Annals of Arid Zone 33(4) 273—278 1994

Remote Sensing in the Evaluation of Morpho-hydrological Characteristics of the Drainage Basins of the Jojri Catchment

Surendra Singh
Central Arid Zone Research Institute, Jodhpur 342 003 India

Abstract Quantitative evaluation of the morphological characteristics of the drainage basins of the Jojri catchment using remote sensing techniques and ground truth has revealed that the drainage basin area, drainage density, stream frequency, bifurcation ratio and circularity ratio influence the surface runoff and peak discharge. The mean annual runoff estimated for all the drainage basins varies from 7.74 to 106.28 ha m. The relations established between morpho-hydrological variables have shown that the mean annual runoff is significantly correlated with drainage basin area, total stream length and first order stream frequency and have a practical application in basin hydrology.

Key words Morpho-hydrological characteristics, drainage basins, mean annual runoff, correlation coefficient, standard error of estimate

In the arid, semi-arid and dry sub-humid areas of Rajasthan, the drainage basins of different type and shape occur under different morpho-geological settings. The quantitative morphological characteristics of the drainage basins influence the runoff intensity and discharge. Accordingly, the studies on the morphological characteristics of the drainage basins of the Luni-Jawai and the west Banas basins to evaluate their surface runoff potentials were done by Ghose *et al.* (1967) and Singh *et al.* (1971). The pair-wise and multiple relationships between and/or among the morphological characteristics of the drainage basins were also established (Singh & Ghose 1973, Singh 1976, Singh *et al.* 1976). The results of these studies have indicated that the quantitative morphological characteristics influence the yields of water and sediment from different drainage basins. The studies on the above aspects of the drainage basins have also been done in USA and other countries by several workers (Maxwell 1955, Morisawa 1957, Schumm 1956).

However, very little work on the evaluation of the morphological characteristics of the drainage basins and their mutual relationships, which influence the runoff intensity and discharge, have been carried out. In the present paper, an attempt, therefore, has been made to evaluate the morphological and hydrological characteristics of the drainage basins of the Jojri catchment and to establish the relation between them for assessing surface water potentials.

Study area

The Jojri catchment, which forms a part of the Luni basin and comprises an area of 1310 km^2 is located between latitudes 26°20′ and 26°35′ N and longitudes 73°40′ and 73° 51′ E. The climate of the catchment is characterised by extreme temperatures during summer months, high evaporation and wind velocity, and low and erratic rainfall. About 90% rainfall occurs from June to September. The average annual rainfall is 424.8 mm and the highest rainfall intensity observed was 291.1 mm day^{-1} on July 17, 1979. The mean daily evaporation decreases with the onset of monsoon from about 9 to 10 mm day^{-1} during June to about 6 to 8 mm day^{-1} during August.

The morpho-pedological characteristics of the catchment are hills, pediments and younger alluvial plains and sand to loamy sand and sandy loam to loam soils. These morpho-pedological characteristics have influenced the development of the drainage network of the Jojri catchment.

Materials and Methods

The drainage map of the Jojri catchment was prepared from the aerial photographs on 1:25,000 scale, Landsat and IRS products and Survey of India topographical maps on 1:50,000 scale. The boundaries of 13 drainage basins selected for this study were accurately delineated from aerial photographs under mirror stereoscope and Zeiss stereopret which provide three dimensional view of relief features and ridge lines. These were subsequently checked in the field (Fig.1). The stream ordering of different order basins (Fig. 2) was done by using the method developed by Horton (1945) and modified by Strahler (1964). The quantitative morphological characteristics of the drainage basins were computed and tabulated by using rotameter, electronic planimeter and calculating machine. The rainfall-runoff estimates were worked out from daily rainfall data for last 70 years and their relationship was established by US Soil Conservation Service (SCS) model. The correlation coefficient, coefficient of determination (R^2) and regression equations were worked out for establishing relations between morphological and hydrological variables.

Results and Discussion

Morphological Characteristics of the Drainage Basins

Quantitative morphological characteristics of the drainage network, measures of the intensity of dissection and shape factors of the drainage basins of the Jojri catchment are discussed below.

Characteristics of the drainage network : Basin area, total number of streams, total stream length, bifurcation ratio and first order stream frequency

Fig 1 Jojri catchment Location of the drainage basin studied.

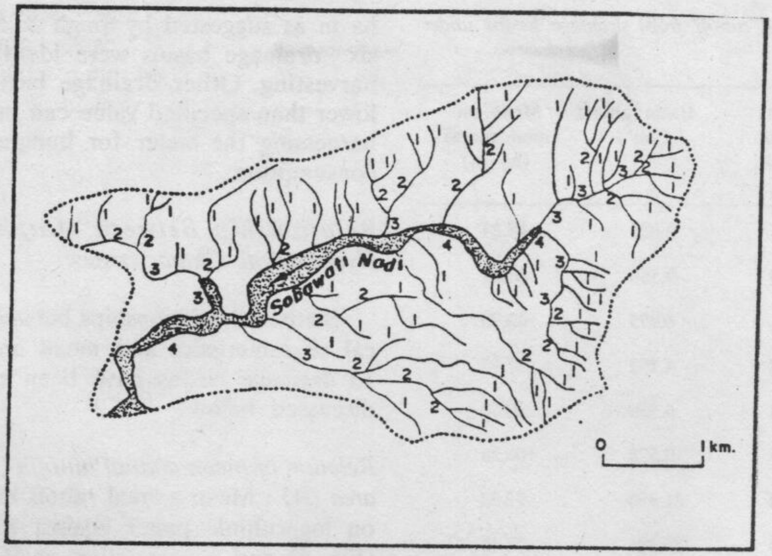

Fig 2 Method of designating 4th order drainage basin

are the characteristics of the drainage network. The size of the drainage basins varies from 3.1 to 26.1 sq. km. The basin area increases with the increase in total stream length and influences the average discharge and peak discharge and both increase with the increase in area. Total stream length of all the drainage basins ranges from 4.7 to 44.5 km and increases with the increase n basin area. The streams of shorter length will result in more rapid discharge and slower infiltration, than the streams of longer length. The bifurcation ratio and first order stream frequency also affect the discharge and runoff intensity. The number of these two geomorphic variables vary from 3.2 to 5.6 and 1.3 to 4.1 streams km^{-2}, respectively. The large number of streams km^{-2} area will enable the runoff to proceed faster because they can carry large amount of water and can also discharge it quickly. Similarly, the numerous first order streams carry stream flow out of a basin rapidly and in shortest possible time.

Drainage density and constant of channel maintenance are the characteristics of the measures of the intensity of dissection and also of drainage network. The drainage density and constant of channel maintenance of the drainage basins vary from 1.2 to 2.8 km km^{-2}; and 0.35 to 0.81 sq. km km^{-1}, respectively. It has been observed that some basins with impermeable subsurface material, sparse vegetation and high relief have higher density and closely spaced streams which will result in a rapid runoff and probably a large volume of flow.

Circularity and elongation ratios are the characteristics of the shape factors and their values vary from 0.39 to 0.79 and 0.52 to 0.75, respectively. These two geomorphic variables also affect the discharge and runoff intensity. It has been observed that 5 drainage basins are more circular and less elongated and hence there will be rapid runoff and quick discharge from these basins than that of less circular and more elongated basins.

Hydrological Characteristics

Mean annual runoff by SCS model was estimated to be 45 mm which is approximately 19 per cent of mean annual rainfall (235 mm). It has been observed from rainfall data that the rainfall is erratic and is not compatible with the runoff trend. The mean annual runoff estimated for all 13 drainage basins varies from 7.74 to 106.28 ha m (Table 1). It may be inferred that the impact of drainage basin on annual runoff is significant and positive. Taking into consideration the criterion of identification of potential ground water sites with runoff greater than 35

Table 1 *Mean annual runoff from drainage basins under study*

Basin number	Mean annual rainfall (mm)	Basin area (km^2)	Mean annual runoff (ha m)
1	54.81	8.800	48.24
2	63.50	9.550	60.64
3	61.21	6.975	42.70
4	67.36	4.152	27.97
5	52.88	6.150	32.52
6	54.29	19.575	106.28
7	45.54	21.350	97.33
8	30.03	26.125	78.45
9	45.54	7.125	32.45
10	25.34	6.075	15.40
11	31.64	4.100	12.97
12	24.97	3.100	7.74
13	20.46	8.875	18.16

ha m as suggested by Singh & Sharma (1979), six drainage basins were identified for water harvesting. Other drainage basins with runoff lower than specified value can only be used for harnessing the water for human and livestock consumption.

Relationship Between Morphological and Hydrological Characteristics

Statistical relationships between morphological characteristics and mean annual runoff of 13 drainage basins have been established and discussed below.

Relation of mean annual runoff (Q) to total basin area (A) : Mean annual runoff has been plotted on logarithmic paper against total basin area (Fig. 3) and a correlation coefficient of 0.874, significant at one per cent level of probability, was obtained for this relationship. The coefficient of determination indicates that 76.4% variation in mean annual runoff is explained by total basin area. The standard error of estimate worked out for this relation from the regression was 15.42%. From the above relation, it can be inferred that mean annual runoff is increasing with an

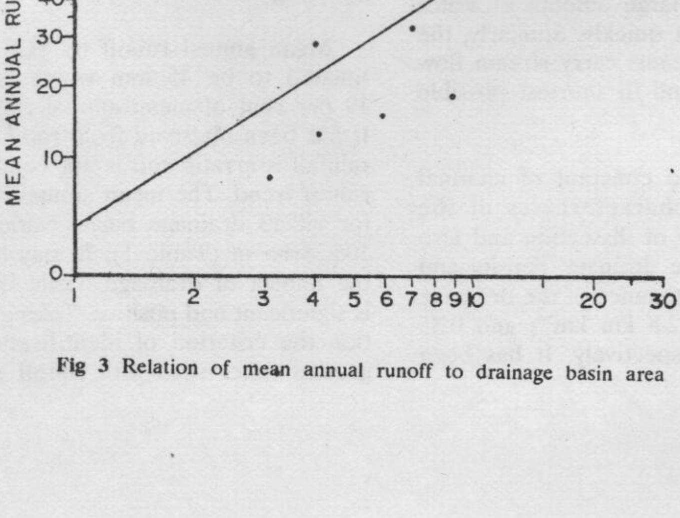

Fig 3 Relation of mean annual runoff to drainage basin area

increase in the basin area and it has been expressed by the following equation:

$$Q = 5.75 A^{3.84} \qquad ...(1)$$

Morisawa (1957) and Singh & Sharma (1979) have also found that the basin area is closely related to streams flow.

Relation of mean annual runoff (Q) to total stream length (L) : Mean annual runoff has been plotted on a logarithmic paper against total stream length and a relationship between these morpho-hydrological variables was established (Fig. 4). The correlation coefficient obtained for this relation is 0.804 which is highly significant at one per cent level of probability. The coefficient of determination shows that 65% variance in mean annual runoff is explained by total stream length. The standard error of estimate obtained for this relation from the correlation coefficient is 18.6%. It is thus obvious that a positive relation exists between mean annual runoff and total stream length and it has been expressed by the following equation:

$$Q = 4.624 L^{1.91} \qquad ...(2)$$

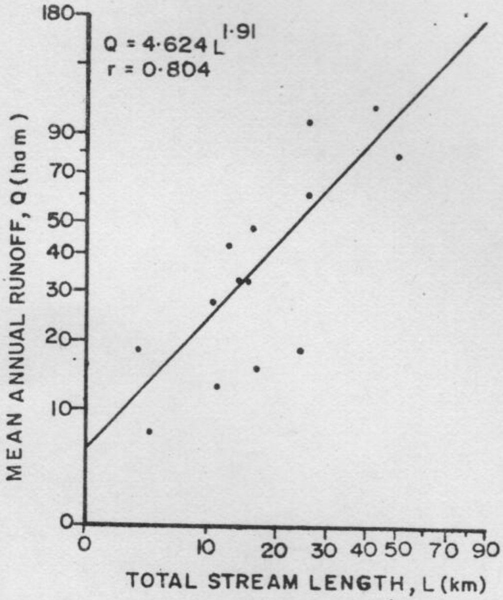

Fig 4 Relation of mean annual runoff to total stream length

Morisawa (1957) and Singh & Sharma (1979) have also reported that these two variables are closely related. to each other.

Relation of mean annual runoff (Q) to first order stream frequency (F) : Mean annual runoff plotted on logarithmic paper against first order stream frequency has indicated that these two morpho-hydrological variables are correlated with each other at five per cent level of probability and 21.16 % variance in mean annual runoff is explained by first order stream frequency. The standard error of estimate of this relation from the correlation coefficient is 34.39%. It has been observed that mean annual runoff is negatively correlated with the first order stream frequency and it shows that with the increase of one variable the other variable decreases. This relationship has been expressed by the following equation.

$$Q = 94.95 E^{-18.01} \qquad ...(3)$$

Morisawa (1957) and Singh & Sharma (1979) have reported that first order stream frequency has a close inverse relationship with hydrologic variable. The mean annual runoff is, however, poorly correlated with drainage density, circularity and elongation ratios due to lower values of these variables, rapid percolation rate and poor surface runoff.

Conclusions

Remote sensing techniques, particularly the aerial photographs, in conjunction with ground truth, have been proved very useful in identification and delineation of the boundaries of the drainage basins of the Jojri catchment and also in evaluating their quantitative morphological characteristics. In other words, due to the three dimension view of the relief features on the aerial photographs under stereoscope, divide lines could be easily identified and the boundaries of different drainage basins could be accurately and rapidly delineated and mapped. The quantitative morphological characteristics and their correlation with hydrological characteristics significantly contribute in estimating the mean annual runoff and evaluating the runoff intensity and average peak discharge from the drainage basins. It has been observed that the drainage basin area, total stream length and first order stream frequency are significantly correlated with mean annual runoff and they directly influence the development and distribution of the surface runoff and discharge of the drainage basins.

It may thus be concluded that the determination and evaluation of the quantitative morphological characteristics have a significant practical utility in evaluating and estimating the hydrological conditions of the drainage basins. The findings of this study could also be applied for evaluating the morpho-hydrological characteristics of the other drainage basins provided they are situated under similar climatological and morpho-geological conditions.

References

Ghose B, Pandey S & Singh S 1969 Quantitative geomorphology of the drainage basins in semi-arid environment. *Annals of Arid Zone* **8** 37-44

Ghose B, Pandey S, Singh S & Gheesa Lal 1967 Quantitative geomorphology of the drainage basins in the Western Rajasthan. *Zeitschrift fur Geomorphologie* **2** 146-160

Horton RE 1945 Erosional development of streams and their drainage basins-hydrophysical approach to quantitative morphology. *Bulletin of Geological Society of America* **56** 276-370

Maxwell JC 1955 The bifurcation ratio in Horton's law of stream numbers. *Transactions of American Geophysical Union* **36** 520

Morisawa ME 1957 Accuracy of determination of stream lengths from topographical maps. *Transactions of American Geophysical Union* **38** 913-920

Schumm SA 1956 Evolution of drainage systems and slopes in bad lands at Perth Amboy, N.J. *Bulletin of Geological Society of America* **67** 596-646

Singh S 1976 Quantitative analysis and evaluation of the geomorphological characteristics and surface water potentials of the drainage basins in western Rajasthan (India). *Indian Journal of Geography* **11 & 12** 59-67

Singh S & Ghose B 1973 Interrelationships between quantitative geomorphic characteristics of the drainage basins in sub-humid to humid environment. *Annals of Arid Zone* **12** 82-99

Singh S, Ghose B, Gupta BS & Kaith DS 1976 Multiple relationships among drainage network variables in the Banas catchment, Rajasthan. *National Georgrapher* **12** 143-151

Singh S & Sharma KD 1979 Application of aerial photointerpretation of the morphohydrological characteristics of the drainage basins in sandstone region of Jodhpur district, western Rajasthan. *The Deccan Geographer* **17** 616-629

Singh S, Wasiullah, Ghose B & Kaith DS 1971 Interpretation of aerial photographs of quantitative characteristics of drainage basins in sub-humid to humid environment. *Indian Geographical Journal* **4, 5 & 6** 1-11

Strahler AN 1964 Quantitative geomorphology of drainage basins and channel networks. In *Handbook of Applied Hydrology* (Ed. VT Chow) pp 439-476