumulative upslope area draining through a point (per unit contour length) and β is the slope gradient (in degree).

Selection of Factors for Groundwater Potential Mapping in Alluvial Plain/Depositional Basin

Groundwater potential mapping in alluvial plain/depositional basin is different than that of the mountain aquifer. The factors that indicates groundwater in mountain area does not resemble to that in flat land. The major indicators for the groundwater potential in flat land is the land use/land cover, soil map, water table, specific yield, distribution of aquifer materials, distribution of ponds and water bodies and different aquifer characteristics. A systematic and comprehensive tube well database in GIS platform serves better for the groundwater potential delineation purpose. Thicknesses of aquifer material, well yield, hydraulic conductivity, water table are some of the decisive parameters for delineating the groundwater potential

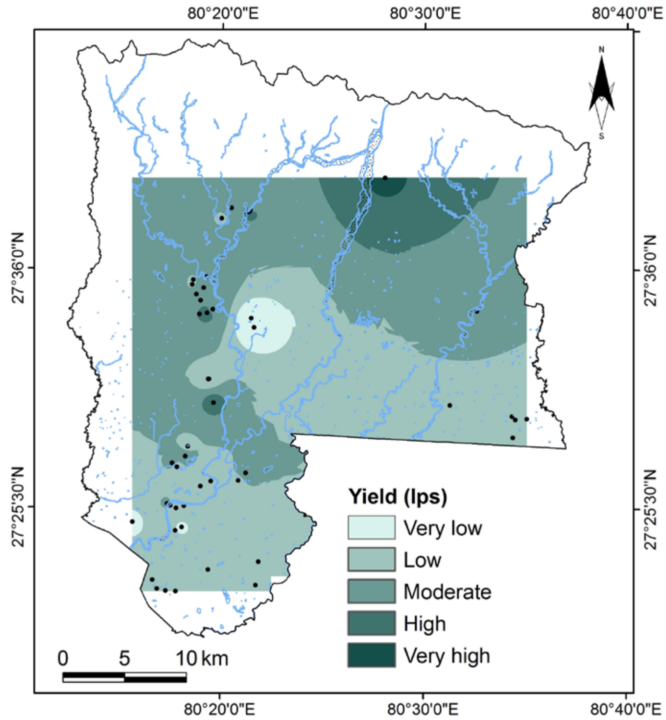

Fig. 11: Yield map of the shallow well, less than 25 m deep (Pathak, 2017).

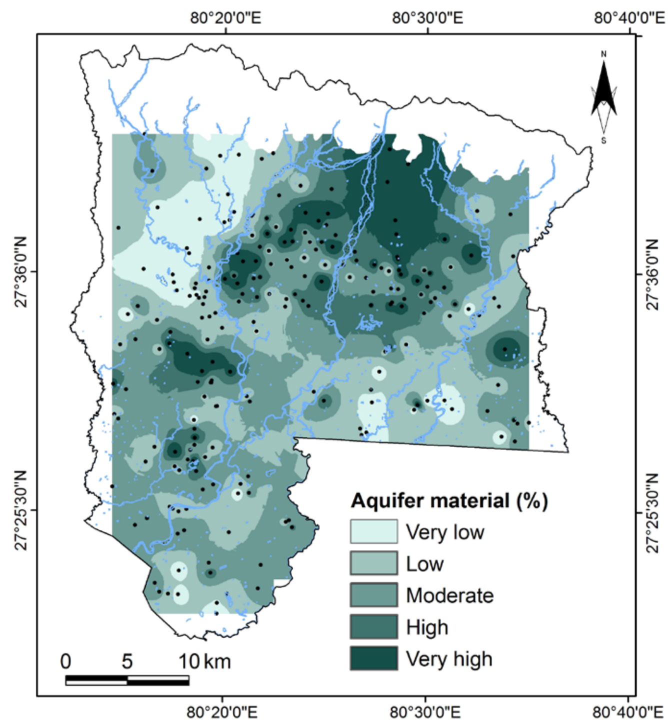

Fig. 12: Percentage of aquifer material within 25 m depth (Pathak 2017).

areas. Pathak (2017) mentioned that in the case of inadequacy of all required data, yield, and thickness of aquifer materials can be used (Fig. 11 and Fig. 12). The groundwater of the plain or flat area has been extensively used for agriculture purpose and urbanization, hence proper consideration has to be paid before mapping the potential zones in overexploited area.

Pathak (2017) used yield values measured from pumping test in 46 wells and produced the yield map of the area (Fig. 11). In addition, the distribution of aquifer material in the area has been produced from the lithologs of more than 200 shallow wells (Fig. 12). The resulting potential map was verified with respect to the groundwater table.

Validation of Groundwater Potential Map

Every model makes some predictions with some assumptions. These predictions are to be tested for validation using the real ground scenario. In general, the groundwater potential map is the prediction with the assumption that the weight for different groundwater indicating factors are assigned as per the site conditions. Therefore, the groundwater potential map must be validated. Generally, validation is done by comparing the potential map with the groundwater depth when there is availability of bore wells data. However, in the mountainous terrain, spring inventory and its discharge can be compared to validate the map. The validation is done either through making direct comparison of the hydrogeologic parameter or spring occurrence in different classes in potential map. The high potential zone should be represented by shallow groundwater table or high yield (in Gangetic Plain or intermountain valley) or more number of springs with significant discharge of groundwater (in mountainous terrain). The validation through preparing the receiver operating curves (ROC) is rather robust method of validation. The Area Under Curve (AUC) helps to quantitatively assess the ROC curve, which identifies the level of accuracy of the prepared model for predicting groundwater potential. The best model is represented by the ROC curve with largest AUC. The AUC varies from 0.5 to 1.0. If the value of AUC is equal to 0.5, the model is unable to predict the groundwater potential, on the other hand, if AUC is 1.0, the model is considered excellently representing the real site condition. Generally, if the AUC greater than 0.7, the model is considered acceptable.

DISCUSSION AND CONCLUSIONS

Identification of groundwater occurrence location using remote sensing data is based on indirect analysis of directly observable terrain features like geological structures, geomorphology, and their hydrologic characteristics. The ability to generate information in spatial and temporal domain is the greatest advantages of using RS data for hydrological investigation and monitoring. This ability is very crucial for successful analysis, prediction and validation of the potential map. Since early, GIS and RS have been successfully used for mapping and extraction of surface features and structures and is considered as integral part of applied geomorphology. These techniques has been extensively used for the detection of landforms, investigation and analysis of land use/land cover (LULC), visual interpretation of aerial photos and is found to be very effective and economic. The high spatial resolution of airborne photographs provides a valuable data source, particularly for detecting smaller landforms (meters to decameters). However, newer datasets like high resolution satellite images and Digital Elevation Models (DEMs) have become progressively popular due to their numerous advantages and qualities (e.g. high level of detail, multi-spectral properties, and increasing global coverage).

For the validation of the groundwater potential map in the Gangetic Plain, intermountain basin and in the areas with wider river valleys, the aquifer parameters like well yield and ground water table can be used. For the mountainous region, spring inventory can be very useful for the validation of the groundwater potential map. Receiver Operating Curve can be produced by comparing the potential map with the occurrence of springs and wells. The area under curve is then calculated which justifies the potential map. Generally, for the acceptable map, area under curve should be greater than 0.7. In view of very limited work carried out so far in the Nepal Himalaya, there is a need to establish weights and ranks of factor map and its classes for different geological setup that is represented by specific geophysical and climatic condition. The research work in this aspect could make significant contribution towards realistic delineation of groundwater potential in the mountainous area of Nepal Himalaya. Likewise, the application of AHP method for the potential mapping is in countable number and it need to be applied at different watersheds belonging to different geophysical condition in the country. Similarly, preparation of groundwater potential map in the Indo-Gangetic Plain is also in limited researches in Nepal. It is necessary to carry out groundwater potential mapping in eastern, central and western Terai in Nepal as the sedimentation pattern, areas of Bhabar zone etc. (which is considered to be the major recharge zone) varies from east to west. Once the methodology is tested, the standardized one could be applied in future and the groundwater potential map could be updated with increased number of investigation tube wells making availability of detailed lithological information and hydrogeological parameters of the aquifers.

REFERENCES

Abdalla, F., 2012. Mapping of groundwater prospective zones using remote sensing and GIS techniques: a case study from the central eastern desert, Egypt. Jour. African Earth Sci., v. 70, pp. 8–17.

Adiat, K.A.N., Nawawi, M.N.M., and 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. Jour. Hydro., v. 440–441, pp. 75–89.

Al-Abadi, A., and Al-Shamma, A., 2014. Groundwater potential mapping of the major aquifer in northeastern Missan Governorate, south of Iraq by using analytical hierarchy process and GIS. Jour. Env. Earth Sci., v. 4(10), pp. 125–150.

Bahuguna, I.M., Nayak, S., Tamilarsan, V., and Moses, J., 2003. Groundwater prospective zones in basaltic terrain using remote sensing. Jour. Indian Soc. Remote Sensing, v. 31(2), pp. 101–105.

Bashe, B.B., 2017. Groundwater potential mapping using Remote Sensing and GIS in Rift valley Lakes Basin, Weito sub-Basin, Ethiopia. Int. Jour. Sci. Engg. Res., v. 8(2), pp. 43–50.

Bera, K., and Bandyopadhyay, J., 2012. Ground water potential mapping in Dulung watershed using remote sensing and GIS technique, west Bengal, India. Int. Jour. Sci. Res. Pub., v. 2(12), pp. 1–7.

Chatterjee, R., and Ray, R.K., 2014. A review of international practices assessment of ground water resources. Govt. of India, Ministry of Water Resources, Central Ground Water Board, Faridabad, 95 p.

Choudhary, R., and Pathak, D., 2016. Land use/land cover change detection through temporal imageries and its implications in water induced disaster in Trijuga watershed, east Nepal: Jour. Nepal Geol. Soc., v. 51, pp. 49–54.

Das, S., Behera, S.C., Kar, A., Narendra, P., and Guha, S., 1997. Hydrogeomorphological mapping in ground water exploration using remotely sensed data: case study in Keonjhar District , Orissa: Jour. Indian Soc. Remote Sensing, v. 25(4), pp. 245-259.

Fetter, C.W., 1994. Applied hydrogeology. Prentice Hall, Englewood Cliffs, 591 p.

Ganapuram, S., Kumar, G.T.V., Krishna, I.V.M., Kahya, E., and Demirel, M.C., 2009. Mapping of groundwater potential zones in the Musi Basin using remote sensing data and GIS: Advances in Engineering Software, v. 40(7), pp. 506–518.

Hussein, A., Govindu, V., and Nigusse, A.G.M., 2017. Evaluation of groundwater potential using geospatial techniques. Applied Water Science, v. 7(5), pp. 2447–2461.

Jaiswal, R.K., Mukherjee, S., Krishnamurthy, J., and Saxena, R., 2003. Role of remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development-an approach. Int. Jour. Remote Sensing, v. 24(5), pp. 993–1008.

Jha, M.K., Chowdary, V.M., and Chowdhury, A., 2010. Groundwater assessment in Salboni Block, west Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. Hydrogeol. Jour., v. 18, pp. 1713–1728.

Krishnamurthy, J., Kumar, N.V., Jayaraman, V., and Manivel, M., 1996. An approach to demarcate ground water potential zones through remote sensing and a geographical information system. Int. Jour. Remote Sensing, v. 17(10), pp. 1867–1884.

Krishnamurthy, J., and Srinivas, G., 1995. Role of geological and geomorphological factors in ground water exploration: a study using IRS LISS data. Int. Jour. Remote Sensing, v. 16(14), pp. 2595–2618.

Leblanc, M., Leduc, C., Razack, M., Lemoalle, J., Dagorne, D., and Mofor, L., 2003. Applications of remote sensing and GIS for groundwater modelling of large semiarid areas: example of the Lake Chad Basin, Africa. In: Hydrology of the Mediterranean and semiarid regions. IAHS, Montpellier. pp. 186-192.

Magesh, N.S., Chandrasekar, N., and Soundranayagam, J.P., 2012. Delineation of groundwater potential zones in Theni District, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geoscience Frontiers, v. 3(2), pp. 189–196.

Manap, M.A., Sulaiman, W.N.A., Ramli, M.F., Pradhan, B., and Surip, N., 2013. A knowledge-driven GIS modeling technique for groundwater potential mapping at the upper Langat Basin , Malaysia. Arab Jour. Geosci., v. 6, pp. 1621–1637.

Mayilvaganan, M.K., Mohana, P., and Naidu, K.B., 2011. Delineating groundwater potential zones in Thurinjapuram watershed using geospatial techniques. Indian Jour. Sci. Tech., v. 4(11), pp. 1470–1476.

Murthy, K.S.R., 2000. Ground water potential in a semi-arid region of Andhra Pradesh-a geographical information system approach. Int. Jour. Remote Sensing, v. 21(9), pp. 1867–1884.

Naveenkumar, Soraganvi, V.S., and Hooli, S.S., 2015. Groundwater potential mapping in a part of Malaprabha River Basin using remote sensing data and geographic information system (GIS). Jour. Env. Earth Sci., v. 5(5), pp. 41–48.

Pathak, D., 2016. Water availability and hydrogeological condition in the Siwalik foothill of east Nepal. Nepal Jour. Sci. Tech., v. 17(I), pp. 31–38.

Pathak, D., 2017. Delineation of groundwater potential zone in the Indo-gangetic plain through GIS analysis. Jour. Inst. Sci. Tech., v. 22(1), pp. 104–109.

Pathak, D., and Shrestha, S.R., 2016. Delineation of groundwater potential zones in rocky aquifers of central Nepal. Jour. Nepal Geol. Soc., v. 50, pp. 161–169.

Paul, M.J., 2006. Impact of land-use patterns on distributed groundwater recharge and discharge - A case study of western Jilin, China. Chinese Geographical Science, v. 16(3), pp. 229–235.

Prasad, R.K., Mondal, N.C., Banerjee, P., Nandakumar, M.V, and Singh, V.S., 2008. Deciphering potential groundwater zone in hard rock through the application of GIS. Env. Geol., v. 55, pp. 467–475.

Pratap, K., Ravindran, K. V, and Prabhakaran, B., 2000. Groundwater prospect zoning using remote sensing and geographical information system. A case study in Dala-Renukoot area, Sonbhadra District, Uttar Pradesh. Jour. Indian Soc. Remote Sensing, v. 28(4). pp. 249-263.

Rahmati, O., Samani, A.N., Mahdavi, M., Pourghasemi, H.R., and Zeinivand, H., 2014. Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS. Arab Jour. Geosci., v. 8(9), pp. 7059–7071.

Rangarajan, R., and Athavale, R.N., 2000. Annual replenishable ground water potential of India - An estimate based on injected tritium studies. Jour. Hydrol., v. 234(1–2), pp. 38–53.

Rao, Y.S., and Jugran, D.K., 2003. Delineation of groundwater potential zones and zones of groundwater quality suitable for domestic purposes using remote sensing and GIS zones of groundwater quality suitable for domestic. Hydrol. Sci. Jour., v. 45(5), pp. 821–833.

Saaty, T.L., 1990. How to make a decision: The Analytic Hierarchy Process. European Jour. Operational Res., v. 48, pp. 9–26.

Saha, S., 2017, Groundwater potential mapping using analytical hierarchical process: a study on Md. Bazar Block of Birbhum District , west Bengal: Spatial Information Research. v. 25(4), pp. 615–626.

Sahid, S., Nath, S.K., and Roy, J., 2000. Groundwater potential modelling in a soft rock area using a GIS. Int. Jour. Remote Sensing, v. 21(9), pp. 1919–1924.

Saraf, A.K., and Choudhury, P.R., 1998. Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. Int. Jour. Remote Sensing, v. 19(10), pp. 1825–1841.

Sener, E., Davraz, A., and Ozcelik, M., 2005. An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. Hydrogeol. Jour., v. 13, pp. 826–834.

Shivakumar, R., Babu, S.S., Madhu, N.S., Viswanath, D.S., Arvind, and Puttaiah, E.T., 2011. Ground water prospect zoning using remote sensing and geographical information system: a case study of Ranebannur Taluk, Karnataka. Int. Jour. Earth Sci. Engg, v. 4(1), pp. 84–91.

Sikdar, P.K., Chakraborty, S., Adhya, E., and Paul, P.K., 2004. Land use/land cover changes and groundwater potential zoning in and around Raniganj coal mining area, Bardhaman district, west Bengal–A GIS and remote sensing approach Jour. Spatial

Hydrology, v. 4(2), p. 1–24.

Suganthi, S., Elango, L., and Subramanian, S.K., 2013. Groundwater potential zonation by remote sensing and GIS techniques and its relation to the groundwater level in the coastal part of the Arani and Koratalai River Basin, southern India. Earth Sci. Res. Jour., v. 17(2), pp. 87–95.

Teeuw, R.M., 1995. Groundwater exploration using remote sensing and a low-cost geographic information system. Hydrogeol. Jour., v. 3(3), pp. 21-30.

Thomas, A., Sharma, P.K., Sharma, M.K., and Sood, A., 1999. Hydrogeomorphological mapping in assessing ground water by using remote sensing data: a case study in Lehra Gaga block, Sangrur District, Punjab. Jour. Indian Soc. Remote Sensing, v. 27(1), pp. 31–42.

Tiwari, A., and Rai, B., 1996. Hydromorphogeological mapping for groundwater prospecting using Landsat-MSS I m a g e s: a case study of part of Dhanbad District, Bihar. Jour. Indian Soc. Remote Sensing, v. 24(4), pp. 281–285.

Varade, A.M., Wath, P., Dongre, K., Khare, Y.D., and Khandare, H., 2011. Integrated approach using remote sensing and GIS for assessment of groundwater situation in parts of Chandrapur and Gadchiroli Districts of Maharashtra. Jour. Indian Geophysical Union, v. 15(4), pp. 195–206.

Vaux, H., 2011. Groundwater under stress: the importance of management. Env. Earth Sci., v. 62, pp. 19–23.

Yeh, H.F., Lee, C.H., Hsu, K.C., and Chang, P.H., 2009. GIS for the assessment of the groundwater recharge potential zone: Env. Geol., v. 58(1), pp. 185–195.