American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-6, pp-49-58
www.ajer.org
Research Paper Open Access

Suitable sites identification for artificial groundwater recharge structures at sub-watershed level using Remote Sensing and GIS – a case study in Indian Punjab

Virender Kumar Sarda
(*Civil Engineering Department, National Institute of Technology, Hamirpur, H.P. (INDIA) – 177005*)

Abstract: *Rapid growing world population has put an increased stress on the demand for water tremendously resulting in the overexploitation of groundwater leading to continuous exhaustion of the groundwater aquifers. In order to alleviate this situation, it has become necessary to make use of the of the internationally accepted groundwater recharge method by identifying potential groundwater recharge sites on sub-watershed basis. For this purpose, the present study was carried out for identifying suitable sites which can be used for artificial groundwater recharge. Morphometric analysis of a watershed consisting of 54 sub-basins in semi -arid region located in Hoshiarpur district of Punjab (India) was carried out. Estimation of all the required parameters based on principles of environmental protection and sustainable development along with state-of-the-art technology have been used in GIS platform for deciding potential recharge sites and the corresponding rainfall harvesting techniques. The outcomes of the study will be useful for planning and initializing groundwater management practices in a particular basin or sub-basins.*

Keywords: *Ground water recharge; Morphometric Parameters; Rainfall harvesting techniques; Prioritization; Remote Sensing; ArcGIS10.0*

I. INTRODUCTION

The increasing demand on water due to increase in population and tremendous industrial growth, put extra stress on the exploitation of subsurface water resulting in the imbalance in hydrogeological system. One way of combating this problem is to harvest rainwater getting lost through runoff. This requires the identification of potential zones where established artificial recharge techniques can be implemented in order to recharge and conserve groundwater. It has been established that state-of-the-art techniques like Remote Sensing (RS) and Geographical Information System (GIS) can play important role in the field of hydrology and water resources development by providing multi-spectral, multi-spectral, multi-temporal and multi-sensor data of the earth’s surface (Choudhury, 1999). Remote sensing data generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation. GIS technology, on the other hand, can provide suitable alternatives for efficient management of large and complex databases (Saraf, 1998). It has been established that Remote Sensing and GIS can help in the identification of potentially favourable hydrogeomorphological zones for various water resources study [Rokade et al. (2007); Ganapuram et al. (2009), Sreedevi et al. (2009), Sethupathi et al. (2011), Ratnam et al. (2005), Kiran and Srivastava (2012), Jadhav and Babar (2013), Rais and Javed (2014)]. The focus of the present study is the identification of artificial groundwater recharge sites and structures suitable for a watershed consisting of 54 sub-basins in semi -arid region located in Hoshiarpur district of Punjab (India) on the basis of morphometric analysis through the use of Remote Sensing data and GIS platform.

II. STUDY AREA

The study area consisting of 54 sub-basins lies in a semi- arid region of Hoshiarpur district in Punjab (India) located between $75^0 50'54.14''$E, $76^0 05'22.12''$E, and 76^0 $05'22.12''$E, $31^0 32'22.12''$N as shown in Fig. 1. It covers an area of 174.385 km^2. This area at the feet of Siwalik hills in Kandi area of Punjab is characterized by rugged terrain and unique physiography to form the most fragile eco-system. This part of the state has a different set of problems as compared to the rest of the state which has nearly plain topography.

2.1 Climate

The climate of Hoshiarpur district can be classified as tropical steppe, hot and semiarid which is mainly dry with very hot summer and cold winter except during monsoon season when moist air of oceanic origin penetrates into the district. There are four seasons a year: hot weather season [mid March to last week of the June]; southwest monsoon [July-September]; the post monsoon season [September-November] and winter season [November- March]. The normal yearly rainfall of the territory is 938 mm which is unequally spread over the area in about 38 days. The southwest monsoon sets in from last week of June and withdraws at the end of September, contributed about 77% of annual rainfall. The wettest months are July and August. Rest 23% rainfall is taken in during non-monsoon period in the wake of western disturbances and thunderstorms. The district has mild climate compared to other districts of the State. This is due to the abundance of hilly terrain on the one hand and sizeable forest covers thereon, on the other.

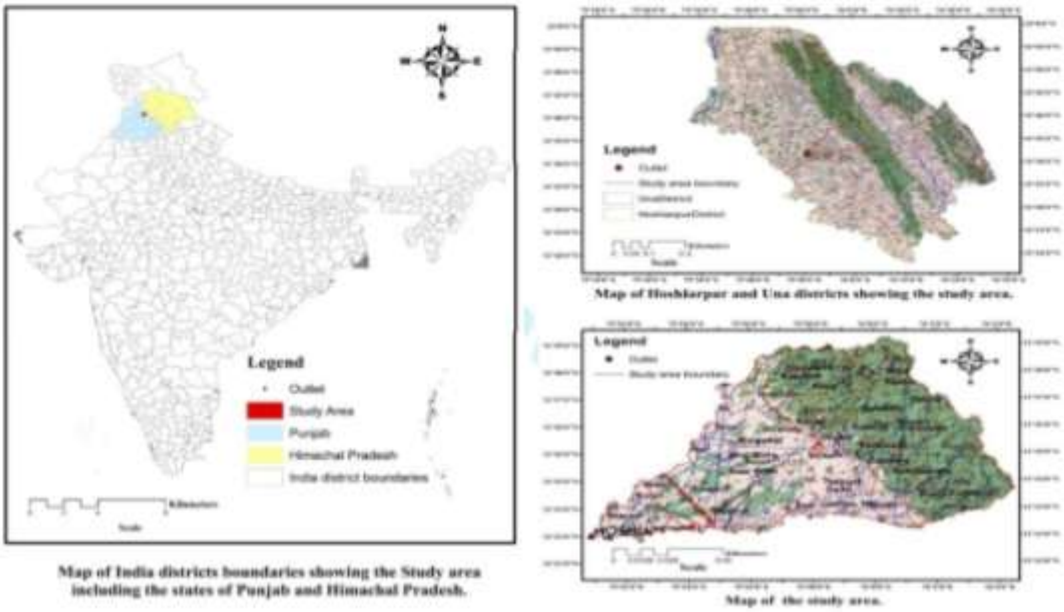

Fig. 1 Study area

2.2 Geology and Geomorphology

Hoshiarpur forms a part of Indo-Gangetic plain and Sutlej sub-basin of the main Indus basin with three distinct geomorphological units, viz, hilly area in the northeast, piedmont zone belt and the alluvial plains occurring south western part of the district. The territory is drained by two major rivers, Beas in the North and northwest and Satluj in the south. Other little streams locally called choes also flows down the Siwalik Hills finally spreading into plains giving rise to fan shaped structure. During the monsoon period, these choes experience flash flood carrying along considerable sand and silt. Unconsolidated alluvial sediments lying south of Siwalik foothills mainly occupy the district. The alluvial sediments are classified as piedmont and fluvial deposits. The piedmont deposits lie along Siwalik Hills, which comprises boulders, pebbles, gravel, sand and clay. The fluvial comprise of silt, sand, gravel and clay in association with Kankar. The major part of the study area is covered with a thick pile of quantarium alluvium. In general the soils are yellowish brown to dark brown in color ranging from calcareous sand to fine sandy loam to silt. Sand is mostly cultivated well drained with estimated infiltration rate of 8-10 cm/hours.

III. DATA AND METHODOLOGY

3.1 Data Collection

Remotely sensed satellite imagery data were processed using Spatial Analyst Tool in Arc GIS 10.0 software for preparing various maps and morphometric parameters were then evaluated for studying the drainage characteristics of the watershed and identification of the potential recharge site. Table 1 gives the detail of data procurement.

Table 1 Details of data used

Sr. no	Details	Source of data
1	S.O.I Toposheets number H43D14 and H43E2 in 1:50,000 scale	Survey of India office Chandigarh
2	CartoSAT-1 DEM satellite imagery data with 2.5 m spatial resolution	NRSC, Hyderabad
3	Land Use/Land Cover maps in 1:50,000 scale	NRSC, Hyderabad
4	ESRI Arc GIS 10.0 software	-

3.2 Methodology

Satellite imagery data and Survey of India topographical maps number at 1:50000 scales are used in GIS software for preparing various maps. Morphometric parameters were then evalu1ated for studying the drainage characteristics of all the sub-watersheds. Hydrology tool under Spatial Analyst tool is used for delineating the watershed areas which results into 54 sub-watershed zones for obtaining stream order map and morphometric analysis data of all the sub-basins from the CartoSAT-1 DEM data (Fig. 2). Raster calculator under Map algebra tool in Arc GIS 10.0 toolbox is used for obtaining drainage map for all the sub-watersheds. For identification of the locations of the artificial groundwater recharge structures Land Use/Land Cover map of the study area is overlaid on the drainage network map. All spatial datasets were projected to UTM 43 North and WGS 1984 datum using Projections and transformations under data management tools in Arc GIS 10.0.

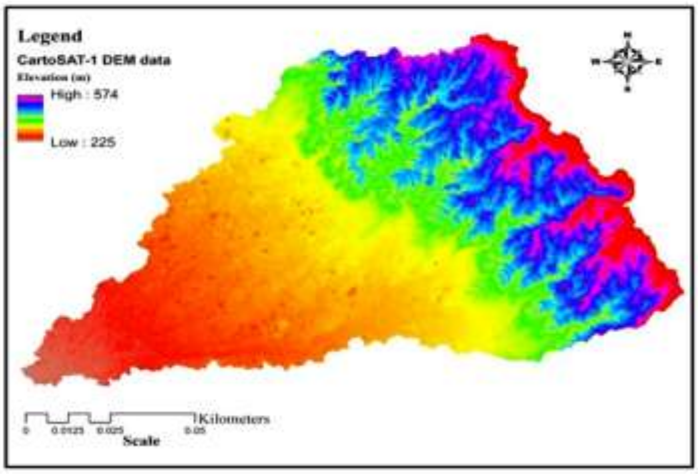

Fig. 2 Cartosat-1 DEM data of the study area

3.3 Land Use/Land Cover map

The land use/land cover maps of Hoshiarpur and Una district at 1:50,000 scale were obtained from NRSC, Hyderabad and according to their coordinate system; these maps were processed in Arc GIS for preparation of the land use/land cover map of the study area (Fig. 3). It consists of the areas like Wastelands / Water bodies, Reservoir / Lakes / Ponds; / Uncultivable / Wastelands, Scrub land; Barren / Uncultivable / Wastelands, Sandy area; Forest deciduous and Forest, Scrub forest; Agriculture, cropland; Agriculture, Plantation, Streams/ Khad; Grass/Grazing; Built-up, Urban and built-up Rural. The upper portion of the watershed having high elevation values mostly consists of the deciduous forest, while, the lower portion of the study area mostly consists of agriculture, croplands.

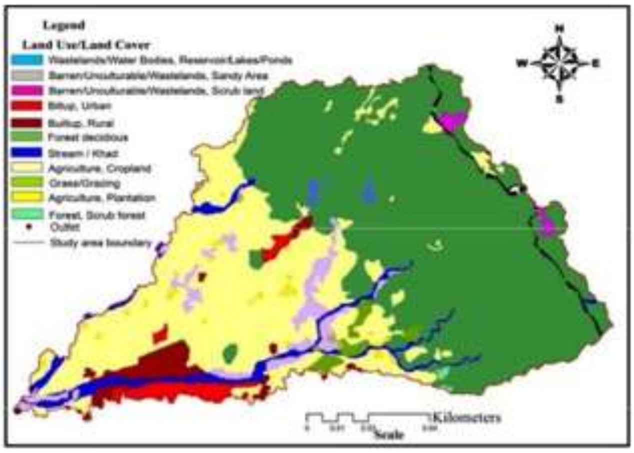

Fig. 3 Land Use/Land Cover map of the study area

IV. RESULTS AND DISCUSSION

In the present study 26 morphometric parameters were evaluated for identifying various characteristics of all the 54 sub-watersheds. Stream order is calculated using Strahler's method (1964) using the Hydrology tool in GIS. Morphometric parameters have been classified into three aspects of the basin slope and contributions:

Linear Aspects; Areal Aspects and Relief Aspects

4.1 Linear Aspects

Various linear aspects determined in this study are: Stream order (u), Stream number (N_u), Stream length (L_u), Mean stream length (L_{um}), Stream length ratio (L_{ur}), Bifurcation ratio (R_b), Mean bifurcation ratio (R_{bm}) and Basin length (L_b).

4.1.1 Stream Order

Stream order (u) expresses the hierarchal relationship between the individual stream segments that make up a drainage network. Stream ordering is the first step in morphometric analysis of the watershed. The stream ordering systems were first advocated by Horton (1945) which was later modified by Strahler (1952). In the present study Strahler's method is used in GIS for determining the stream order. It has been observed from the result that the frequency of stream decreases as the stream order increases and the maximum frequency lies in the case of first order streams for all the sub- watersheds. Figure 4 gives the stream order map of all the sub-basin of the study area.

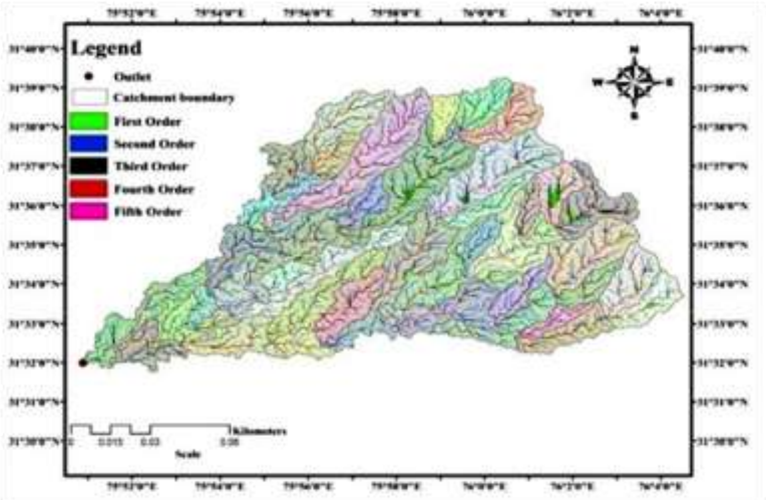

Fig. 4 Stream Order map for all the sub-basins

4.1.2 Stream Number

The number of stream segments present in each order u is expressed as stream number (N_u). According to Horton (1945) the numbers of stream segments of each order form an inverse geometric sequence with order number. In the present study stream number follows Horton's law, i.e. stream number decrease with increase in stream order for all the sub-basins. Figure 5 shows the variation of stream number (N_u) according to stream order (u) for all the sub watersheds.

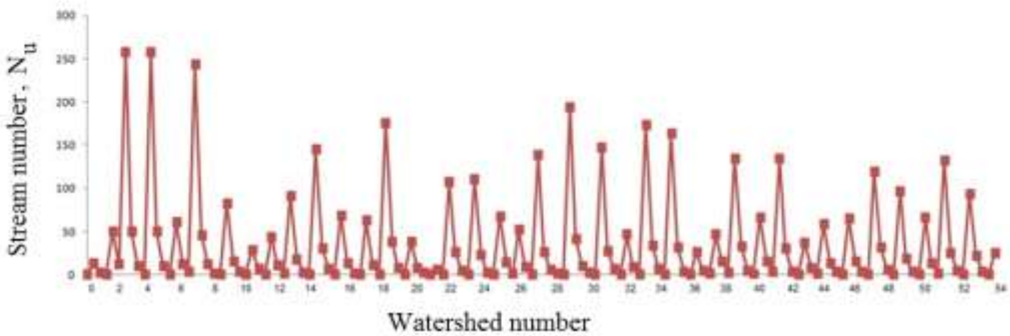

Fig. 5 Variation of stream number according to stream order for all the water sheds

4.1.3 Stream Length

Stream length (L_u) of a stream order is the total length of all the streams in that order. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in watershed of increasing order, Strahler (1964). Figure 6 shows the variation of stream length (L_u) according to stream order (u) for all the sub watersheds. Stream Length is calculated in GIS software using manual digitization and it decreases with the increase in the stream orders for all the sub-watersheds (Figure 6) except in case of watershed numbers 4, 5, 9, 16, 18, 23, 24, 25, 26, 32, 41, 50, 51 and 52 in the present study.

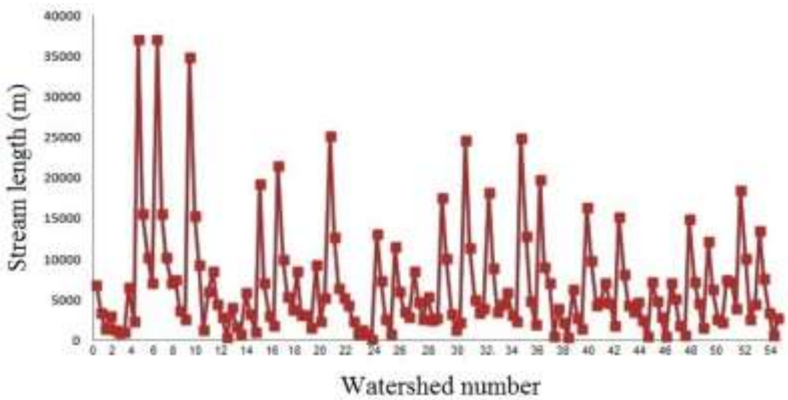

Fig. 6 Variation of stream length according to stream order for all the water sheds

Table 2 shows the range of other liner aspects of the study area.

Table 2 Linear aspects of the study area

Sr. No.	Linear aspects	Range
1	Mean stream length, L_{um} (Km)	0.5 – 4.5
2	Stream length ratio, L_{ur} (Km)	0.196 – 3.464
3	Bifurcation ratio, R_b	2 - 12
4	Mean bifurcation ratio	3 – 8.36
5	Basin length, L_b (Km)	0.43 - 4.65

It has been found that the variation in the stream length ratio of streams of different orders may be due to variation in slope and topography of the basin. It has been observed that biffurcation R_b is not same from one order to its next order. These irregularities are dependent upon the geological and the lithological development of the drainage basin [Strahler, 1964]. The lower values of R_b are characteristics of the watersheds, which have suffered less structural disturbances [Strahler, 1964] and the drainage pattern has not been distorted because of the structural disturbances [Nag, 1998]. On the other hand, higher bifurcation ratio is the result of large variations in frequencies between successive orders and indicates a mature topography [Sreedevi et al., 2004]. The range of mean bifurcation ratio indicates that sub-basin number 2, 4, 5, 6, 8, 9, 10, 12, 13, 15, 18, 20, 24, 25, 30, 31, 33, 35, 37, 39, 42, 44, 47, 48, 50, 51, 52, 54 falls under normal basin category and that the geologic structures do not distort the drainage pattern, in the study area while all the other sub-basins do not fall under normal basin category.

4.2 Areal Aspects

Various areal aspects that have been determined in the present study are: Drainage density (D_d), Drainage texture (D_t), Elongation ratio (R_e), Circularity ratio (R_c), Form factor ratio (R_f), Stream frequency (F_s), Infiltration number (I_f), Length of overland flow (L_g), Constant of channel maintenance (C), Compactness coefficient (C_c) (C_c) and Shape factor ratio (R_s).

4.2.1 Drainage Density

Drainage density is the ratio of the total length of all the streams in the basin in the area of the watershed expressed in km/km^2 [Horton, 1945; Strahler, 1952 and Melton, 1958]. In the present study the drainage density is calculated by the method proposed by Horton (1932). Figure 7 show the drainage network map for all the sub-watersheds. It can be seen that drainage density varies from 4.27 to 10.35. Low drainage density means subsoil material is permeable with dense vegetation, low relief and coarse drainage texture. On the other hand, high drainage density is indication of weak or impermeable subsurface material with sparse vegetation, mountainous/steep relief and fine drainage texture [Nag, 1988].

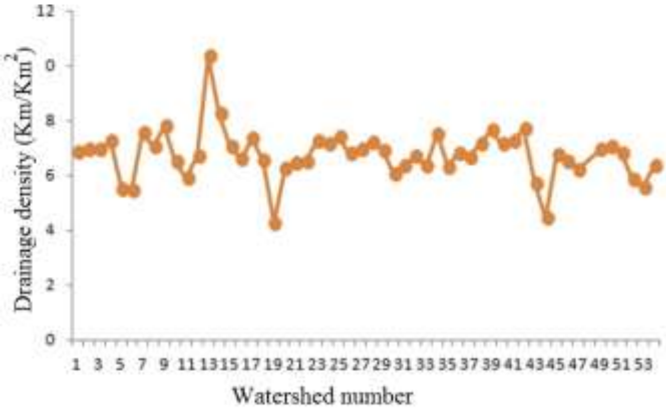

Fig. 7 Variation of drainage density for all the watersheds

It can be noted from the drainage network [Fig. 8] that all the sub-watersheds shows dendritic to sub-dendritic patterns.

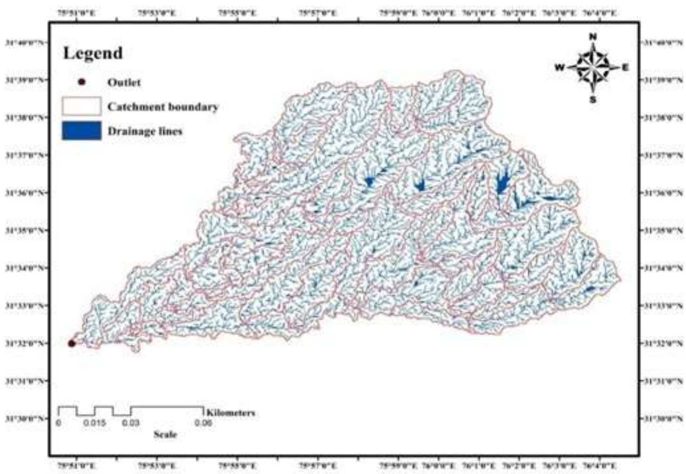

Fig. 8 Drainage network map of the study area

4.2.2 Drainage Texture

Drainage texture is one of the important concepts of geomorphology and is defined as the total number of stream segments of all orders in a basin divided by the perimeter of the basin. It indicates the relative spacing of drainage lines. Drainage texture depends on lithology, infiltration capacity and relief aspect of the terrain. It is the total number of stream segments of all orders per perimeter of that area [Horton, 1945]. Smith (1939) has classified drainage texture into five different textures, i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). The drainage texture of the study area varies from 1.9 to 14.86 (Figure 10) for all the sub-watersheds. Hence, drainage texture varies from very fine to very coarse.

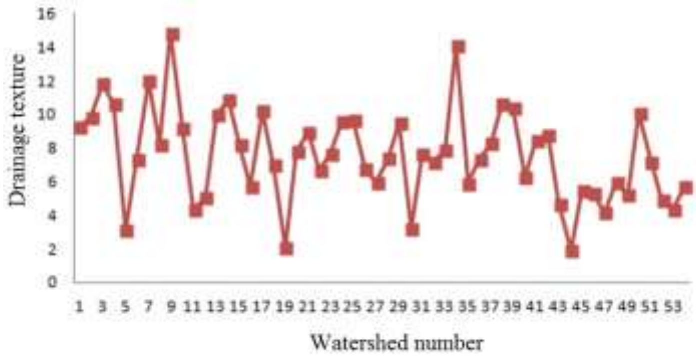

Fig. 9 Variation of drainage texture for all the watersheds

Table 3 gives the ranges of other areal aspect parameters determined for the study area.

Table 2 Areal aspects of study area

Sr. No.	Areal Aspects	Estimated values of subwatersheds
1	Stream Frequency, F_s	22.98 – 43.77
2	Elongation ratio, R_e	0.73 – 0.98
3	Circularity ratio, R_c	0.09 – 0.39
4	Form factor ratio, R_f	0.42 – 0.76
5	Shape factor, R_s	1.32 – 2.37
6	Infiltration number, I_f	128.36 – 389.28
7	Length of overland flow (Km), L_g	0.05 – 0.12
8	Constant of channel maintenance, C	0.1 – 0.23
9	Compactness coefficient, C_c	1.6 – 3.4

The values of stream frequency indicate an increase in stream population with respect to the drainage density of the basin. The range of elongation ratio of the study area shows that shape of watershed varies from oval to less elongate. Miller and Summerson (1960) have described the basin of the circularity ratios range 0.4 to 0.7 to be strongly elongated and highly permeable homogenous geologic materials. The circularity ratio of the study area shows that it does not come under the above range indicating its less strong elongated shape and near to highly permeable homogenous geologic materials for all the sub-watersheds. The form and shape factor range of the area indicates its elongated shape, less peak flow for longer duration and less runoff, but in case of watershed number 44 form factor ratios is 0.76 indicating its circular shape with high peak flows of shorter duration. High values of infiltration index of the study area indicate a high infiltration rate and low runoff in the watershed and vice-versa. Lower value of length of overland flow indicates high drainage density and less time for runoff to infiltrate.The mean compactness coefficient comes out to be 2.3.

4.3 Relief Aspects

Relief aspects which are calculated in the present study: Total basin relief (H), Height of basin mouth (z), Maximum height of the basin (Z), Relief ratio (R_{hl}) and Ruggedness number (R_n).

4.3.1 Height of basin mouth

Height of the basin mouth is the lowest point of elevation on the watershed or the outlet of the watershed. It is determined in Arc GIS 10.0 software and varies from 225 m to 379 m for all the sub-watersheds.

4.3.2 Maximum height of the basin

Maximum height of the basin is the highest point of elevation on the watershed. It is determined in Arc GIS 10.0 software and varies from 258 m to 574 m for all the sub-watersheds.

4.3.3 Total basin relief

The difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. The total basin relief for all the sub-watersheds varies from 12 m to 253.

4.3.4 Relief Ratio

The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line [Schumm, 1956]. The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin has been suggested by Schumm (1956) who found that sediment loss per unit area is closely correlated with relief ratios. In the present study, the value of relief ratio was found to vary from15. 13 to 107.91. It has been observed that areas with low to moderate relief and slope are characterized by moderate value of relief ratios. Low value of relief ratios is mainly due to the resistant basement rocks of the basin and low degree of slope.

4.3.5 Ruggedness Number

Strahler (1968) defined ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. Calculated accordingly the ruggedness number for all the sub-watersheds vary from 0.12 to 1.99. The low ruggedness value of watershed implies that the area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density.

V. IDENTIFICATION OF GROUNDWATER RE-CHARGES SITES SUITABLE FOR DIFFERENT SUB-BASINS

In order to locate the sites for groundwater recharge structures (Check Dams and Percolation Tanks), land use/land cover map of the study area was overlaid on drainage map of all the sub-basins as shown in Fig. 10.

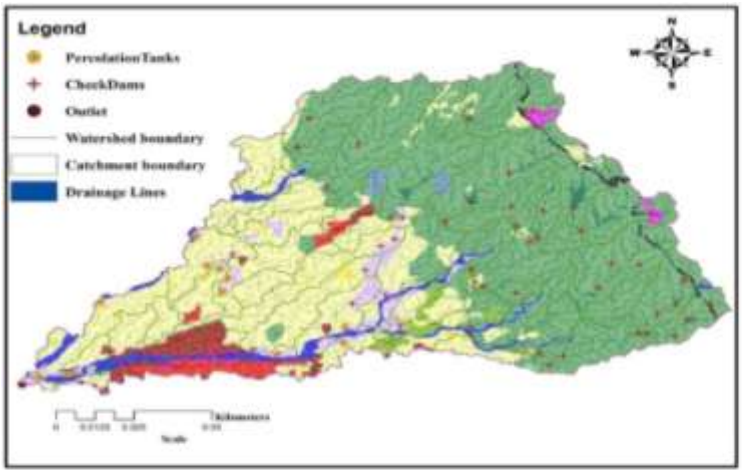

Fig. 10. Identification of suitable sites for constructing artificial groundwater recharge sites in the study area

From this figure areas having high permeability like Barren / Uncultivable / Wastelands, Scrub land; Barren / Uncultivable / Wastelands, Sandy area; Forest deciduous and Forest, Scrub forest were identified as areas suitable for locating groundwater recharge structures in a sub-basin. Water conservation structures suitable for different zones were identified on the basis of morphometric parameters. Higher values of bifurcation ratio and lower values of elongation ratio suggest for a check dam due to low soil permeability and high erosion rate. Whereas, lower values of ruggedness number suggest percolation tanks (Rais and Javed 2014). Based on the above discussion, sub-basins namely 3, 16, 23, 27, 49 have high mean bifurcation values $(R_{bm} > 7)$ which suggests sites for a check dam; while, sub-basins namely 1, 2, 3, 4, 7, 9, 13, 14, 17, 20, 21, 24, 25, 26, 28, 29, 32, 34, 38, 39, 41, 42 were having low elongation ratio values $(R_e < 0.8)$ also suggests sites suitable for check dams. On the other hand, sub-basins namely 10, 11, 12, 19, 20, 21, 22, 30, 31, 32, 33, 35, 38, 41, 43, 44, 45, 46, 47, 48, 50, 51, 52, 53, 54 have low ruggedness number values $(R_n < 0.5)$ which suggest selection of a percolation tank. By considering all the above situations based on morphometric parameters thirty one sub-basins suggests for groundwater recharge structures like check dam and percolation tanks (Table 4).

Table 4 Detailed description of selection of suitable sites for artificial groundwater recharges structures

Sr. No.	Watershed No.	Stream Order	Proposed Structure	Land Use / Land Cover
1	1	Fourth	Check dam	Forest deciduous
2	2	Fourth	Check dam	Forest deciduous
3	3	Fourth	Check dam	Forest deciduous
4	4	Third	Check dam	Barren/Uncultivable/Wastelands, Scrub land; Forest deciduous
5	7	Second, Fourth	Check dam	Forest deciduous; Barren/Uncultivable/Wastelands, Sandy Area
6	9	Second	Check dam	Forest deciduous
7	13	Second	Check dam	Forest deciduous
8	14	Fourth	Check dam	Barren/Uncultivable/Wastelands, Scrub land; Forest deciduous
9	16	Third	Check dam	Forest deciduous
10	17	Fourth	Check dam	Barren/Uncultivable/Wastelands, Sandy Area
11	20	First, Second	Percolation tanks	Barren/Uncultivable/Wastelands, Sandy Area
12	21	First, Second, Third	Check dam, Percolation tanks	Barren/Uncultivable/Wastelands, Sandy Area
13	23	Third	Check dam	Barren/Uncultivable/Wastelands, Sandy Area
14	24	Second	Check dam	Barren/Uncultivable/Wastelands, Sandy Area
15	25	Second	Check dam	Forest deciduous
16	26	Second	Check dam	Barren/Uncultivable/Wastelands, Sandy Area
17	27	Third	Check dam	Forest deciduous
18	28	Fourth	Check dam	Barren/Uncultivable/Wastelands, Sandy Area
19	29	Second	Check dam	Barren/Uncultivable/Wastelands, Sandy Area
20	32	First, Third	Check dam, Percolation tanks	Barren/Uncultivable/Wastelands, Sandy Area
21	33	Second	Percolation tanks	Barren/Uncultivable/Wastelands, Sandy Area
22	34	Third	Check dam	Forest deciduous

23	38	Second, Third	Check dam, Percolation tanks	Barren/Uncultivable/Wastelands, Sandy Area
24	39	Second	Check dam	Forest deciduous
25	41	Second	Check dam	Forest deciduous
26	42	Third	Check dam	Barren/Uncultivable/Wastelands, Sandy Area
27	45	First	Percolation tanks	Barren/Uncultivable/Wastelands, Sandy Area
28	46	First	Percolation tanks	Forest, Scrub forest
29	49	Third	Check dam	Barren/Uncultivable/Wastelands, Sandy Area
30	51	Second	Percolation tanks	Barren/Uncultivable/Wastelands, Sandy Area
31	54	First, Second	Percolation tanks	Barren/Uncultivable/Wastelands, Sandy Area

VI. CONCLUSION

Quantitative geomorphologic analysis of the watershed gives us an idea about the characteristics of the watershed. Table 2 and Table 3 give a detailed description of the morphometric parameters evaluated for all the 54 sub-watersheds in the present study. The drainage network of all the sub-watersheds shows dendritic to sub-dendritic patterns. The stream number decrease with increase in stream order for all the sub-basins. The mean bifurcation ratio values suggests that sub-basin number 2, 4, 5, 6, 8, 9, 10, 12, 13, 15, 18, 20, 24, 25, 30, 31, 33, 35, 37, 39, 42, 44, 47, 48, 50, 51, 52, 54 falls under normal basin category and in which the geologic structures do not distort the drainage pattern, while, all the other sub-basins do not fall under normal basin category. High values of ruggedness number show the areas which are prone to soil erosion and high relief ratio values suggests a high degree of slopes with high surface runoff. The morphometric parameters evaluated through remote sensing data and GIS are of high importance and weightage for structuring a framework for developmental process in the study region. Land Use/Land Cover and morphometric analysis of the study area revealed that thirty-one sub-basins out of fifty-four were found to be suitable for constructing artificial groundwater recharge structures. Present study demonstrates that advancement in the Remote Sensing and GIS technologies provide an effective analytical tool which makes the watershed management relatively easier.

REFERENCES

[1] J. I. Clarke, Morphometry from Maps, *Essays in Geomorphology*. Elsevier publication.Co. New York, 1996, 235-274.

[2] Faniran, A. (1968), The index of drainage intensity – A provisional new drainage factor, Australian Journal of Science, 31, pp. 328-330.

[3] Ganapuram, S., Vijaya Kumar, G.T., Murali Krishna, I.V., 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 40 (2009) 506–518.

[4] Gardiner, V. (1975), Drainage basin morphometry. British Geomorphological Group, Technical Bulletin, 14, pp. 48.

[5] Gregory, K.J., and Walling, D.E. (1968), The variation of drainage density within a catchment. International Association of Scientific Hydrology - Bulletin, 13, pp. 61-68.

[6] Gravelius, H. (1914), Flusskunde, Goschen'scheVerlagshandlung, Berlin.

[7] Horton, R.E. (1932), Drainage basin characteristics. Transactions American Geophysical Union, 13, pp. 350-61.

[8] Horton, R.E (1945), Erosional development of streams and their drainage basins; Hydro physical Approach to Quantitative Morphology. Geol. Soc. Am. Bull., 56, pp. 275-370.

[9] Jadhav, S. I. and Babar, M. (2013), Morphometric Analysis with Reference to Hydrogeological Repercussion on Domri River Sub-basin of Sindphana River Basin, Maharashtra, India. Journal of Geosciences and Geomatics, 2013, Vol. 1, No. 1, 29-35.

[10] Khan, M.A., Gupta, V.P. and Moharana, P.C (2001), Watershed prioritization using remote sensing and geographical information system: a case study from Guhiya (India), Journal of Arid Environments, 49, pp. 465-475.

[11] Kiran, V. S. S. and Srivastav, Y. K. (2012), Check Dam Construction by Prioritization of Micro Watershed, using Morphometric Analysis as a Perspective of Remote Sensing and GIS for Simlapal Block, Bankura, W.B. Bonfring International Journal of Industrial Engineering and Management Science, Vol. 2, Special Issue 1. ISSN 2277 - 5056.

[12] Melton, M.A. (1958), Geometric properties of mature drainage systems and their representation in E4 Phase Space. Journal of Geology, 66, pp. 35-54.

[13] Miller, O.M. and Summerson, C.H. (1960), Slope zone maps. Geographical Review, 50, pp. 194-202.

[14] Nag, S.K. (1998), Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. Journal of Indian Society of Remote Sensing, 26 (1), pp. 69-76.

[15] NookaRatnam, K., Srivastava, Y.K., VenkateswaraRao, V., Amminedu, E. and Murthy, K.S.R (2005), Check dam Positioning by Prioritization of Microwatersheds using SYI model and MorphometricAnalysis - Remote sensing and GIS Perspective. J. Indian society of Remote Sensing, 33 (1) pp. 25-38

[16] Rais, S and Javed, A (2014), "Identification of Artificial Recharge Sites in Manchi Basin, Eastern Rajasthan (India) Using Remote Sensing and GIS Techniques". Journal of Geographic Information System, 2014, 6, 162-175.

[17] Schumm, S.A. (1956), Evolution of drainage systems and slopes in Badlands at Perth Anboy, New Jersey. Bulletin of the Geological Society of America, 67, pp. 597-646.

[18] Sethupathi A.S, Lakshmi Narasimhan C, Vasanthamohan V, and Mohan S.P. (2011),Prioritization of miniwatersheds based on Morphometric Analysis using Remote Sensing and GIS techniques in a draught prone Bargur – Mathur sub-watersheds, Ponnaiyar River basin, India. International Journal of Geomatics and Geosciences,Volume 2, No. 2. ISSN 0976 – 4380.

[19] Singh, N. (1990), Geomorphology of Himalayan rivers (a case study of Tawi basin), Jay Kay Book House, Jammu Tawi.

[20] Singh, S., and Singh, M.C. (1997), Morphometric analysis of Kanhar river basin.National Geographical Journal of lndia, 43 (1), pp. 31-43.

[21] Smith, G.H. (1939), The morphometry of Ohio: The average slope of the land (abstract), Annals of the Association of American Geographers, 29, pp. 94.

[22] Sreedevi, P.D., Owais, S., Khan, H.H. and Ahmed, S. (2009) Morphometric Analysis of a Watershed of South India Using SRTM Data and GIS. Journal Geological Society of India Vol.73, April 2009, pp. 543-552.

[23] Sreedevi, P.D., Subrahmanyam, K. and Ahmed, S. (2004) The Significance of Morphometric Analysis for Obtaining Groundwater Potential Zones in a Structurally Controlled Terrain. Environmental Geology, Vol. 47, No. 3, 2004, pp. 412-420.
[24] Strahler, A.N. (1952), Dynamic basis of geomorphology.Bulletin of the Geological Society of America, 63, pp. 923- 938.
[25] Strahler, A.N. (1957), Quantitative analysis of watershed geomorphology. Transactions American Geophysical Union, 38, pp. 913-920.
[26] Strahler, A.N (1964), Quantitative geomorphology of drainage basins and channel networks. In: V.T. Chow (Ed), Handbook of Applied Hydrology. McGraw Hill Book Company, New York, Section 4II.
[27] Strahler, A.N. (1968), Quantitative geomorphology In: Fairbridge, R.W. (Eds), The Encyclopedia of geomorphology, Reinhold Book Crop, New York.