SIGNIFICANCE OF MORPHOMETRIC ANALYSIS AND GEOMORPHOLOGY TO DELINEATE GROUNDWATER POTENTIAL ZONES OF BANAS RIVER BASIN, RAJASTHAN USING SRTM DATA AND GIS TECHNIQUES

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ABSTRACT

Groundwater is the main source of water that meets the agricultural, industrial and household requirements. Groundwater is affected by many factors such as physico-chemical characteristics of soil, rainfall, soil erosion, weathering of rocks, chemical reactions sub-surface, role of micro-organism, human and agricultural wastes and industrial effluents. The river Banas originating from the Khamnor hills of the Aravalli ranges (about 5 kms from Kumbalgarh) is one of the major rivers of the state which, in its entire course, flows through Rajasthan. It flows from Kumbalgarh towards the south upto Gogunda plateau and after cutting the Aravalli ranges at right angles; it flows through Nathdwara, Rajsamand and Railmagra. Morphometric analysis of Banas river basin was carried out using Remote Sensing and GIS techniques. The total area of the Banas river basin is 702.55km^2. Detailed drainage map was prepared from SOI (Survey of India) toposheets (45h/5 and 45h/9) and was updated using IRS-P6, LISS-III (Precision geocoded) data of 7th May, 2010 using ARC GIS software. The drainage pattern of the basin is dendritic to sub-dendritic with fifth order drainage.The drainage density of the Banas river basin is 3.32km/km^2, which is indicative of less permeable material, sparse vegetative cover and moderate to high relief. For detailed study, Shuttle Radar Topographic Mission (SRTM) was used for delineating watershed boundary and for preparing Digital Elevation Model (DEM) and slope map. GIS was used used in evaluation of linear and areal aspects of morphometric parameters. Geomorphologically the study area are classified into 4 categories, viz. burried pediment, pediment, structural hills, structural ridges and valleys. The result indicated that 24.31% of the area is under good groundwater potential zone whereas 41.15% of the area is under moderate zone. 28.80% of the area falls under poor groundwater potential zone and 5.72% falls under very poor zone.

Keywords: Drainage density, Banas river basin, Bifurcation ratio, Morphometric analysis.

1. Introduction

The water being so abundant is still a rare commodity. Without doubt, water is vital for all living beings. In the hard rock terrain availability of groundwater is limited and its occurrence is essentially confined to fractures and weathered zones (Javed and Wani, 2009). RS and GIS have been proved to be useful tools for groundwater studies. In the past, several researchers have used RS and GIS techniques for the delineation of groundwater potential zones (Krishnamurthy et al., 1996; Kamaraju et al., 1995; Saraf and Choudhury 1998; Shahid et al., 2000; Jaiswal et al., 2003; Sikdar et al., 2004; Sener et al., 2005; Ravi Shankar and Mohan, 2006; Solomon and Quiel 2006; Jha and Peiffer 2006; Khan and Mohrana, 2002) with successful results.

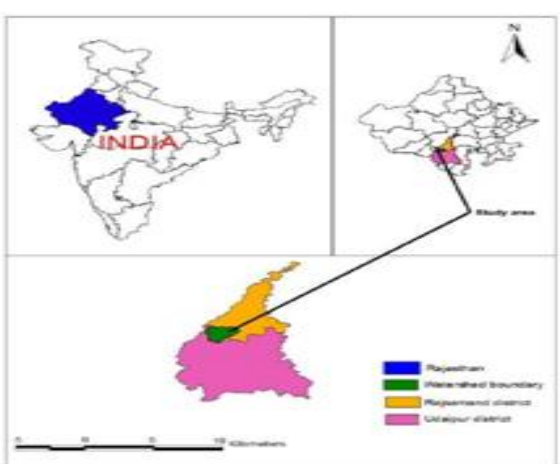
Morphometry is the measurement and mathematical analysis of the configuration of the earth’s surface, shape and dimension of its landforms (Clarke, 1966). This analysis can be achieved through measurement of linear, aerial and relief aspects of the basin and slope contribution (Nag and Chakraborty, 2003). Morphometric analysis provides quantitative description of the basin geometry to understand initial slope or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler, 1964). The Morphometric study involves the evaluation of stream parameters through the measurements of various stream properties (Kumar et al., 2000, Ali, S. A et al., 2003; Ali, S.A. et al., 2005; Piresteh et al., 2007).

Remote sensing techniques using satellite images are convienient tools for morphometric analysis. The satellite remote sensing has the ability to provide synoptic view of large area and is very useful in analyzing drainage morphometry. The image interpretation techniques are less time consuming than the ground surveys, which coupled with limited field checks yield valuable results.

2. Study area

Banas river basin falls in Udaipur district of Rajasthan. The total area of the banas river basin is 702. 55 sq.km. The study area is located lies between latitude $25^{0}00^{'}$ – $24^{0}45^{'}$N and longitude 73 $^{0}25^{'}$ – $73^{0}45^{'}$E falling in Survey of India toposheets No.45H/5 and 45H/9 on 1:50,000 scale. (Fig.1). The study area falls under tropical climate. It has high temperatures in summer and is very cold in winters. The summers have a mean maximum of 40^{0}C and a mean minimum of 25.8^{0}C, while the winter mean maximum is 22^{0}C and the mean minimum is 8.3^{0}C. Monsoon arrives in the month of July heralded by dust and thunderstorms. It annually receives around 637mm of rainfall. This scanty amount of rainfall makes more humid. The humidity reaches to the extent of 90 percent during the month of monsoons.

The river Banas originating from the Khamnor hills of the Aravalli ranges (about 5 kms from Kumbalgarh) is one of the major rivers of the state which, in its entire course, flows through Rajasthan. It flows from Kumbalgarh towards the south upto Gogunda plateau and after cutting the Aravalli ranges at right angles; it flows through Nathdwara, Rajsamand and Railmagra. The river collects the major run-off of Udaipur, Chittorgarh and Bhilwara district by the tributary Berach. This river usually dries up during the summer season. The total length of this river is about 480 kms and its main tributaries are Berach, Khari Dai, Mashi, Dundh and Morel. The river Banas as well as tributaries are ephemeral and flow only in response to heavy precipitation.



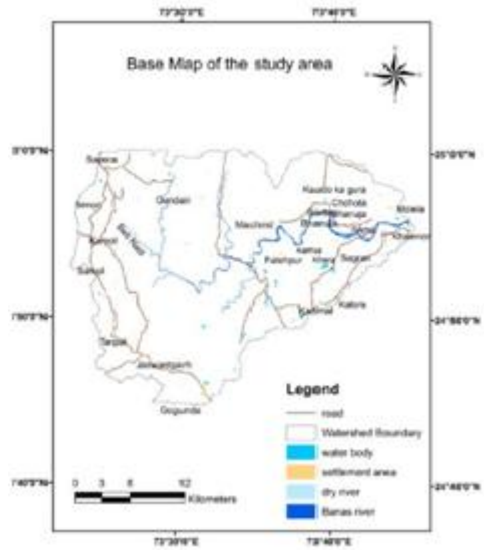


Fig.1. Location map of the study area

3. Data Used and Methodolgy

Survey of India (SOI) topographic map on 1:50, 000 scale bearing no. 45H/5 and 45H/9 was obtained from Survey of India, Dehradun has been used for drainage map and was updated using IRS P6, LISS III (Precision geocoded) data of 7^{th} May, 2010. The important information on elevation, watershed boundary, contour lines, major roads, villages or towns and railway networks were extracted from the toposheet and a base map was generated. For detailed study, Shuttle Radar Topographic Mission (SRTM) was used for delineating watershed boundary and for preparing Digital Elevation Model (DEM) and slope map.

The present study utilized digital data of Indian Remote Sensing (IRS P6 LISS III) (Path-93 and Row-54) of 7^{th}May, 2010 having a spatial resolution of 23.5 metre was procured from National Remote Sensing Agency, Hyderabad and a standard FCC was generated.

Four geomorphic units identified through visual interpretation of FCC of IRS P6 LISS III (Precision geocoded) satellite data based on photographic and geotechnical elements such as tone, texture, shape, size, pattern, association etc.

Drainage map was prepared by on screen digitization. Quantitative morphometric parameters such as stream length, bifurcation ratio and basin area have been calculated through the use of a Geographical Information System using Arc GIS environment.

4. Result and Discussion Geology and Minerals

A number of calcite occurrences in the form of veins, vein lets and pockets along the strike of the formation and joint planes have been found in marble bands with calc-gneisses/granulites around Gayphal, Vishva, Sayra, Padrara and others places. The ultramafic rocks in the Aravalli Supergroup occur only in the belt south of Nathdwara, traversing the belt of type Aravalli rocks. The ultramafic rocks also occur as thin conformable bands within quartzite, phyllite and mica - schists in the Jharol belt between Gogunda ($24^{0}46'$: $73^{0}32'$) and Jharol ($24^{0}24'$: $73^{0}29'$). Lithologically, the ultramafic rocks are represented by talc-chlorite (antigorite) schist and serpentinite with variable proportions of actinolite-tremolite, talc-tremolite, asbestos and dolomite. Magnetite (as well as chrome spinel) is a common accessory mineral.

Eighteen types of geologic lithology namely, (1) biotite schist and calc biotite schist, (2) biotite schist and calc schist, (3) biotite schist and gneiss, (4) calc silicate rocks, (5) cherty breccias, (6) chloritic phyllites and meta tuff, (7) dolomite, (8) dolomitic marble, (9) epiclastic conglomerate, (10) feldspathic schist, (11) garnetiferous mica schist, (12) granite and gneiss, (13) hornblende schist, (14) meta siltstone and phyllite, (15) mica schist, (16) pegmatite and composite gneisses, (17) phyllite and mica schist, (18) quartzite are found in the study area.(Fig.2).These litho units are soft and friable. Gneiss is grey to dark colored, medium to coarse grained rocks. Schist litho units are hard and compact, fine to medium grained and characterized by alternating bands of light and dark colored ferromagnesian minerals. Granite is grey colored, medium to coarse grained rock mainly composed of quartz, feldspar with biotite and hornblende as minor constituents. Quartzites are grey, pink, pale and light green. Quartzites occupies west and south west part of the study area.

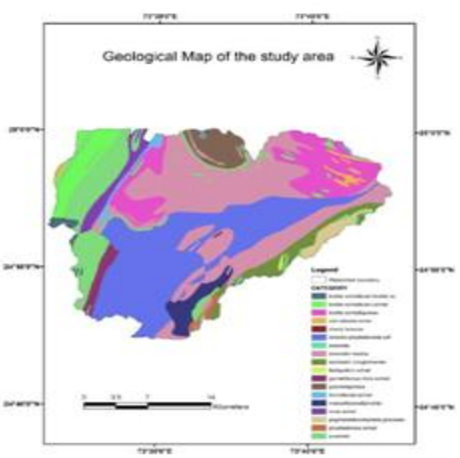


Fig.2.Geological Map of Study Area

5. Digital Elevation Model

Topographical elevation map for the study area was developed by Digital Elevation Model (DEM) extracted from the Shuttle Radar Topography Mission (SRTM) data. The slope map for the study area was prepared from the DEM. The topographic map was prepared from SRTM data is shown in Fig.3. On the basis of topographic elevation, the study area can be divided into six topographic elevation classes. The highest topographic elevations (about 1288 m MSL) exists in the northern portion of the study area. The topographic elevation is usually low in the north eastern portion of the study area.

6. Slope map

The topographic slope of the area has its own importance in affecting the run-off, recharge and movement of surface water. The slope map of the study area developed from DEM, is shown in Fig.4 which reveals 9 slope classes: (1) 0 - 9% (2) 10 – 18% (3) 19 – 26% (4) 27 – 35% (5) 36 – 44% (6) 45 – 53% (7) 54 – 62% (8) 63 – 70% (9) 71 – 79%. It can be seen from the figure that the lowest slope exists in the north east portion of the area, which indicate almost flat topography. The slope between 36 – 44% exists in the form of stretched strips along the hillocks lying in the northern portion of the study area. The slope 0 – 9% dominates in the study area.

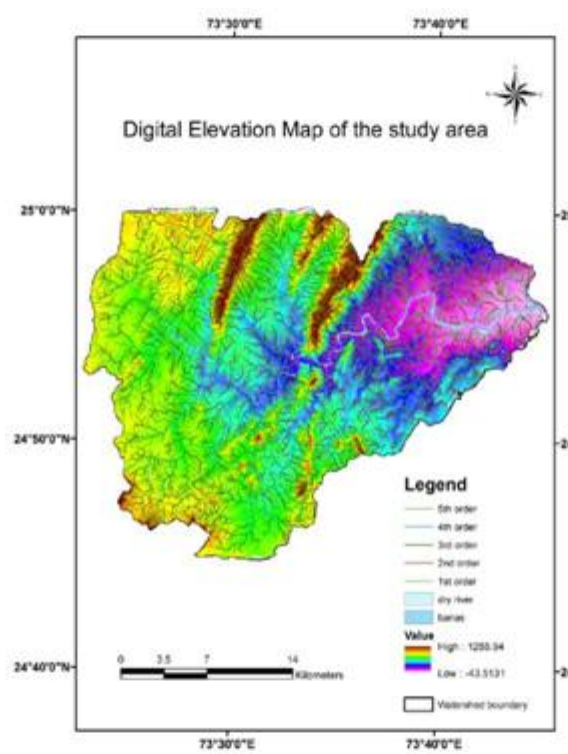


Fig.3. Drainage network superimposed on DEM

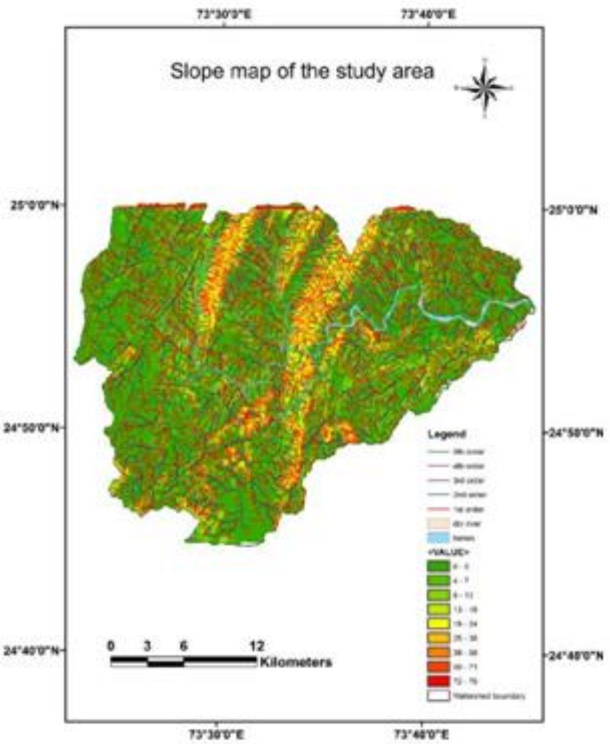


Fig.4. Drainage network superimposed on Slope map

7. Geomorphology

Geomorphological mapping involves the identification and characterization of the fundamental units of landscape. The underlying lithology, slope and the type of existing drainage pattern influences the genesis and processes of different geomorphic units (V.B.Rekha et al., 2010). Geomorphologic map results important geomorphic units, landforms and underlying geology to provide a better understanding of the process, lithology, structures and geologic controls relating to groundwater delineation as well as to groundwater prospects. Geomorphologically, the study area consists of pediment, burried pediment, structural hills, structural ridges and valleys as shown in Fig.5. The study area has burried pediment mainly in the north, north east, north west, east, south east portion encompassing an area of 326.194km^2. It is moderate to good for groundwater occurrence. The study area has pediment mainly in the western and southern portion encompassing an area of 143.326km^2. It is poor to moderate for groundwater occurrence. The study area has structural hills and structural ridges & valleys also covering an area of 202.04km^2 and 30.64km^2 respectively (Table 1).

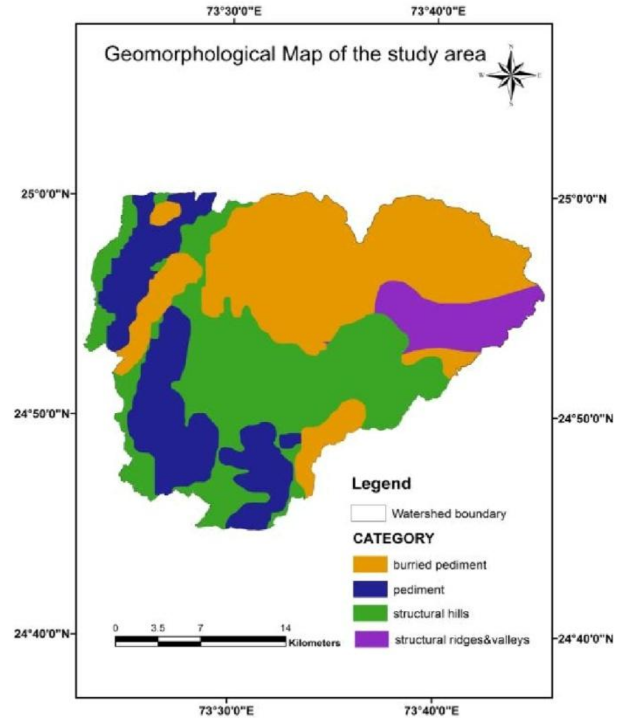


Fig.5. Geomorphological Map of the study area

Geomorphic units	Image Characteristics (On FCC)	Area (km^{2})	Groundwater prospects
Burried pediment	Drak red tone	326.194	Good to moderate
Pediment	Light grey tone, rough texture	143.326	Poor to moderate
Structural ridges&Valleys	Dark tone	30.64	Poor
Structural hills	Dark green of tonal variation and by thick vegetation	202.04	Very poor

Table 1. Geomorphic units, Image characteristics(FCC), Area and Groundwater prospects

8. Morphometric Analysis

Morphometric parameters have been classified into
(a) Linear aspect
(b) Areal aspect

Linear aspect include Stream order (U), Stream number (Nu), Stream length (Lu), Mean stream length (Lsm), Stream length ratio (RL) and Bifurcation ratio (Rb). Areal aspects include drainage density (D), Stream frequency (Fs), Drainage texture (Rt), Circularity ratio (Rc), Elongation ratio (Re), Length of overland flow (Lg), Constant of channel maintenance (C) and infilteration number.

The whole banas watershed is of fifth order. The drainage pattern of the study area is predominantly dendritic to sub-dendritic in nature (Fig.6). Mean stream length of Banas river basin reveals an increasing trend with the increase in stream order. The stream length ratio (RL) between streams of different orders reveals variation in Banas river basin. This may be attributed to variation in slope and topography.

Since bifurcation ratio is a dimensionless property, and drainage systems in homogeneous materials tend to display geometrical similarity, it shows a small variation from region to region (Chow, 1964). The lower values of bifurcation ratio are characteristics of the watersheds which have suffered less structural disturbances (Nag, 1998). Whereas higher bifurcation ratio is the result of large variation in frequencies between successive orders and indicates a mature topography (Sreedevi et al., 2004). The bifurcation ratio of the Banas river basin ranges from 3.04 to 2.64 and its mean bifurcation ratio is 3.95 which falls under normal basin category (Table 2).

Drainage density has been interpreted to reflect the interaction between climate and geology (Ritter et al., 1995). (Horton, 1932) introduced drainage density as an expression to indicate the closeness of spacing of channels. Thus drainage density is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area (Chow, 1964). It is considered as an important indicator of the linear scale of land form elements in stream eroded topography. Density factor is related to climate, lithology, relief, infiltration capacity, vegetative cover, surface roughness and run-off index. Out of which only surface roughness has no significant correlation with drainage density. (Langbein, 1947) recognized significance of drainage density as a factor determining the time of travel by water and stated that drainage density values between 0.55 and 2.09 km/km^2 correspond to humid regions. (Nag, 1998) found that low drainage density generally results in areas of highly resistant rocks or permeable subsoil material, dense vegetation and low relief. High drainage density results due to weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture whereas high drainage density leads to fine drainage texture. Banas river basin possess high drainage density i.e $3.32 km/km^2$ which is indicative of less permeable material, sparse vegetative cover and moderate to high relief (Table 2).(Obi Reddy et al., 2004) found that lower Fs values indicate permeable sub-surface material and low relief, whereas higher values are the characteristic of resistant sub-surface material, sparse vegetation and high relief. The stream frequency of the Banas river basin is 5.49 (Table 2). Infilteration number is the product of the drainage density and stream frequency of the basin. The infilteration number of the basin is 18.28 (Table 2) indicating low infilteration and high run-off.

The Constant of Channel Maintenance of the basin is 0.30 (Table 2). This low value indicates high structural disturbances, low permeability, steep to very steep slopes and high surface run off.The value of Length of Overland Flow of the basin is 0.15 (Table 2). The value is equals to the half of the constant of channel maintenance.(Horton, 1945) defined drainage texture as the total number of stream segments of all orders divided by the perimeter of the watershed. He also recognized infiltration capacity as the dominant factor influencing drainage texture which includes drainage density and stream frequency as well. Drainage texture (Rt) depends upon a number of natural factors such as climate, rainfall, vegetation, lithology, soil type, infiltration capacity, relief and stage of development (Smith, 1954). (Smith, 1954) classified drainage density into five different classes of drainage texture, i.e. less than 2, indicates very coarse, between 2 and 4 is coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. The soft or weak rocks devoid of vegetation generally exhibit a fine texture, whereas in massive and resistant rocks coarse drainage texture is developed.

The Banas river basin has a value of 24.137 which falls under very fine drainage texture (Table 2).

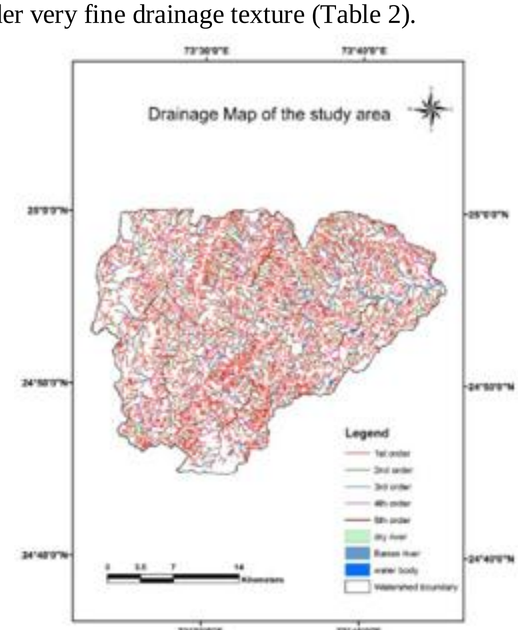


Fig.6. Drainage network of the study area derived from SOI toposheets and digital IRS P6 LISS III

(Miller, 1953) and (Strahler, 1964), defined circularity ratio (Rc), as the ratio of the area of the basin (A) to the area of a circle having the same circumference as the perimeter (P) of the basin. Circularity ratio (Rc) is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin (Chopra et al., 2005)

The circularity ratio of the Banas watershed is 0.02 (Table 2).

Morphometric Parameters	Formula	Reference	Result				
Bifurcation ratio (Rb)	Rb = Nu/Nu1 Where, Rb = Bifurcation ratio Nu = Total no. of stream segments of order 'u' Nu1 = No. of segments of the next higher order	Schumn (1956)	I/II	II/III	III/IV	IV/V	
			3.04	1.93	2.57	2.64	
Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler(1957)	2.54				
Drainage density (D)	D = Lu/A Where, D = Drainage density Lu = Total stream length of all orders A = Area of the basin (Km^2)	Horton (1932)	3.32				
Stream frequency (Fs)	Fs = Nu/A Where, Fs = Stream frequency Nu = Total no. of streams of all orders A = Area of the basin (Km^2)	Horton (1932)	5.49				
Drainage texture (Rt)	Rt = Nu/P Where, Rt = Drainage texture Nu = Total no. of streams of all orders P = perimeter of the basin (Km)	Horton (1945)	24.13				
Circularity ratio (Rc)	$Rc = 12.57A/P^2$ Where, Rc = Circularity ratio A = Area of the basin (Km^2) P^2 = Perimeter (Km)	Miller (1953)	0.02				
Length of overland flow (Lg)	Lg = 1/D*2 Where, Lg = Length of overland flow D = Drainage density	Horton (1945)	0.15				
Constant channel Maintenance (C)	C = 1/D	Schumn (1956)	0.30				
Infilteration number	18.28						
Stream frequency	5.49						
Perimeter of the basin (km)	159.92						
Area of the basin (sq.km)	702.55						

Table 2. Results of parameters of morphometric analysis of Banas river basin

10. Conclusion

The present study represented the application of Remote Sensing and GIS techniques in delinating groundwater potential zones. Satellite (IRS P6, LISS III) and SRTM data were used to generate various thematic maps namely DEM, slope map, geological map, geomorphological map, drainage map. Groundwater prospect map generated through the integration of all these maps. The basin possess high drainage density i.e 3.32km/km^2 which is indicative of less permeable material, sparse vegetative cover and moderate to high relief. The infilteration number of the basin is 18.28 indicating low infilteration and high run-off. The Constant of Channel Maintenance of the basin is 0.30. This low value indicates high structural disturbances, low permeability, steep to very steep slopes and high surface run off. The Banas river basin has a value of 24.137 which falls under very fine drainage texture. The study reveals that groundwater is promising in the burried pediments and pediments. The groundwater potential zones found in the basin are classified into four zones such as good (170.822 sq. km, 24.31%), moderate (289.126 sq. km, 41.15%), poor (202.34 sq. km, 28.80%) and very poor (40.254 sq. km, 5.72%).

Hence, good groundwater potential zones are found in the northern and north-east portion of the study area(Fig.7).

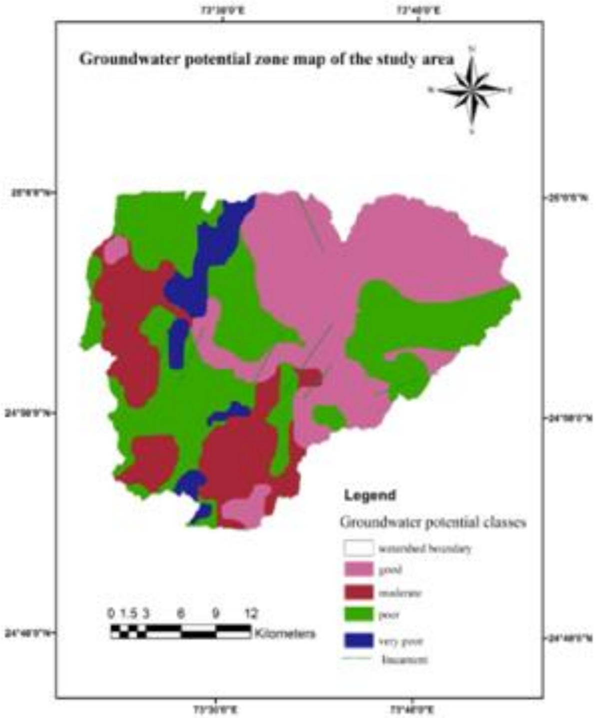


Fig.7. Groundwater potential zone map of the study area

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