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Drainage Basin Morphometry for Identifying Zones for Artificial Recharge: A Case Study from the Gagas River Basin, India

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Abstract: Drainage basin morphometry is a quantitative way of describing the characteristics of the surface form of a drainage basin and provides important information about the region's topography and underlying geological structures. It plays an important role in hydrogeological investigations for delineating zones of adequate groundwater potential and selecting sites for construction of artificial recharge structures.

In the present study an attempt was made to discover the stream properties in the Gagas River Basin of Almora district in the state of Uttarakhand using the various stream attributes. Based on the study the potential zones for the construction of artificial recharge structures in the basin were identified.

Keywords: Drainage Basin morphometry, Gagas Basin, Artificial recharge, Groundwater.

INTRODUCTION

Basin morphometry refers to the measurements of Basin shapes. Drainage basin morphometry plays a significant role in determining the groundwater potential of a given area and suitable places for artificial recharge. Morphometric features such as basin shape and basin relief influence the nature of hydrographs and hydrological variables. Drainage pattern provides information on the topography and underlying geological structure. Drainage density varies with relative age, differing geology, drainage area etc and enables comparisons of basins and streams.

Drainage basin morphometry of the Gagas Basin, Almora was carried out using the SRTM DEM data (http://srtm.usgs.gov/data/obtaining.html). The Gagas River Basin has been designated as an evolving HELP basin. HELP (Hydrology for Environment, Life and Policy) is a cross-cutting program of UNESCO led by the International Hydrological Program (www.unesco.org/water/ihp/help/).

An attempt is made hereto find out holistic stream properties from the measurements of various stream attributes and identifying zones for artificial recharge.

STUDY AREA

Gagas River basin covers an area of 510 km^2 and lies between the latitudes 29°51'55" N and 29°35'49" N and longitudes 79°20'36" E and 79°33'15" E in the Almora district of the Uttarakhand (Fig.1). The topography of the region varies from 2746 m above mean sea level in the head reaches of the Gagas River in the Northeastern part to 762 m above mean sea level at the mouth of the Gagas River in the western part of the basin. The average elevation of the river basin is about 1381 m above mean sea level.

Geologically the study area is a part of the Lesser Himalayan Zone (Valdiya, 1988). In the Gagas Basin the most frequent rock type is mica-schist. It is usually finely foliated. The main component is mica. Often quartz dykes concordant to the foliation are visible. On some locations the original material is impregnated to form quartzitic rocks. Granite-gneissic outcrops are seen at some localities. Bands of granite-gneiss disintegrate on weathering into quartz and feldspars. The silica grains possess voids when put together and become permeable due to increased porosity. Such beds are seen in Ranikhet. Weathering of the granite-gneisses provides enough porosity for water to infiltrate to form water storage. Phyllite bands are impervious (Pal, 2002).

Morphologically the region is characterized by a series of deeply incised river valleys and high ridges. The major rivers are meandering and often surrounded by flood plains. This is the case in the north to south heading section of the Gagas and the Riskana. When the rivers are heading to the west they usually cut deep into the rocks and have no widespread flood plains. These deep gorges result from high erosive power of the river system (Kharkwal, 1993).

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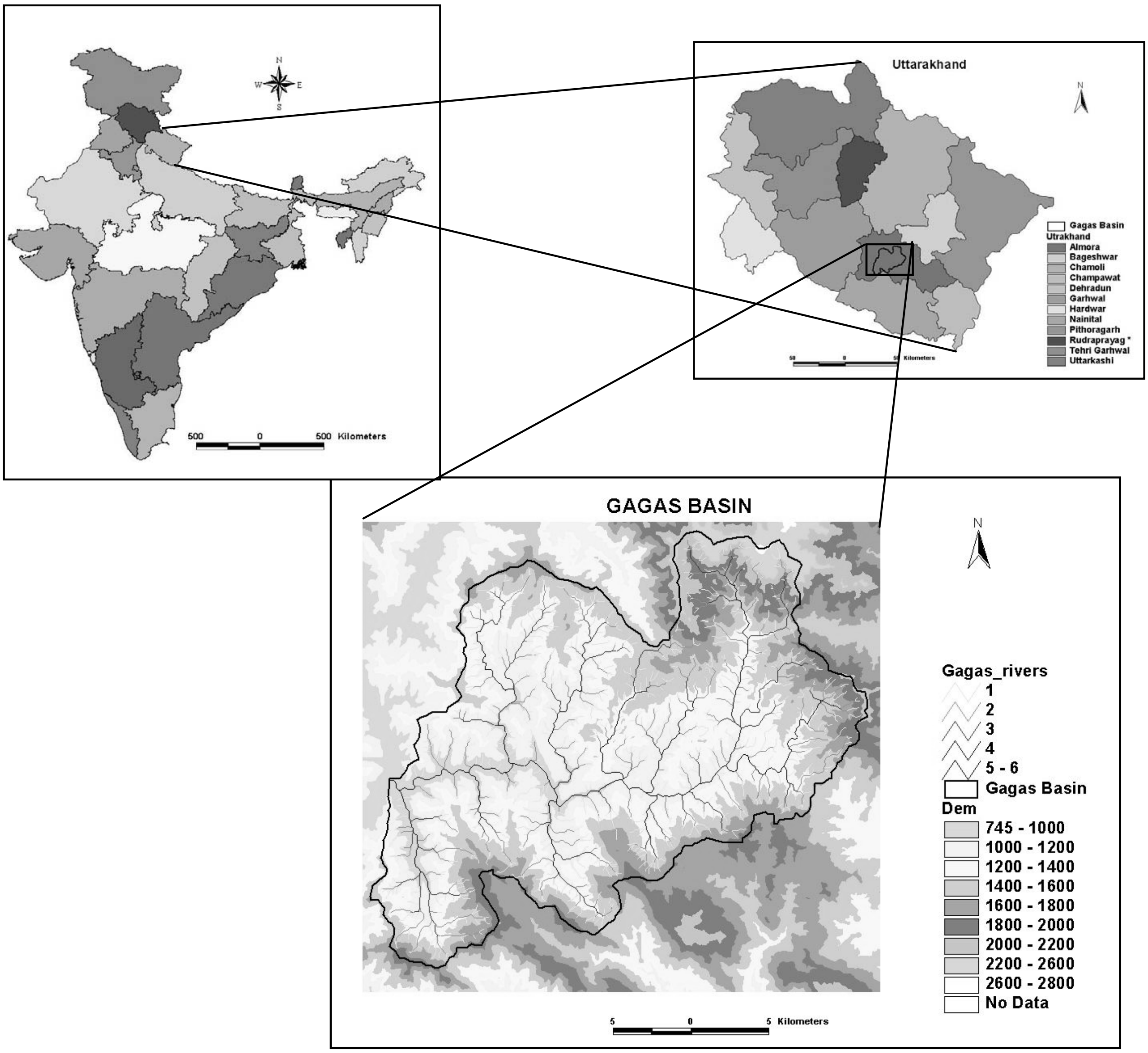

Fig.1 Location Map of the Gagas River Basin.

More than 80% of the annual precipitation in the region occurs during the southwest monsoon, which starts in the third week of June and can last till mid-October (Asthana, 2003). Of the remaining, 15% rainfall is caused by cyclones and 5% by local thunderstorms distributed over the rest of the year (Jalal, 1988). The temperature of the region varies from about 30°C in summers to about -2°C in winter.

METHODOLOGY

The morphometric analysis of the Gagas Basin was carried out on the basis of the available DEM data from SRTM, (http://srtm.usgs.gov/data/obtaining.html). The DEM from SRTM is available on 90 m by 90 m spatial resolution. Using Watershed Analysis Tools in ArcView, the Gagas Basin was further subdivided into 13 sub-basins. The drainage channels were classified into different orders using Strahler’s 1964 classification. Other basin parameters such as basin area, basin perimeter, basin length and stream length were obtained which were further used to obtain the different ratios such as Drainage Density, Drainage Texture, Bifurcation Ratio, Stream Length Ratio, Stream Frequency, Form Factor, Elongation Ratio, and Circulatory Ratio.

RESULTS AND DISCUSSIONS

The total drainage area of the Gagas basin is 512 km^2. The basin was further divided into 13 sub-basins for analysis,

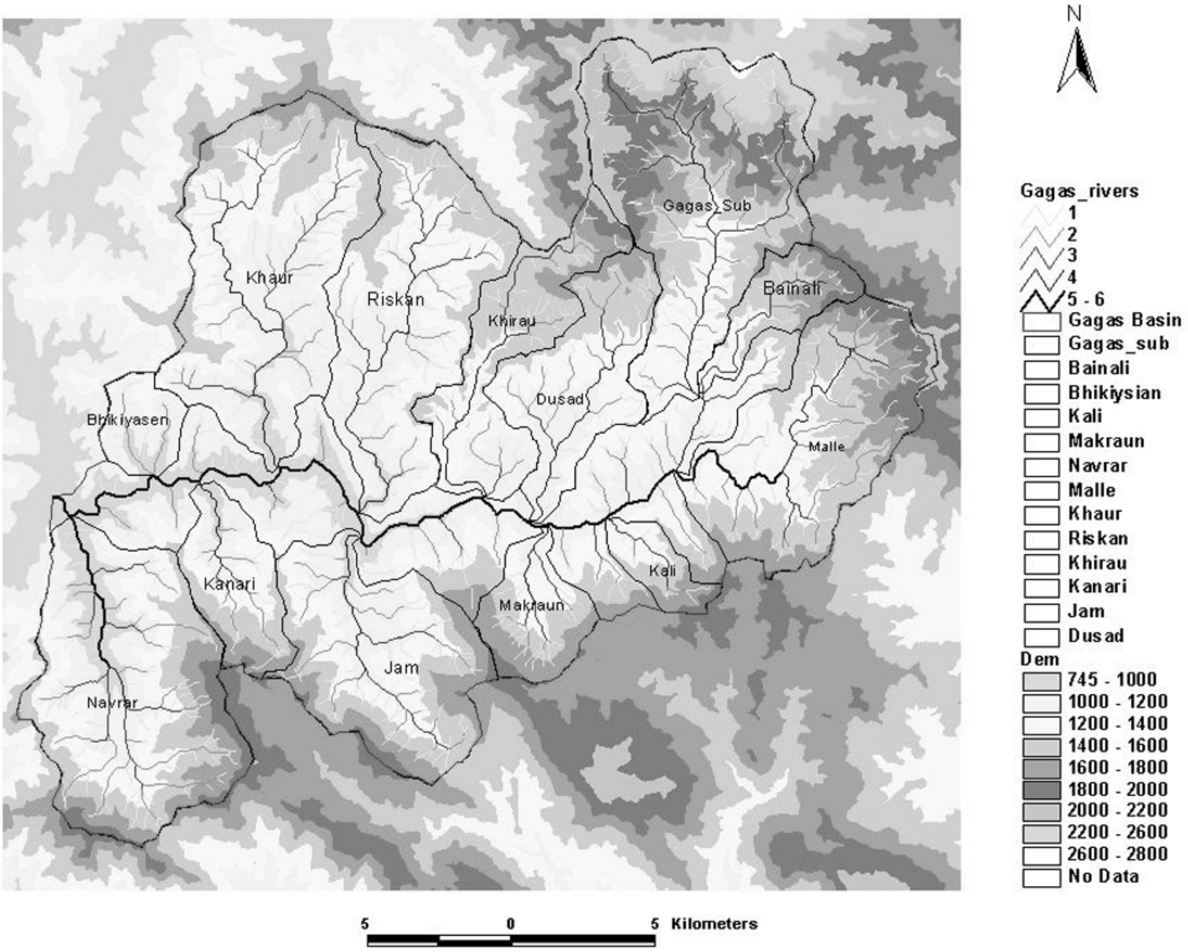

Fig.2. Gagas Basin with the different sub-basins.

(Fig.2). The basin demarcation has been carried out in GIS using the DEM data obtained from SRTM. Some small areas are left between the 13 sub-basins which are a part of the Gagas basin. The drainage pattern is dendritic in nature and is influenced more by the general topography of the area rather than by any structural control. The areas of the different sub-basins are given in Table 1.

Drainage Density

Drainage Density is defined as the total stream length in a given basin to the total area of the basin, (Strahler. 1932, 1945). It is related to various features of landscape dissection such as valley density, (Montgomery and Dietrrich, 1994; Tucker and Bras, 1998), channel head source area, (Montgomery and Dietrich, 1989), climate and vegetation, (Moglen et al. 1998), soil and rock properties, (Smith, 1958; Kelson and Wells, 1989), relief (Montgomery and Dietrich, 1988) and landscape evolution processes. Strahler (1964) noted that low drainage density is favored when basin relief is low and vice-versa.

The drainage density varies from 1.44 to 1.93 for the various sub-basins in the Gagas Basin, (Table 1). The drainage density for the entire Gagas Basin is 1.64. A low

Table 1. Area, drainage density, drainage texture and bifurcation ratio of the Gagas Basin and the Sub-basins

Basin	Area (km^2)	Drainage Density (km/km^2)	Bifurcation Ratio	Drainage Texture
Bhikiyasen	8.07	1.44	7.50	3.04
Riskan	51.16	1.53	4.53	3.54
Kali	6.75	1.59	3.83	4.23
Dusad	26.56	1.62	3.64	3.65
Gagas_sub	63.51	1.62	5.17	4.30
Kanari	16.11	1.63	3.28	4.26
Khaur	61.60	1.66	5.11	4.22
Malle	47.32	1.69	3.19	4.01
Jam	41.61	1.70	4.43	4.45
Bainali	11.22	1.72	4.70	4.30
Navrar	55.39	1.77	3.56	3.67
Khirau	27.49	1.79	3.78	4.50
Makrun	13.76	1.93	3.21	5.75
Gagas	512.60	1.64	4.19	4.08

drainage density indicates permeable subsurface strata and is a characteristic feature of coarse drainage which generally shows values less than 5.0.

Drainage Texture

Drainage texture is a product of drainage density and stream frequency, (Smith, 1950). The drainage texture of the Gagas Basin is 4.08, (Table 1) which is at the border of coarse and intermediate textures. However, the textures of the sub-basins vary from 3.04 to 5.75. Generally, texture below 4 is designated as coarse and 4 to 10 as intermediate, (Smith 1950). Bhikiyasen, Riskan, Dusad and Navrar sub-basins show a coarse texture having a value of less than 4.

Bifurcation Ratio

Bifurcation Ratio is defined as the ratio of the number of streams of any given order to the number of streams in the next lower order. The average of all these ratios gives the bifurcation ratio. The term was introduced by Horton in 1932.

The bifurcation ratio for the Gagas Basin is 4.19 and it varies from 3.19 to 7.50 for the 13 sub-basins (Table 1). If the bifurcation ratio is low, there will be high chance of flooding as the water will tend to accumulate in one channel rather than spreading out. Chow (1964) stated that the values of bifurcation ratio lies between 3 to 5 for watersheds where geological structures do not have an influence on the drainage pattern. However, the Bhikiyasen sub-basin shows an average bifurcation ratio of 7.5. This is mainly due to the fact that the basin area is very small and consists only of 1st and 2nd order streams and there is a big difference in the frequencies between the successive orders.

Stream Order

The stream order has been demarcated on the basis of Strahler (1964) stream ordering system. The number of streams gradually decreases as the stream order increases. The Gagas Basin has been designated as a 6th order basin. The stream order and the total number of stream segments in each order for the different sub basins have been given in Table 2.

Table 2. Stream order and number of stream for the Gagas Basin

Basin	I order	II order	III order	IV order	V order	VI order	Total 1
Bhikiyasen	15	2	-	-	-	-	17
Kali	14	3	1	-	-	-	18
Bainali	22	5	1	-	-	-	28
Kanari	30	9	2	1	-	-	42
Khaur	127	25	4	1	-	-	157
Jam	86	18	4	1	-	-	109
Khirau	52	13	3	1	-	-	69
Makrun	30	7	3	1	-	-	41
Dusad	46	10	3	1	-	-	60
Riskan	92	20	5	1	-	-	118
Gagas-sub	129	33	5	1	-	-	168
Navrar	123	22	7	2	1	-	155
Malle	85	19	5	2	1		112
Gagas	995	215	48	11	2	1	1272

The variation in the number of stream orders for the different sub-basin is a result of the variation in the physiographic conditions of the region. Moreover, less number of streams in a given basin shows the presence of a mature topography and at the same time presence of a large number of streams indicates the topography is still undergoing erosion.

Stream Length

Horton's law of stream length states that geometrical similarity is maintained in the basins of increasing orders. The length of stream is maximum in case of first order. The law holds true in case of Gagas Basin also. The length of the first order stream is maximum in all the 13 sub-basins, (Table 3).

Table 3. Stream length (in kilometers) for the different orders for Gagas Basin

Basin	I order	II order	III order	IV order	V order	VI order	Total
Bhikiyasen	5.637	5.995	-	-	-	-	11.63
Kali 5.544	1.339	3.831	-	-	-	10.71	
Bainali	8.52	2.578	8.247	-	-	-	19.35
Kanari	12.881	7.457	2.546	3.446	-	-	26.33
Khaur	53.353	23.31	12.954	12.361	-	-	101.98
Jam 37.88	19.163	8.135	5.581	-	-	70.76	
Khirau	22.663	11.08	7.566	7.974	-	-	49.28
Makrun	15.931	3.039	4.4	3.194	-	-	26.56
Dusad	16.461	14.767	4.065	7.631	-	-	42.92
Riskan	35.335	21.765	8.407	12.941	-	-	78.45
Gagas-sub	48.368	28.009	15.457	11.31	-	-	103.14
Navrar	46.835	29.813	13.691	1.838	5.835	-	98.01
Malle	35.578	26.178	4.812	7.645	5.869	-	80.08
Gagas	403.427	220.292	101.856	76.671	39.174	1.26	842.68

Stream Length Ratio

The stream length ratio is the ratio between the lengths of streams in a given order to the total length of streams in the next order. The stream length ratios for the Gagas Basin (Table 4) and other sub-basins vary widely and are strongly dependant on the topography and the slope. The stream length ratio has an important relationship with the surface flow discharge and the erosional stage of the basin.

Table 4. Stream length ratio for the different orders for Gagas Basin

Basin	1/2	2/3	3/4	4/5	5/6
Bhikiyasen	0.94				
Kali	4.14	0.35			
Bainali	3.30	0.31			
Kanari	1.73	2.93	0.74		
Khaur	2.29	1.80	1.05		
Jam	1.98	2.36	1.46		
Khirau	2.05	1.46	0.95		
Makrun	5.24	0.69	1.38		
Dusad	1.11	3.63	0.53		
Riskan	1.62	2.59	0.65		
Gagas-sub	1.73	1.81	1.37		
Navrar	1.57	2.18	7.45	0.31	
Malle	1.36	5.44	0.63	1.30	
Gagas	1.83	2.16	1.33	1.96	31.19

Stream Frequency

According to Horton (1945) stream frequency is defined as the ratio of the total number of stream segments of all the orders in the basin to the total area of the basin. The stream frequency for the Gagas basin is 2.48/km^2 (Table 5). The stream frequency is dependant more or less on the rainfall and the temperature of the region.

Table 5. Stream frequency, lenght, form factor, elongation ratio and circulatory ratio for the Gagas Basin

Basin	Stream frequency	Length (km)	Form Factor	Elongation ratio	Circulatory ratio
Bhikiyasen	2.11	3.64	0.61	0.88	0.81
Riskan	2.31	13..10	0.30	0.62	0.44
Kali	2.67	4.78	0.30	0.61	0.56
Dusad	2.26	10.40	0.25	0.56	0.38
Gagas_sub	2.65	13.60	0.34	0.66	0.47
Kanari	2.61	7.10	0.32	0.64	0.57
Khaur	2.55	13.06	0.36	0.68	0.57
Malle	2.37	10.10	0.46	0.77	0.57
Jam	2.62	8.95	0.52	0.81	0.55
Bainali	2.50	6.41	0.27	0.59	0.41
Navrar	2.08	11.65	0.41	0.72	0.63
Khirau	2.51	11.36	0.21	0.52	0.27
Makrun	2.98	5.38	0.48	0.78	0.68
Gagas	2.48	30.84	0.54	0.83	0.41

Basin Length

According to Gregory and Walling (1973) basin length is the longest length of the basin from the head waters to the point of confluence. The Gagas River originates in the Pandukholi forests and joins the Ramganga River near Bhikiyasen village. The length of the Gagas Basin is 30.84 km, (Table 5). The length of the other sub-basins has been given in Table 5.

Form Factor

Form factor is defined as the ratio of the basin area to the square of the basin length. Long narrow basins have larger lengths and hence smaller form factors. Circular basins have intermediate form factors, which are close to one. Short wide basins have the largest form factors. Gagas Basin has a form factor of 0.54, (Table 5). Among the sub-basins Bhikiyasen is the closest to a circular basin with a form factor of 0.61 and Khirau is the most elongated sub-basin with a form factor of 0.21.

Elongation Ratio

It is defined as the ratio of the diameter of a circle with the same area as the basin to the basin length. The elongation ratio of the Gagas Basin is 0.83, (Table 5). It is believed that the elongated shapes of the basins are due to the guiding effect of thrusting and faulting in the basin.

Circulatory Ratio

It is defined as the ratio of the basin area to the area of the circle having the same perimeter as the basin. This factor is influenced more by the lithological characteristics of the basin rather than anything else. The low, medium and high values of the circulatory ratio are indications of the youth mature and old stages of the life cycle of the tributary basins. Gagas Basin shows a circulatory ratio of 0.41 (Table 5), whereas Bhikiyasen appears to be the most mature sub basin with a circulatory ratio of 0.81, and Khirau sub basin is in the youth stage of its development with a circulatory ratio of 0.27. This anomaly is mainly due to the diversity of slope and relief present in the basin.

Slope

Due to the rugged nature of the terrain the area shows a high relief ratio and the average slope of the region is about 18.5°. However, the 4th orders streams and beyond are characterized by slope of less than 10° (Fig.3) and are potential sites for construction of check dams and traditional artificial recharge structures.

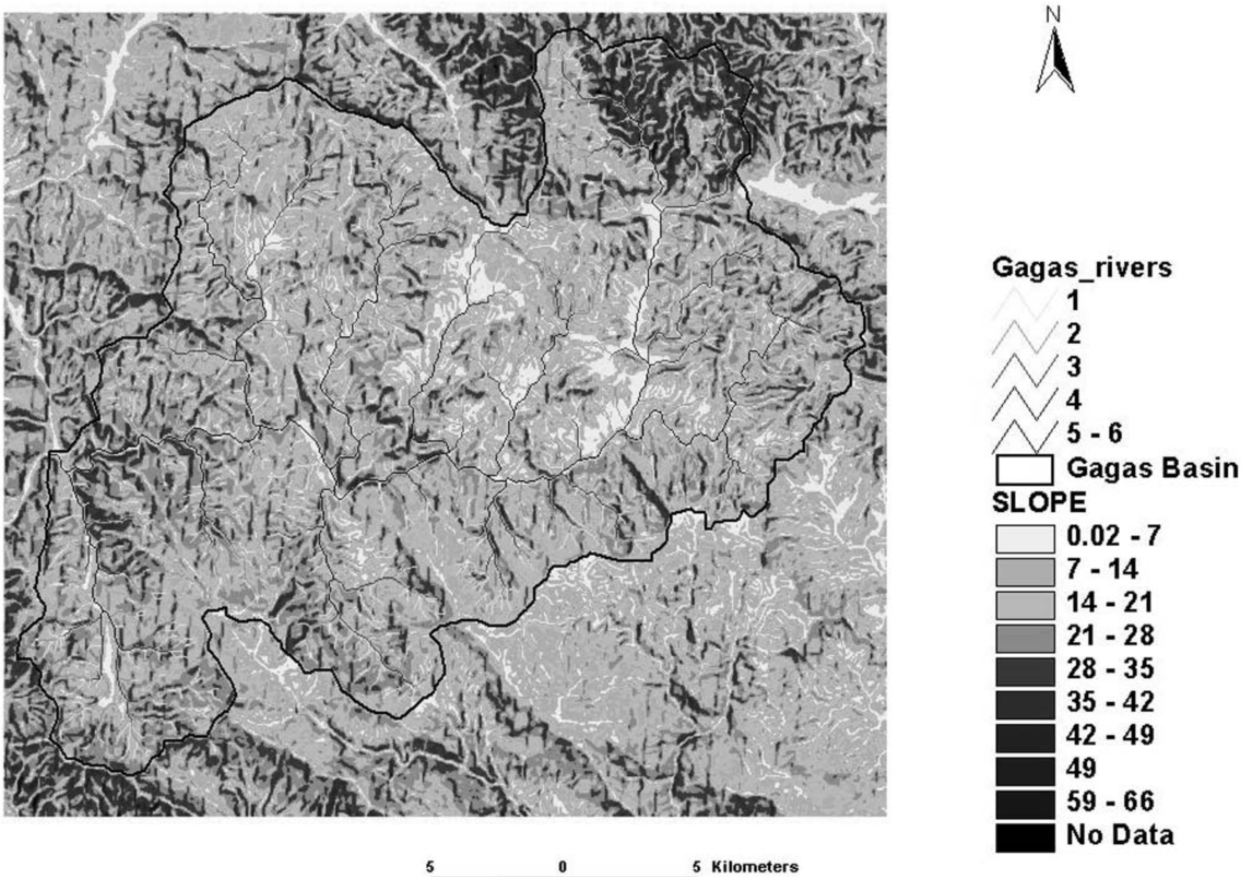

Fig.3. Slope map of the Gagas River Basin.

CONCLUSIONS

Based on the stream order Gagas Basin has been designated as a 6th order basin. The drainage density of the Gagas River Basin and the sub-basins reveals that the nature of sub-surface strata is permeable as the drainage density values are less than 5. Such type of drainage density values constitutes a characteristic feature of coarse drainage and shows good potential for the construction of artificial recharge structures. The mean bifurcation ratio of the Gagas Basin is about 4.19 indicating that the drainage pattern is not much influenced by geological structures.

In the present scenario where water resources are becoming scarce, this exercise of calculating the various attributes of a drainage basin plays a significant role in locating sites for artificial recharge structures.

However, a comparison of all the thirteen basins shows that the Bhikiyasen, Riskan and Kali sub-basins have the lowest drainage density, and hence are better suited for construction of recharge structures.

From the DEM map of the basin, it is noticed that the stream segment up to the 3rd order is traversed by high altitude and steep slopes, whereas the 4th, 5th and 6th order streams fall in relatively flat zones and these sites are important locations for the construction of check dams in the area.

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