Hydrological-drainage analysis for evaluation of groundwater potential in a watershed basin of southern Karnataka, India: A remote sensing and GIS approach

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Abstract

Development of watershed basins is necessary to evaluate the regional characteristics and identify the potential of groundwater recharge zones. A combination of morphometric analysis and hydrogeological information were used to evaluate the potential of groundwater and develop watershed plans. Hydrological-drainage characteristics of all the seven watersheds (I-VII) of the Gurpur River basin have been analyzed using IRS-P6, LISS-III remotely sensed satellite image of 2008 in conjunction with Survey of India, topographical maps (1:50,000 scale). Sub-watershed-wise morphometric parameters - linear, areal and relief - were computed using established mathematical equations and GIS techniques. The average values of bifurcation ratio (Rb) of sub-watersheds indicate the structural control is not as pronounced as the geomorphic control for development of drainage network. Analysis of the shape parameters such as form factor (Ff), elongation ratio (Re), circularity ratio (Rc) suggests that the Gurpur basin is in an elongated form. Computed value of stream frequency (Fs) in the sub-basins II, III and VI indicates the occurrence of steep ground slopes, with less permeable rocks while drainage density (Dd) indicates the nature of the surface strata of the river basin is moderately permeable. Based on morphometric prioritization results high priority value was found in sub-watersheds III, II and so on.

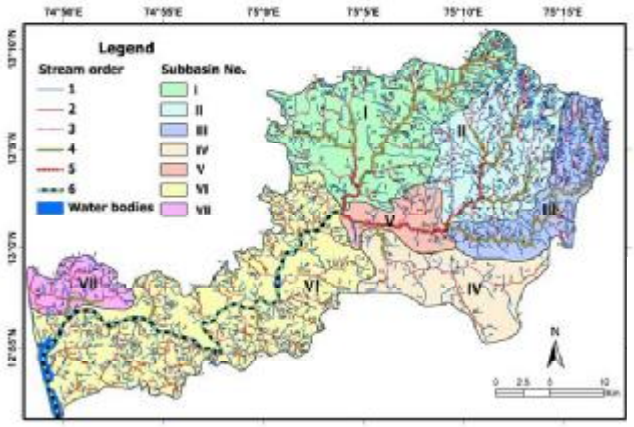
Keywords: *Morphometric analysis, Watershed prioritization, Gurpur River, Southern Karnataka, India*

Introduction

Enhancement of groundwater recharge potential by development of watershed basins is a major issue due to an acute shortage of groundwater resources on which urban/rural livelihood depends in some parts of India. It is necessary to evaluate the regional characteristics in order to identify the potential of groundwater recharge zones. Analysis morphometric parameters such as linear, areal and relief is a major advancement in the quantitative study of the geometry of river basin which helps in understanding the influence of drainage morphometry on landforms and their characteristics [1; 2].

Total drainage area of the Gurpur River basin is 837 km^2 which lies between latitudes 12°52' - 13°11'N and longitude 74°48' - 75°17'E in Dakshina Kannada district, southern Karnataka, India (Fig. 1). It is a sixth-order stream with a total length of ~87 km channel. Geologically the basin area is overlaid by the Pliocene to Recent laterite capped plateaus and alluvium over the gneisses and continental type of sedimentary deposits with dolerite and norite dikes [3]. The basin consists of gneisses of the Peninsular Gneissic Complex with enclaves of high

grade supracrustals [4]. The average annual maximum temperature is 30.9^{o} C and minimum is 23.7^{o} C. Annual average rainfall is ~3900 mm, of which about 80% is received during the southwest monsoon (June–September) months. In the present study, an attempt has been made to analyze hydrological-drainage / morphometric characteristics of all the seven watersheds (I-VII) of the Gurpur River basin (Fig. 1).



Materials and Methods

The data products employed in this study are Survey of India (SOI) topographical maps, No. 48 L/13, 48 O/4, 48 O/8 and 48 P/1 of 1:50,000 scale, and the geocoded Indian Remote Sensing Satellite (IRS) –P6, Linear Imaging Self Scanner (LISS–III, 23.5 m resolution) images of 2008, were used for systematic analysis of various morphometric, lithological and landform characteristics of the river basin. Based on drainage pattern, the basin was divided into seven sub-watersheds and morphometric analyses were carried out at sub-watershed level in ArcGIS (Fig. 1). The digital elevation model (DEM) was generated based on the contour values at 20 m interval to evaluate the height and slope of the basin. Drainage network of the basin was analyzed as per the laws of Horton [5] and stream ordering is made after Strahler [6]. Finally, prioritization of sub-watersheds was carried out by assigning weight factors to all the computed morphometric parameters.

Results and Discussion

Evaluation of morphometric parameters

Quantitative morphometric analysis gives information about the hydrological nature of the underlying geology, precipitation, exogenic and endogenic forces within the drainage basin. Various drainage patterns identified in the river basin are dendritic, trellis, rectangular, barbed and braided. Dendritic to sub-dendritic type of drainage is the most common in the study area because of homogeneous nature of the basement gneiss. Based on drainage orders, the Gurpur River basin has been classified as sixth order basin to analyse the linear, areal and relief morphometric parameters.

Linear parameters

Stream orders (U) of the Gurpur basin have been ranked according to Strahler [6] ordering system. Total number of streams in the sub-watersheds of the river basin varies from 35 to 609 in sub-watersheds V and VI respectively. The lower number of streams of sub-watershed

indicates maturity of topography, whereas higher number of streams (i.e., 1st & 2nd orders) indicates, the area is prone to erosion. *Stream length ratio (Rl)* is an important relationship with discharge of the surface flow and erosional stage of the basin [5]. The average Rl of all the seven sub-watersheds varies from 1.40-7.98. This indicates the rock formations in the area, drained by the 5th order streams, is gentler in slope and/or more permeable than the rock-surfaces drained by the lower order streams. *Bifurcation ratio (Rb)* is the ratio of any given order (U) to the number of streams (Nu) in the next higher order [6]. The computed value of the Rb of sub-watersheds and total Gurpur basin is less than 5 which indicates that structurally controlled development of drainage network is not as pronounced as the geomorphic control (Table 1).

Table 1. Morphometric parameters of sub-watersheds and total watershed basin of Gurpur River.

Parameters	I	II	III	IV	V	VI	VII	Whole basin
Area (A) (km^2)	179	127	82	87	39	288	36	837
Length (L) (km)	25	21	16	17	10	33	10	60
Number of streams (Nu)	339	366	276	55	35	609	71	1751
Stream length ratio (Rl)	1.62	1.89	3.59	1.70	7.98	1.54	1.40	3.52
Bifurcation ratios (Rb)	2.43	2.92	2.90	2.02	2.60	5.99	1.47	4.30
Form factor (Ff)	0.29	0.30	0.32	0.32	0.35	0.27	0.36	0.31
Elongation ratio (Re)	0.60	0.62	0.64	0.63	0.67	0.59	0.67	0.63
Circularity ratio (Rc)	0.40	0.62	0.36	0.41	0.42	0.27	0.49	0.42
Drainage density (Dd)	1.88	2.50	2.57	0.88	1.23	1.74	1.62	1.77
Stream frequency (Fs)	1.90	2.89	3.36	0.63	0.91	2.12	1.95	1.97
Const. channel maint. (C)	0.53	0.40	0.39	1.13	0.82	0.57	0.62	0.64
Basin relief (R)	1360	1720	1790	100	160	80	160	1850
Basin relief ratio (Rr)	0.063	0.107	0.106	0.007	0.020	0.006	0.013	0.033
Gradient ratio (Gr)	0.061	0.107	0.106	0.003	0.012	0.005	0.009	0.033
Ruggedness number (Rn)	2.55	4.31	4.60	0.09	0.20	0.31	0.13	3.28

Areal parameters

Form factor (Ff) is the ratio of the basin area (A) to the squared value of the basin length (L) [5]. The Ff varies from 0 (in highly elongated shape) to 1 (in perfect circular shape) [7]. The average value of Ff of the Gurpur basin is 0.31. In sub-watersheds (I-VII), the Ff varies from 0.29 (I) to 0.36 (VII) indicates the whole basin is in an elongated form (Table1; Fig. 1). *Elongation ratio (Re)* is the ratio between the diameter of a circle of the same area as the basin (D) and maximum basin length (L) [8]. The computed value of Re varies from 0.59 (VI) to 0.67 (V & VII) and these range are usually associated with high relief and steep ground slopes [8]. The average value of Re of the whole Gurpur basin is 0.63 refers to the fact that the basin is in an elongated shape (Fig. 1). *Circularity ratio (Rc)* is the ratio of the area of basin (A) to the area of the circle having the same circumference as the perimeter (P) of the basin [9; 6]. The value of Rc ranges from 0.27 - 0.62 in the sub-watersheds VII and II respectively (Table 1), is attributable to differences in geomorphological features in the Gurpur river basin. This indicates that the basin is not circular in shape and quantity of discharge is less. *Stream frequency (Fs)* is the ratio between the number of streams (Nu) for

all orders within a basin and the basin area (A). The computed Fs value in the Gurpur basin ranges from 0.63 (IV) - 3.36 (III) per km^2. High Fs values (>2 /km^2) indicate occurrence of steep ground slopes, with less permeable rocks, which facilitates greater runoff, less infiltration, sparse vegetation and high relief conditions. *Drainage density (Dd)* is the length of stream per unit area divided by the area of drainage basin [5]. In the Gurpur basin value of Dd ranges from 0.88 (IV) to 2.57 (III) per km, with an average of 1.77 / km. The Dd value less than 5 suggests that the nature of the surface strata of the river basin is permeable, which is a characteristic feature of a coarse-drainage density [10, 11]. *Constant of channel maintenance (C)* is the inverse of drainage density (Dd). The C value of sixth order Gurpur basin is 0.64 (Table 1), which indicates that on an average 0.6 km^2 of surface area is required to maintain one km of stream channel length. Sub-watersheds II and III have low 'C' value (<1) indicates that they are under the influence of structural disturbance, low permeability, steep to very steep slopes and high surface runoff, while high value indicates structural disturbances and less run off conditions.

Relief parameters

Basin relief (R) is the difference in elevation between the highest and the lowest point of the basin. The maximum height of the Gurpur River basin is 1870 m and the lowest is 20 m. Hence, the relief of the basin is 1850 m. Analysis of r*elief ratio (Rr)* of the Gurpur basin is 0.0328, whereas Rr value of sub-watersheds varies from 0.006 (VI) to 0.106 (II). The high Rr value indicates hilly region and low value is the characteristic of pediplain and valley. *Slope* analysis is an important parameter in geomorphic studies which controlled by climato-morphogenic processes in the area underlying the rocks of varying resistance. The Gurpur River basin area slope varies from 2.5^o to 87°. The maximum steepness was observed in sub-watersheds I, II and III. *Gradient ratio (Gr)* is an indication of channel slope from which the runoff volume could be evaluated. The basin has a gradient ratio of 0.328 while the value of sub-watersheds ranges from 0.003 (IV) to 0.106 (III). *Ruggedness number (Rn)* is a result of basin relief (R) and drainage density (Dd) that indicates the structural complexity of the terrain [8]. The Rn of the Gurpur River basin is 3.28 (Table 1) which is a very high value, indicates very high basin relief (1850 m). The sub-watersheds I, II and III have very high value which suggests high relief and drainage density.

Identification of groundwater potential zones

Drainage pattern of an area is very important in terms of its groundwater potentiality. Linear parameters have a direct relationship with erodability. Higher the value of linear parameters more the erodability, which ranked as 1, the second highest value as rank 2 and so on. On the contrary, the shape parameters have an inverse relation with erodability. The lower the values of shape parameters, more is the erodability. Thus, the lowest value of shape parameter was rated as rank 1 and the second lowest as rank 2 and so on. The rating has been done based on every single parameter; the rating values for every sub-watershed were averaged to arrive at a compound value. Based on average value of these parameters, the sub-watershed having the least rating value was assigned highest priority number 1, next higher value was assigned priority number 2 and so on [12]. Based on ranks and compound parameters value of the Gurpur River basin, the sub-watershed III has given the highest priority with high compound

value as compared to the other sub-watersheds. The priority-wise ordered as III, II, IV sub-watersheds followed by sub-watersheds, VI, I, VII and V.

Conclusions

The observed mean Rb value of sub-watershed VI is the influence of structural control on the development of drainage network, whereas the sub-watersheds I-V & VII indicate geological structures do not seem to exercise a dominant control over the drainage pattern for the watershed. Analysis of the shape parameters such as form factor (Ff), elongation ratio (Re) and circularity ratio (Rc) suggest that the Gurpur basin is in an elongated form associated with high relief, steep ground slopes and differences in the geomorphological features. High Fs values (>2 /km^2) in the sub-basins II, III and VI indicate the occurrence of steep ground slopes, with less permeable rocks, which facilitates greater run-off, less infiltration, sparse vegetation and high relief conditions. Dd value suggests that the nature of the surface strata of the river basin is permeable, which is a characteristic feature of a coarse-drainage density. The high relief ratio (Rr) and gradient ratio values indicate hilly regions from which the runoff volume could be evaluated. Prioritization of the study area was carried out after delineating it into seven sub-watersheds. The study reveals that the sub-watershed III gets maximum priority followed by II, VI, I, VII, V and IV sub-watersheds. The analysis clearly indicates hydrogeological relationships among the various morphometric parameters of the basin help to understand their role in changing the surface area of the region.

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References

1- Gangalakunta P. Obi Reddy G. P., Amal K., Maji A. K., Gajbhiye S., 2004, Drainage Morphometry and its Influence on Landform Characteristics in a Basaltic Terrain, Central India: a Remote Sensing and GIS Approach: International Journal of Applied Earth Observation and Geoinformation, v. 6, p. 1-16.

2- Subba Rao, 2009, A numerical Scheme for Groundwater Development in a Watershed Basin of Basement Terrain: A Case Study from India: Hydrogeology Journal, v. 17, p. 379-396.

3- Radhakrishna, B.P. and Vaidyanadhan, R., 1994, Geology of Karnataka: Geological Society of India, Bangalore, p. 9-17.

4- Krishnaswamy, V. S., 1981, Geological and Mineral Map of Karnataka and Goa: Geological Survey of India, scale 1:5,00,000.

5- Horton, R. E., 1945, Erosional Development of Streams and their Drainage Basins: Hydrophysical Approach to Quantitative Morphology: Geological Society of American Bulletin, v. 56, p. 275-370.

6- Strahler A. N., 1964, Quantitative Geomorphology of Drainage Basins and Channel Networks, In Handbook of Applied Hydrology, editor Chow V.T.: Handbook of applied hydrology. McGraw Hill, New York, p 39–76.

7- Manu, M. S., Anirudhan, S., 2008, Drainage Characteristics of Achankovil River Basin, Kerala. Journal Geological Society of India, v.71, p. 841-850.

8- Schumm S. A., 1956, Evolution of Drainage System and Slope in Badlands at Perth Amboy, New Jersey: Geological Society of American Bulletin, v. 67, p. 597-646.

9- Miller V. C., 1953, A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area. Virginia and Tennessee, Proj. NR 389-402, Tech. Rep 3, Columbia University, Department of Geology, ONR, New York.

10- Smith K. G., 1950, Standards for Grading Texture of Erosional Topography: American Journal of Science, v. 248, p. 655–668.

11- Strahler A. N., 1957, Quantitative Analysis of Watershed Geomorphology: Transactions of the American Geophysical Union, v. 38, p. 913-920.

12- Biswas S., Sudharakar S. and Desai V.R. (1999). Prioritization of Sub-watersheds based on Morphometric Analysis of Drainage Basin: A Remote Sensing and GIS Approach: Journal of Indian Society of Remote Sensing, v. 27, p. 155-166.