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At-a-station Hydraulic Geometry of the Mahi River with Special Implication to Annual Maximum Series

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ABSTRACT

Hydraulic geometry is of fundamental importance in flood hydrology and geomorphology. It refers to the rate of change of hydraulic variables, namely width, mean depth, and mean velocity, as discharge increases. An attempt has been made to find out at-a-station hydraulic geometry of the Mahi River with special reference to Annual Maximum Series (AMS).Data regarding hydraulic variables associated with annual peak discharges are available for six sites on the Mahi River and its tributaries. These data have been used to derive at-a-station hydraulic geometry equations. The b/f ratio, m/f ratio and total variance have been computed. The hydraulic geometry exponents (b, f, and m) were plotted on Rhode's ternary diagram. The results of the analysis for all the sites clearly show that the rate of change in mean velocity (m) and mean depth (f) with discharges are greater and the rate of change in width (b) are very slow except one site i.e. Rangeli on the Som River. The rate of change in width (b) with discharge is much slower for Khanpur, Padardi Badi and Mataji sites on the Mahi River which are attributed to nearly box-shaped nature of channels. The rate of change in width (b) with discharge is moderate on the Anas River at Chakaliya and Jakham River at Dhariawad indicating semicircular channel form. However, the rate of change in width (b) with rising discharge is much higher for the Som River at Rangeli. This is attributed to wide open channel of the river. The b/f ratios indicate that the rate of change in width is always lower than the rate of change in mean depth which has important implications for efficiency of the channel since the flood power is directly related to the flow depth. The higher m/f ratios reveal that there is more rapid increase of measured sediment load with increase of discharge. The total variance values for three sites namely Rangeli, Dhariawad and Chakaliya are closer to the theoretical value (0.33). This suggests that the effects of changes in discharge are absorbed equally by all the three variables. However, the total variance values for the remaining three sites namely Khanpur, Padardi Badi, and Mataji are not absorbed equally by all the three variables, but by one or two hydraulic geometry variables. This fact, therefore, suggests that the alluvial river channel of the Mahi River is not a true alluvial channel, which is self-formed through the independent adjustment of the morphological variables. The b-f-m or ternary diagram indicates that three sites fall in sector 6, two sites in sector 2 and a site in sector 3. The sector 6 represents the channel where Froude number and slope-roughness ratio increases and width-depth ratio and velocity-area ratio decreases with increasing discharge.Thesector2 reveals the decrease in width-depth ratio and increase in competence, Froude number, velocity-area ratio, and slope-roughness ratio with rising discharge. Whereas, sector 3 shows the channel characteristics where width-depth ratio, competence, Froude number, and slope-roughness ratio increase and velocity-area ratio decrease with increasing discharge.

Keywords: At-a-station Hydraulic Geometry, Ternary diagram, Mahi River

I. INTRODUCTION

Hydraulic geometry is an account of how the dynamic properties of a river channel responsible with increase in discharge. It may be considered as either at-a-station changes or downstream responses to increasing discharge. At-a-station hydraulic geometry describes the channel characteristics mainly refers to the geometric rate of change of hydraulic variables, specifically width (w), mean depth (d), and mean velocity (v), as discharge (Q) increases. These associations are labelled by the term “hydraulic geometry” [1]. However, the associations have been based almost merely on the numerical similarity of the exponents. The implicit assumptions in such analysis is that channels, as characterized by a particular set of b, f and m values, differ only in their rate of response to changing discharge [2]. Rhodes [3], suggests in his investigations that the hydraulic geometry equations are simple allometric accounts of a set of extremely complex interrelationships. The geometric relationships cannot entirely explain nor describe river systems. Though, investigations of the similarities and differences in the hydraulic geometries of rivers have provided understandings into the operation of fluvial systems. A triangular coordinate system on which the exponents (b, f and m) of hydraulic geometry calculations with their totality by 1.00 for each site are plotted, is a graphical presentation assigned by the name of Ternary diagram or else b-f-m diagram [2]. The objective of this paper, is therefore, to find out at-a-station hydraulic geometry of the Mahi River and its tributaries with special reference to Annual Maximum Series (AMS) and to interpret Rhodes’ ternary diagram.

II. STUDY AREA

The Mahi River is the third major west flowing interstate river of the India located in western India (Fig. 1). The river originates near Mindha village of Sardarpur taluka of Dhar district of Madhya Pradesh at an elevation of 500 m ASL. It flows for the distance 538 km. River occupy the total area 34,842 km² and lies between 72° 21’ to 75° 19’ E and 21° 46’ to 24° 30’ N. The major right bank tributaries of the Mahi River are the Som and the Jakham and left bank tributaries are the Anas and the Panam. Geographically, the basin bounded by Aravalli hills in the north and northwest, Vindhya in the south and the east and Gulf of Khambhat in the southwest. The lithology comprises metamorphic rocks of Aravalli Super Group, the Deccan Traps Basalt, and the alluvial deposits of Pleistocene and Holocene age. The data of hydraulic parameters of the AMS were available for three sites on the Mahi River and three on its tributaries (Figure 1).

III. DATAAND METHODOLOGY

In order to derive at-a-station hydraulic geometry equations, the values of width, depth and velocity for mean annual discharge data along the river are required. However, data regarding hydraulic variables associated with annual maximum series (AMS) were available for three sites on the Mahi River and three on its major tributaries namely the Jakham, the Som and the Anas. These data have been used to derive at-a-stationhydraulic geometry equations to understand the nature of changes in the

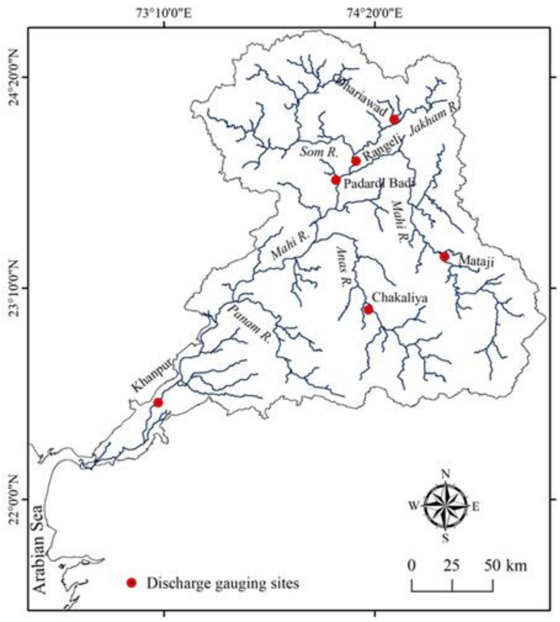


Figure 1. Discharge gauging sites on the Mahi River and itstributaries.

hydraulic variables with discharge. The equations are as under;

$$w = {}_aQ^b \qquad \text{....Eq.1}$$

$$d = {}_cQ^f \qquad \text{....Eq.2}$$

$$v = {}_kQ^m \qquad \text{....Eq.3}$$

Where, w = width; d = mean depth; v = mean velocity;Q = water discharge and a, c, k, b, f and m are numericalconstants.

Above three equations mainly used to express and associate stream channels forms. The changes between discharges as the independent variables and the dependent of width, depth, velocity have often been expressed as simple power-functions [3]. The b/f ratio, m/f ratio and total variance have been computed for understanding of the rate of change in width, mean depth and mean velocity. All the hydraulic geometry exponents (b, f, and m) of the six sites were plotted on Rhode's ternary diagram. This kind of analysis provides values statistically more accurate than those obtained by other methods and offers a unique set of equations. The original presentation of the diagram considered only at-a-station hydraulic geometry exponents [2]. For the graphical data presentation, the divided b-f-m diagram is a tool for the interpretation of the hydraulic geometry [4].

IV. Results And Conclusions

The results of hydraulic geometry of six sites are shown in Table 1 and Fig. 2, 3 and 4.The results of are not absorbedequally byall the three variables, butby oneor two hydraulic geometry variables [3]. This behavior of the hydraulicvariables can be attributed to the rectangular appearance of the chann-

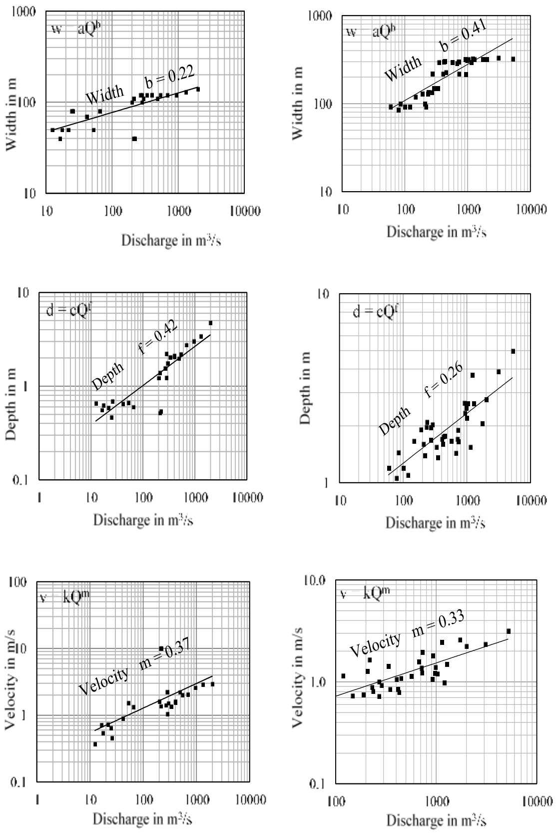
Table 3. exponent values of at-a-station hydraulic geometry

No.	River	Site	Width (b)	Depth (f)	Velocity (m)	b/f ratio	m/f ratio	Total Variance
1	Mahi	Khanpur	0.04	0.53	0.43	0.08	0.81	0.47
2	Mahi	Padardi Badi	0.02	0.45	0.53	0.04	1.18	0.48
3	Mahi	Mataji	0.13	0.26	0.61	0.50	2.35	0.46
4	Som	Rangeli	0.41	0.26	0.33	1.58	1.27	0.34
5	Jakham	Dhariawad	0.22	0.42	0.37	0.52	0.88	0.36
6	Anas	Chakaliya	0.15	0.45	0.40	0.33	0.89	0.39

the analysis for all the sites clearly show that the rate of change in mean velocity (m) and mean depth (f) with discharges are greater than the rate of change in width (b) except one site i.e. Rangeli on the Som River (Fig. 3b). The rate of change in width with discharge is muchslower for Khanpur, PadardiBadi and Mataji sites on the Mahi River which are attributed to nearly box-shaped nature of channels (Fig. 2a, b and 4a).Therefore, the increase in the discharge is primarily compensated by a remarkable increase in depth. This has important implications for competence of the channel since the flood power is directly related to the flow depth [5]. The rate of change in width (b) with discharge is moderate on the Jakham River at Dhariawad (Fig. 3a) and Anas River at Chakaliya (Fig.4b) indicating semicircular channel form. However, the rate of change in width (b) with rising discharge is much higher for the Som River at Rangeli (Figure 3b). This is attributed to wide open channel of the river.

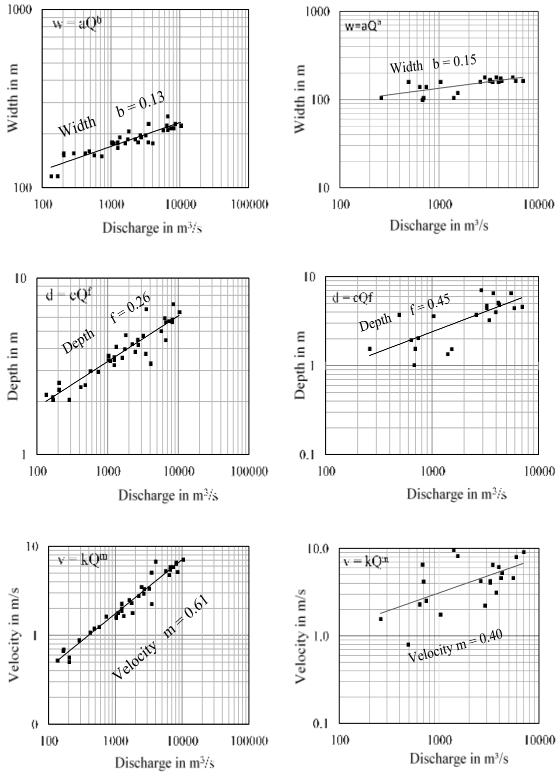
According to Rhodes [3], hydraulic geometry is linked with Langbein's concept of minimum variance.Hence,the total variance is the sum of the square of thehydraulicgeometry exponents.On the basis calculations of the total variance, values for all the six sites lie between 0.34 and 0.48 (Table 1) and are closer to theoretical minimum total variance, which is 0.333 [3].Nevertheless, the total variance values for the sites viz. Rangeli on the Som River, Dhariawad on the Jakham River and Chakaliya on the Anas River are 0.34, 0.36 and 0.39 respectively and all these values are closer to the theoretical value. In other hand, the total variance values are higher of the sites on Mahi River such as Khanpur, PadardiBadi and Mataji with 0.47, 0.48 and 0.46 respectively. This proposes that at the latter sites, the effects of changes in discharge el and to the cohesive nature of the bank material of the selected sites. This fact, therefore, suggests that the alluvial river channel of the Mahi River is not a true alluvial channel, which is self-formed through the independent adjustment of the morphological variables [6], [7], [8].

The values of b, f, and m of the six sites were plotted on the ternary diagram (Figure 5).It indicates that three sites fall in sector 6,two sites in sector 2 and a site in sector 3. The sector 6 represents the channel where Froude number and slope-roughness ratio increases and width-depth ratio and velocity-area ratio decreases with increasing discharge. The sector 2 reveals the decrease in width-depth ratio and



a. Jakham River at Dhariawad b. Som River at Rangeli

Fig. 3 At-a-Station hydraulic geometry



a. Mahi River at Mataji b. Anas River at Chakaliya

Fig. 4 At-a-station hydraulic geometry

increase in competence, Froude number, velocity-area ratio, and slope-roughness ratio with rising discharge. Whereas, sector 3 shows the channel characteristics where width-depth ratio, competence, Froude number, and slope-roughness ratio increase and velocity-area ratio decrease with increasing discharge.The b-f-m diagram offers a means of grouping and comparing hydraulic geometry of the channels of theMahi River and itstributaries and suggests empirical classification based on hydraulic geometry.

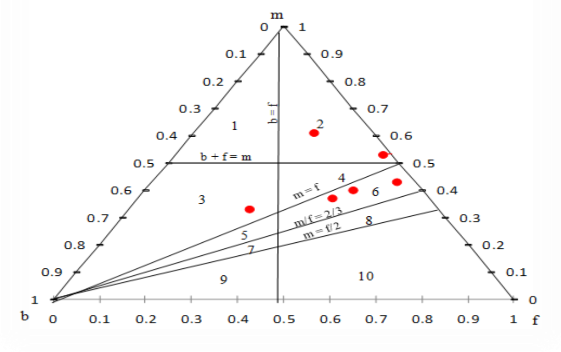


Figure 5. The width-depth-velocity (b-f-m) or Ternary diagram

II. ACKNOWLEDGEMENT

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