Discharge Prediction Approaches in Compound Meandering Channel

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ABSTRACT

Natural or artificial channels are composed of a deep main channel and shallow floodplain flanked either to its one or both sides. When water overflows it's in banks and reaches overbank region, it causes severe damage in the floodplain coverage, therefore it necessitates accurate estimation of discharge prediction for the remedial measures. In this paper, various discharge prediction approaches like Single Channel Method (SCM), Divided Channel Methods (DCM) have been demonstrated. For evaluation of the value of manning's 'n', different roughness formulae have been considered. These approaches are also applied to the various researchers' data sets. For a comparative study, graphs have been plotted between actual discharge and predicted discharge for various researchers' data sets. The mean percentage of error has been calculated to evaluate the suitable approach for discharge assessment in the compound meandering channel. Again, for more refinement standard deviation of the mean percentage error has been shown. Stage-Discharge curve has also been drawn for the best suitable methods.

Keywords: Discharge prediction, meandering channel, SCM, DCM, mean error, stage-discharge

1. Introduction

Almost all natural rivers tend to meander. If the length of a river remains straight for 10 to 12 times of its channel width, then the river is considered as straight ,which is quiet insignificant in natural criteria. A river is stated to be meandering if it has sinuosity greater than 1.5. A lot of researches are carried out to predict discharge for straight channels, but this paper comprises predictive approaches for discharge assessment in compound meandering channel. When heavy rainfall occurs, water from main channel reaches to floodplain and hence cause various disasters and losses. So accurate prediction of estimation of discharge is an important factor .Estimation of discharge prediction helps in various water resources engineering projects

Hook (1974) measured bed elevation contour in a simple meandering flume with movable sand .For various discharges he calculated bed shear stress, sediment transport distribution and secondary flow. From his laboratory experiments he concluded that secondary current increases with the increment of discharge.Toebes and Sooky (1967) conducted experiments on compound meandering channel. They analyse the internal flow structure between floodplain and main channel. Their observational study signify of existing an imaginary horizontal fluid boundary between top edge of the main channel and flood plain. Ervine, Willetts, Sellin and Lorena (1993) analyzed the various parameters like bed roughness, sinuosity, aspect ratio, meander belt width etc. And they concluded that these parameters play important role for conveyance in the compound meandering channel.

Classical discharge estimation follows basically three formulae for estimation of discharge prediction; Chezy's formula (1769), Darcy-Weisbach formula (1857) and Manning's formula (1889). This paper presents Single Channel Method (SCM), Divided Channel Method (DCM), and Coherence Method for discharge prediction in compound meandering channel. Manning's 'n' plays vital role as it has the influence of sinuosity(s), width ratio (α), relative depth (β), roughness coefficient (γ), aspect ratio of main channel (δ), bed slope (S_o).So various researches proposed the value of Manning's roughness coefficient (n) in combination of above parameters based on some assumptions, which lead to quiet efficient result for estimation of discharge prediction in compound meandering channel. Here all cross-sections have taken along the bend-apex of the compound meandering channel .Various predictive approaches have been applied through different data sets

2. Methods of Estimation of Discharge in Compound Meandering Channel

2.1 SINGLE CHANNEL METHOD (SCM)

It is one of the simplest method for computation of discharge considering the single entity of the channel with the average roughness coefficient. In this case, cross-sectional velocity is assumed to be uniform. Myers and Brennen (1990) concluded that Single Channel Method (SCM) underestimate the prediction of discharge when the floodplain depth is low. This is due to the assumption of uniform velocity at the cross-section. Discharge estimation can be done through SCM by three formulae like Manning's, Chezy's or Darcy-Weisbach equation.

$$Q = \frac{1}{n} R^{\frac{2}{3}} S_0^{\frac{1}{2}} A \qquad (1)$$

$$Q = AC\sqrt{RS_0} \qquad (2)$$

$$Q = \sqrt{\frac{8g}{f}} A\sqrt{RS_0} \qquad (3)$$

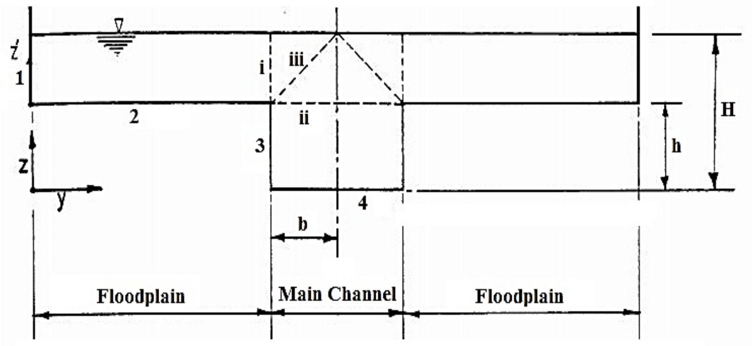
Where Q= Total discharge of the compound channel, n= Manning's roughness coefficient, S_o =Bed slope of the compound channel, A=Cross-sectional area of the compound channel, .R=Hydraulic mean radius of the compound channel, C =Chezy's constant, g =acceleration due to gravity, f=Darcy-Weisbach friction factor of the compound channel.

2.2 DIVIDED CHANNEL METHOD (DCM)

Divided channel method is one of the most widely used method for calculation of discharge. In this case, cross-section is divided into homogeneous subareas where uniform velocity is assumed in each sub section. Researchers follow three imaginary divisional interfaces while considering the subsections of the compound channel i.e..horizontal, vertical and diagonal. These divisional methods are found to be suitable results than Single Channel method (SCM) for calculation of discharge. Again horizontal division methods (HDM) and vertical division method (VDM) is further divided in to HDM-I, HDM- II, VDM-I &VDM-II. In HDM-I, the horizontal imaginary line is not considered for wetted perimeter of the main channel while calculation of discharge in compound meandering channel. In HDM-II, that horizontal imaginary line is considered for wetted perimeter, while calculation of discharge in compound meandering channel. In a similar way, an imaginary vertical division interface is considered from the top of the bank of the main channel to the top of the fluid layer. In VDM- I, that imaginary vertical lines are excluded for the wetted perimeter for the discharge calculation of the compound meandering channel and in VDM- II ,that imaginary vertical lines are being considered for the wetted perimeter for discharge calculation of compound meandering channel. In diagonal division method, an imaginary diagonal interface is assumed from the top of the bank of the main channel to central line of the water surface. Such interface length is not considered of wetted perimeter for estimation of discharge in compound channel. So all the divisional discharge are being added together to get total discharge of the compound channel. So mathematically it can be represented as

$$Q_{total} = \sum_{i=1}^{i=N} Q_i = \left(\frac{1}{n_i}\right) A_i R_i^{\frac{2}{3}} S_0^{\frac{1}{2}} \qquad (4)$$

Where, Q_{total} =Total discharge obtained through the compound channel, Q_i=Sectional discharge after applying divisional methods, A_i =Subsectional area , R_i =Subsectional hydraullic mean radious, S_0=Bed slope of the compound channel and N= number of sundivisions.



i. Vertical Interface

ii. Horizontal Interface

iii.Diagonal Interface

Figure1. Preview of divisional methods in compound channel

2.3 COHERENCE METHOD (COHM)

Coherence method (COHM) is a 1-D method which is a modification of traditional divided channel method.Acker (1991-1992) developed a new correction coefficient based on the previously experimental data sets and acknowledged as 'Discharge Adjustment Factor '(DISADF).While considering the effect of momentum transfer,DISADF is being multiplied with Q_{DCM} .Coherence can also be stated mathematically as the ratio of discharge obtained through single channel method to discharge through divided channel method.

$$COH = \frac{Q_{SCM}}{Q_{DCM}} \qquad (5)$$

If the value of COH is nearly equal to 1, then the channel is to be treated as single entity. For COH value significantly less than 1, DISADF is being multiplied with the Q_{DCM}. If COH value is very small i.e. less than 0.5, then DISADF remain insignificant. For this purpose, Discharge Deficit factor is being subtracted from the discharge obtained through divided channel method.

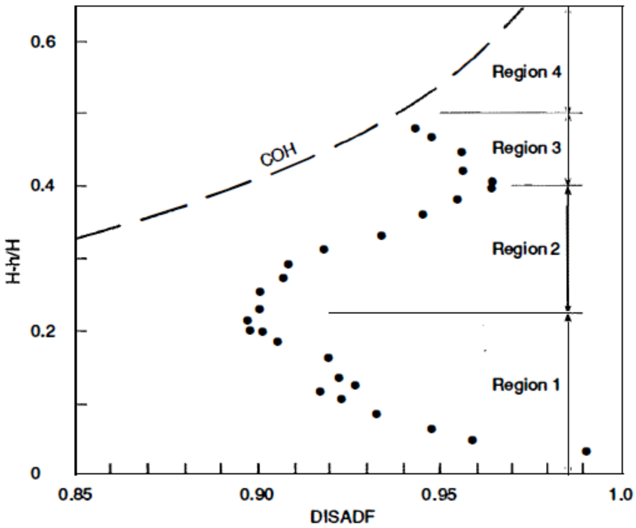


Figure 2. Discharge Adjustment Factor (DISADF) of FCF data (Phase A)

Figure 2 depicts the graph between DISADF with relative depth comprising 4 regions from the experimental study of FCF-phase A datasets. He formulated the discharge by consideration of flow region based on the value of relative depth.

For region-1, $Q_1 = Q_{DCM} - DISDEF$; $\beta < 0.2$ (6)

For region-2, 3, 4, $Q_i = Q_{DCM} \times DISADF_i$,i=2, 3, 4 ; $\beta \geq 0.2$ (7)

2.4 ROUGHNESS PREDICTION APPROACHES FOR MEANDERING CHANNEL

2.4.1 Soil Conservative Service (SCS)

The Soil conservative service, SCS (1963) method was used for obtaining the value of roughness coefficient based on the sinuosity of the meandering channel.

$$\frac{n'}{n} = \left(\frac{f'}{f}\right)^{\frac{1}{2}} = 1.0, \text{ For } s < 1.2 \qquad (8)$$

$$\frac{n'}{n} = \left(\frac{f'}{f}\right)^{\frac{1}{2}} = 1.15 \text{ For } 1.2 \leq s < 1.5 \qquad (9)$$

$$\frac{n'}{n} = \left(\frac{f'}{f}\right)^{\frac{1}{2}} = 1.3 \text{ For } s \geq 1.5 \qquad (10)$$

Where, n = assumed Manning's n value, f =assumed friction factor, n'=modified manning's n value, f'=modified friction factor, s=sinuosity of the meandering channel

2.4.2 Linearized Soil Conservative Service (LSCS)

James (1992) proposed Linearized Soil Conservative service (LSCS), which gives modified Manning's roughness values based upon of some sinuosity range.

$$\frac{n'}{n} = 0.43s + 0.5, \text{ for } s < 1.7 \qquad (11)$$

$$\frac{n'}{n} = 1.3 \quad , \qquad \text{for } s > 1.7 \qquad (12)$$

Where, n = assumed Manning's n value, f =assumed friction factor, n'=modified manning's n values, f'=modified friction factor, s=sinuosity of the meandering channel

2.4.3 Shino, Al-Romaih and Knight (SAK)

Shino, Al-Romaih and Knight (1999) analyzed the bed slope and sinuosity of meandering channel for discharge estimation and formulated sinuosity (s) in terms of friction factor (f),

$$s = 10\left(\frac{f}{8}\right)^{\frac{1}{2}} \qquad (13)$$

Where,s = sinuosity of the meandering channel, and f = friction factor

2.4.4 Dash and Khatua (DK)

Dash and Khatua (2016) proposed Manning's n is to be dependent upon aspect Ratio (δ), Reynolds number (Re), Froude number (Fr), bed slope (So), and sinuosity(s).which can be represented as

$$n = 0.013(1-0.015\delta^{-0.116}+0.3021\ln(s) +0.15Re^{0.0924}-0.3\ln(Fr)-9.852S_o(1-374S_o) \qquad (14)$$

2.4.5 Pradhan and Khatua(PK)

Pradhan and Khatua (2017) proposed Manning's n which has the effect on Relative depth, Reynold's number(Re),Froude's number(Fr),width ratio(α),bed slope (So),sinuosity(s) and length scale factor (m),which is given by the below equation as

$$n = \frac{1}{250}\left(\frac{R^{0.84}{S_o}^{0.25}m^{0.08}s}{g^{0.25}\alpha\beta\nu^{0.5}}\right) \qquad (15)$$

3. Meandering Channel Datasets for Analysis

To analyze the above discharge prediction methods, a large sets of field and experimental data were collected and being applied through these approaches. The data comprises FCF B (1991) series which is a large scale data. Patra (2000) dataset was a doubly meandering channel data(Both main channel and floodplain had sinuosity) .Similarly Khatua (2008) data were taken with variable flume size, sinuosity, bed slope such as type II & type III.Mohanty (2014) and Pradhan (2017) were also considered for meandering channel datasets. All these discharge results had taken by considering the cross-section at bend-apex of the compound meandering channel. So for better presentation,FCF B series, Patra(2000),Khatua(2008)(2 nos of data sets),Mohanty(2014)&Pradhan(2017)have been abbreviated as B21,PIII,KII,KIII,MII & PKI respectively. Required parameters for calculation of discharge for various data sets are given as Table: 1.

Table: 1. Experimental Parameters for datasets of Meandering Compound Channel

DATA SERIES (no. of experimental runs)	Side Slope of main channel (V:H)	Manning' n (n_{mc}=n_{fp})	Sinuosity		Height of the main channel, h(m)	Width if the main channel b(m)	Overall Width of compound Channel B(m)	Bed Slope (So)	Relative Depth (β)=$\frac{H-h}{H}$	Actual Discharge Q(m^3/sec)
			S_{mc}	S_{fp}						
B21(16)	1V:1H	0.012	1.374	1.00	0.15	0.90	10.00	0.000996	0.08609-0.48048	0.0824-0.98939
PIII(3)	1V:0H	0.026	1.043	1.043	0.25	0.44	1.38	0.0061	0.15254-0.20886	0.094535-0.108583
KII(12)	1V:0H	0.01	1.44	1.00	0.12	0.12	0.577	0.0031	0.09909-0.33884	0.009006-0.031358
KIII(12)	1V:1H	0.01	1.91	1.00	0.08	0.12	1.93	0.0053	0.08467-0.27992	0.012757-0.048474
MII(5)	1V:1H	0.01	1.11	1.00	0.065	0.33	3.95	0.0011	0.19354-0.40909	0.017074-0.080667
PKI(5)	1V:1H	0.01	4.11	1.00	0.065	0.33	3.95	0.00165	0.235-0.350	0.028-0.052

4. Results and Discussions

All the experimental datasets has been ascertained and arranged according to the year of experiments done. Various discharge prediction approaches like SCM,HDM-I,HDM-II,VDM-I,VDM-II,DDM,COHM, have been applied through these experimental datasets .Similarly different formulae for Manning's roughness coefficient to have also been applied ,while assessing the discharge calculation in compound meandering channel. So as to predict the best suitable method, graph between actual discharge and predicted discharge, gives clear picture for better acceptable method among all, which have been depicted from Figure 3 to Figure 8.

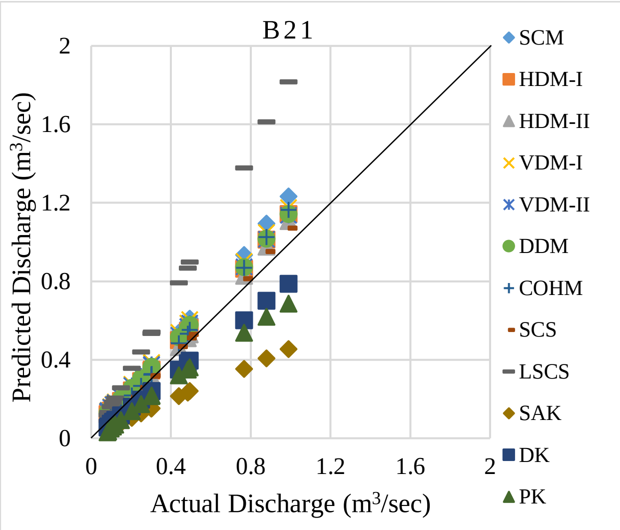
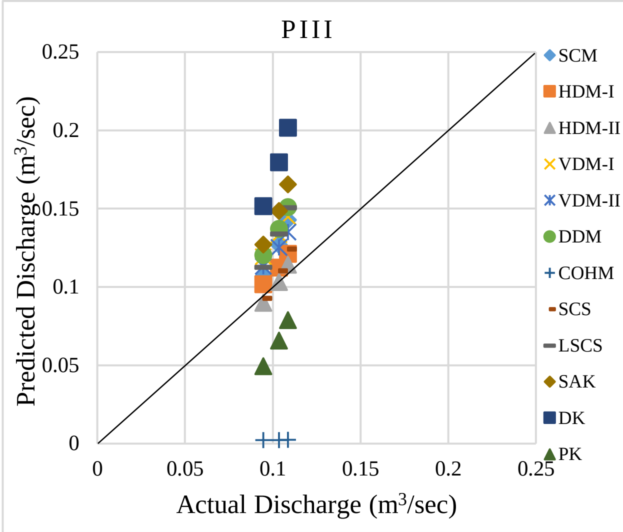


Figure 3



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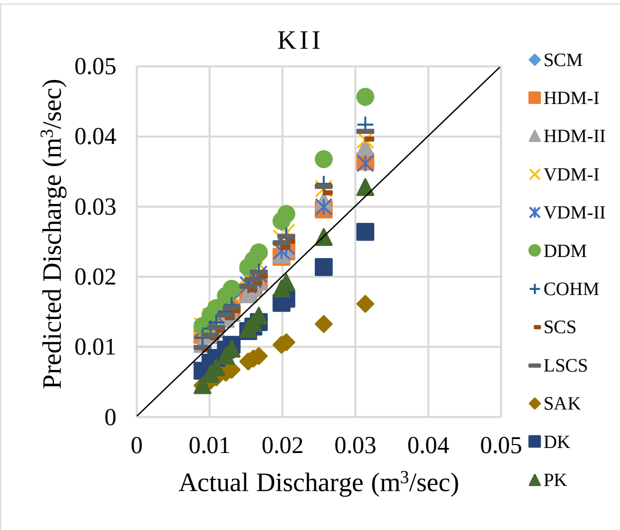
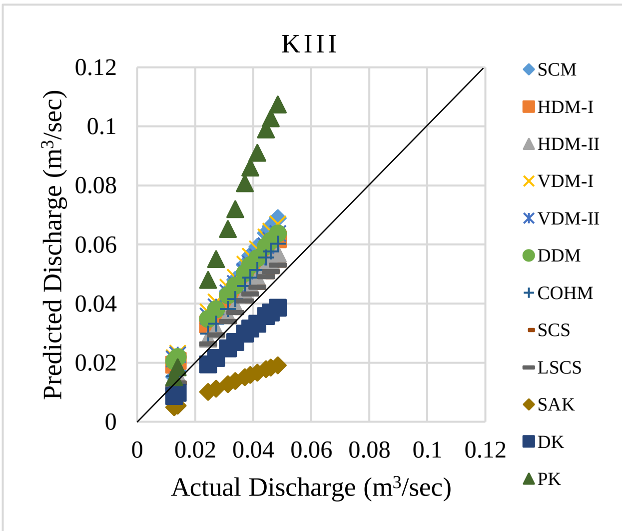


Figure 5



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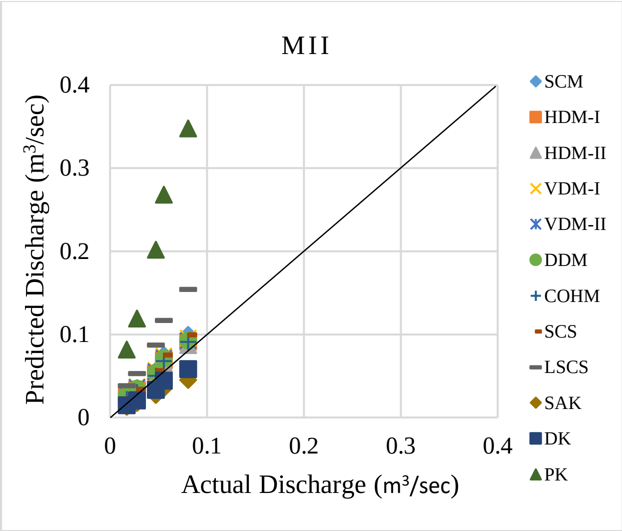

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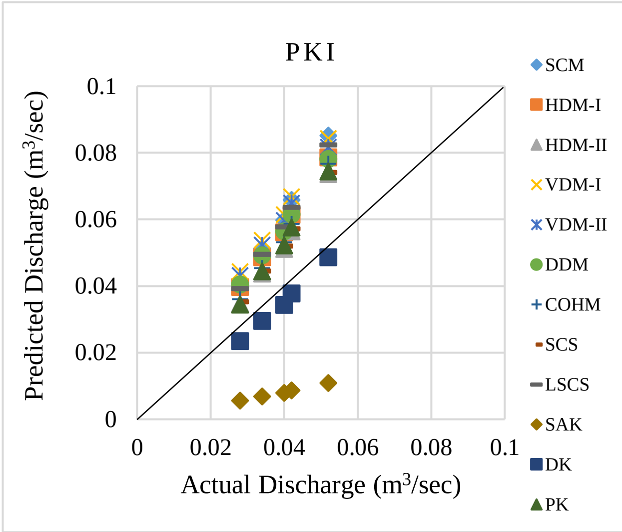

Figure 8

For FCF B21 channel data sets, all methods gave better results when depth of water in compound meandering channel is less, it varies significantly when the depth of flow increases. Among them HDM-II, COHM, SCS gave accurate results of predicted discharge. In PIII channel, HDM-II, SCS method gave satisfactory results. By considering KII & KIII channel datasets, HDM-II & DK were found to be more appropriate .In case of MII channel datasets, HDM-II, COHM, DK had better fitted curve between actual discharge & predicted discharge. For PKI datasets, COHM & DK led to commendable results among other methods.

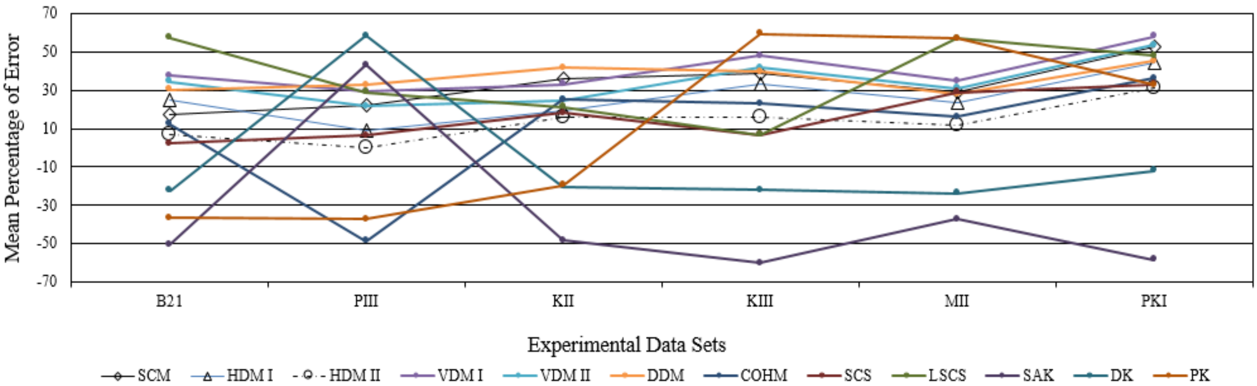

Figure 9

From the above results, by plotting scattering points among actual discharge and predicted discharge, conclusions cannot be made. For better analysis of each data sets, mean percentage of error has been calculated and plotted in line diagram for actual view of the accuracy as shown in Figure 9. From SCM and divisional methods (HDM-I,HDM-II,VDM-I,VDM-I & DDM), HDM-II agreed very well with actual versus predicted discharge for all data sets .COHM method also found to be suitable for all data sets. On the other hand among the approaches for prediction of Manning's n, Dash and Khatua (2016) method gave quiet significant result. Figure 10 signifies mean percentage of errors with standard deviation of three best methods for the datasets. Values of standard deviation of their corresponding mean error gave a clear-cut idea about the range of the mean error and helps to state more appropriate method. From these three methods (HDM-II, COHM, DK), Coherence method maintain least percentage of error with suitable range of its standard deviation.

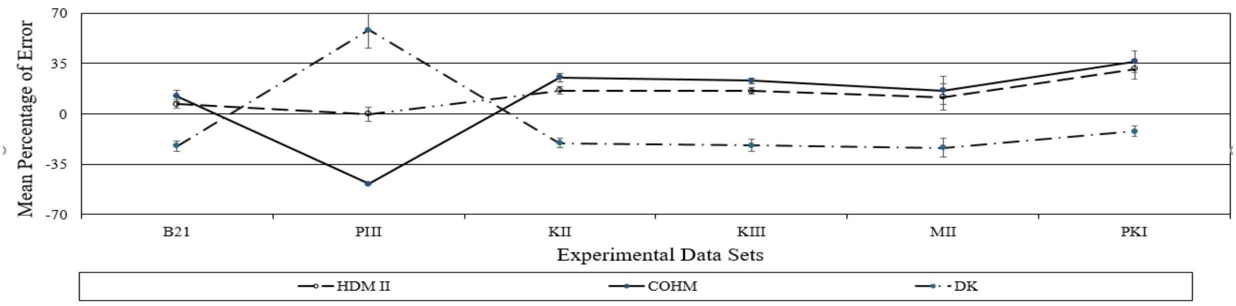

Figure 10

For better understanding the behavior of flow mechanism across overbank stage , sets of stage- discharge curve is being plotted below as Figure 11 to Figure 16 .For B21 dataset, we concluded that when depth of water in overbank stage is low, all methods are found to suitable, but when depth of flow increases, some try to over predict and some tend to under predict the actual discharge .DK method under predict the discharge and HDM-II &COHM over predict from the actual discharge.COHM over predicts slightly than HDM-II.For PIII datasets,HDM-II gave very accurate result other than COHM & DK method.HDM-II under predicts the discharge when flow depth in overbank region is low and over predicts the discharge, when flow depth increases considerably.COHM &DK are highly overestimate the actual discharge value for PIII datasets. For the analysis of KII datasets,DK method under predict the actual discharge and HDM-II & COHM try to over predict the actual discharge.COHM over predicts more than HDM-II.Same scenario was seen for KIII datasets too.DK method was found to be under estimate the actual discharge while HDM-II &COHM overestimate .Same effect was encountered for MII datasets also. And at last for PKI datasets, the variation is quit more.DK method under predict

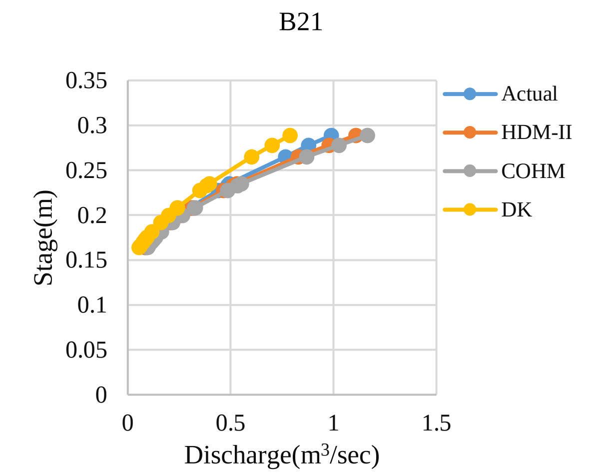

Figure 11

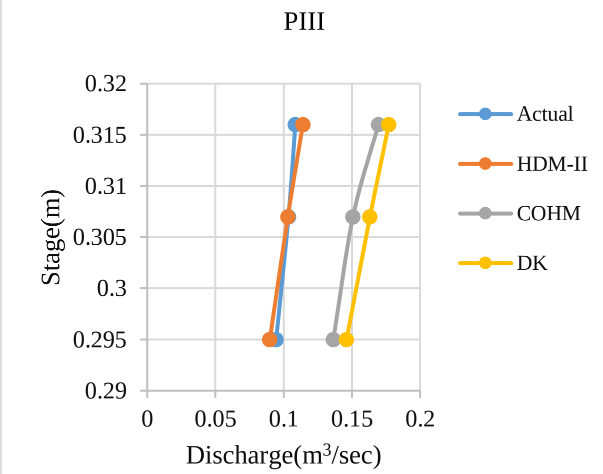

Figure 12

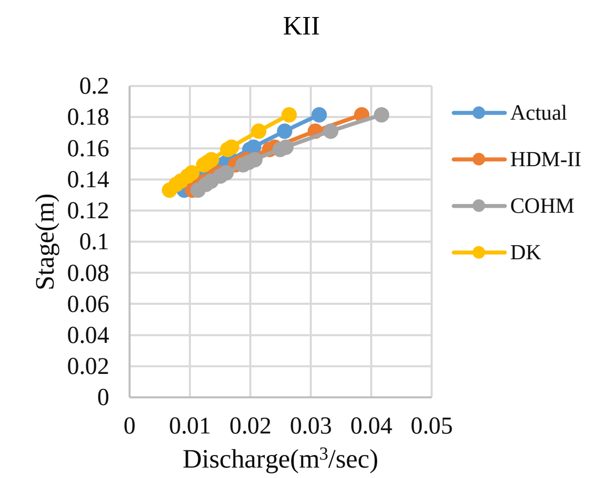

Figure 13

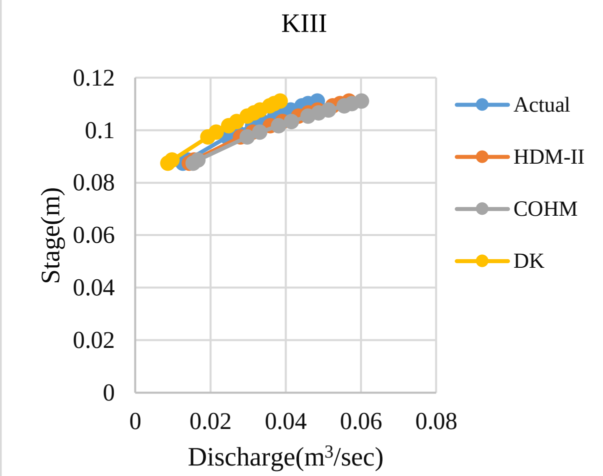

Figure 14

the discharge value while HDM-II & COHM over predict significantly. These graphs were shown as below from Figure 11 to Figure 16.

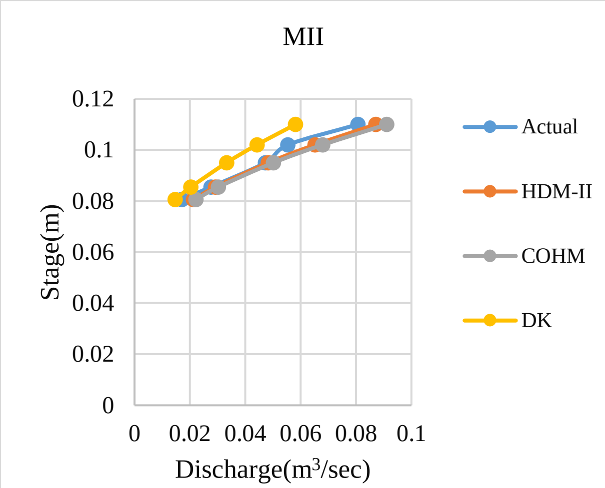

Figure 15

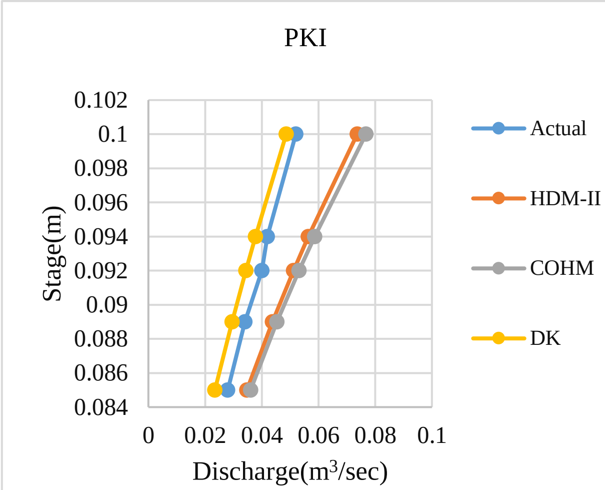

Figure 16

5. Conclusion

The above work led to the following conclusions;

1. Among all the divisional methods, HDM-II gave the most appropriate discharge results comparable with actual discharge.
2. Predicted discharge by Coherence method agreed very well with actual discharge for the datasets.
3. From the various Manning's roughness prediction approaches, Dash and Khatua (2016) method led to more acceptable.
4. From the stage-discharge relationship it is found that, all the 3 best methods (HDM-II, COHM & DK) tend to converge with actual discharge datasets when flow depth in the overbank stages is low and they vary considerably when flow depth increases. Dash and Khatua (DK) method generally underestimates the actual discharge while HDM-II and Coherence method (COHM) overestimate the actual discharge. And between HDM-II and COHM, COHM method over predicts slightly more than HDM-II.
5. Although all discharge prediction approaches gave good results in compound meandering channel, other analytical and soft computing approaches needs to be consideration for the datasets in order to state best suitable method.

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