Computational Water, Energy, and Environmental Engineering, 2015, 4, 25-37

http://dx.doi.org/10.4236/cweee.2015.43004

Modeling of Discharge Distribution in Bend of Ganga River at Varanasi

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Received 1 May 2015; accepted 6 June 2015; published 9 June 2015

Abstract

Dynamics of river behavior play a great role in meandering, sediment transporting, scouring, etc. of river at bend, which solely depends on hydraulics properties such as horizontal and vertical stress, spatial and temporal variation of discharge. Therefore understanding of discharge distribution of river Ganga is essential to apprehend the behavior of river cross section at bend particularly. The measurement of discharge is not very simple as there is no instrument that can measure the discharge directly, but velocity measurement at a section can be made. Velocity distribution at different cross sections at a time is also not easy with single measurement with the help of any instrument and method, so it required repetitions of the measurement. Velocity near the end of bank, top and bottom layer of natural streams is difficult to be measured, yet velocity distribution at these regions plays important role in characterizing the behavior of river. This paper deals with the new advanced discharge measurement technique and measured discharge data has been used for modelling at river bend. To carry out the distribution of discharge and velocity with depth in river Ganga, the length of river in study area was distributed into 14 different cross sections, M-1 to M-14, measured downstream to upstream and the measurement was done by using of ADCP (Acoustic Doppler Current Profiler). At each cross section, profiles were measured independently by an ADCP and data acquired from ADCP were further used for the regression modeling. A multiple linear regression model was developed, which showed a high correlation among the discharge, depth and velocity parameters with the root mean square error (R^2) value of 0.8624.

Keywords

ADCP, Discharge, Linear Regression, River, RMS

1. Introduction

Flow in open channel and a natural river is often described by simplifying cross section. But in reality cross sec-

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How to cite this paper: Chauhan, M.S., Dikshit, P.K.S. and Dwivedi, S.B. (2015) Modeling of Discharge Distribution in Bend of Ganga River at Varanasi. *Computational Water, Energy, and Environmental Engineering*, **4**, 25-37.
http://dx.doi.org/10.4236/cweee.2015.43004

tion of river and its bend is so complicated that it needs vast practical experience to understand the hydrodynamics. On the other hand the most dangerous natural disaster, worldwide known as flood, can cause a huge economic losses as well as losses of life and livelihood. Therefore understanding the flow behavior and estimation of discharge for open channel flow (most commonly natural rivers) is very vital hence it had keen interest for the researchers for decades. Many researchers develop various methods for the discharge estimation; however, some enhance the accuracy of the previously available methods. Researcher develops regression based models [1]-[3] and some develop soft computing methods [4]-[6]. The main river flow (discharge of river) might be changed at a very large scale as human interruption takes place in term of occupying the place along the river bank or within the river basin [7]. Regression based approach is most commonly very useful for the ungauged sites for discharge estimation [8]-[10].

The increase in the flow of any river is caused by the large volume of rainfall in its basin, which would probably change the physical parameters of the river involving the changes in the depth due to bank erosion' taking place and width of flow [11]-[14]. The river hydrodynamics could directly affect the flow pattern of river and may change in river morphology. [15]-[18] observed that the meandering is one of the most common pattern followed by fluvial rivers. A lot of research work is completed by researchers for the study of bankfull discharge and bankfull velocity of river, but there is a lack of research about the natural flow and natural velocity of river.

It is to understand that, the discharge of river is a function of river meandering wavelength and amplitude, as the higher the value of river meandering wavelength and amplitude, higher will be the discharge and vice versa. The above understanding gives a way to go forward with this research in the direction that the river parameters must naturally have a relationship with each other. The main purpose of this paper is to develop a correlation among parameters of Varanasi bend of holy River Ganga which are directly related to the physical parameters of river *i.e.* discharge, depth and velocity. The complete measurement on the Varanasi bend was done in the month of November 2013.

With the progresses of measuring discharge and understanding behavior of Natural River, Acoustic Doppler Current Profiler (ADCP) technologies, a moving boat discharge measurement technique is gradually replacing the classic procedure using mechanical meters when the water is sufficiently deep for ADCP applications. While measuring discharge through ADCP, the transducers of an ADCP are mounted facing down and barely submerged under the water surface. They ping continuously while the boat is traversing from bank to bank. The boat motion is monitored by bottom tracking acoustic pings or by a global positioning system (GPS). The water flux crossing the vertical plane of the boat path is computed, which is the same as the river discharge. The ADCP can be used for measuring a velocity profile in the vertical when the ADCP is held at a fixed position for taking a large number of the single ping velocity measurements. The averaged single ping velocity profiles reduce the measurement errors so that a meaningful mean velocity profile can be obtained.

This paper is designed to address the following objectives by using data generated from the ADCP

- Quantify the discharge and velocity distribution for the different cross section along the bend of river Ganga
- Identify relationships between different hydraulic parameters and thus perform regression analysis.

Organization of paper includes:

- an overview of the discharge measurement and regression modeling
- description of study area (Section 2)
- descriptions of the methods used (Section 3)
- the data analysis and model development (Section 4)
- discussion of the results (Section 5); and
- conclusions (Section 6).

2. Study Area

Varanasi (25˚20'N and 83˚7'E) is located in the middle Ganges valley of North India, in the Eastern part of the Uttar Pradesh, along the left crescent-shaped bank of the Ganges, averaging between 50 feet (15 m) and 70 feet (21 m) above the river. It is oldest city situated on the convex bank of holy River Gangaas shown in **Figure 1**. It is called the longest river of India, having its total length 2525 KM from Gangotri to Ganga Sagar. Being located in the Indo-Gangetic Plains of North India, the land is very fertile because low level floods in the Ganges continually replenish the soil. Varanasi is often said to be located between two confluences: one of the Ganges and Varuna, and other of the Ganges and Assi, although the latter has always been a rivulet rather than a river. The

Figure 1. Study area: natural bend in river Ganga at varanasi.

distance between the two confluences is around 2.5 miles (4.0 km). Rarely has any river gathered in itself so much meaning and reverence as the Ganga has over three millennia in the Indian subcontinent. The land-water interface on the Ganga's banks is fashioned out of the need to access the rising and falling water levels in the monsoon and dry seasons. The cultural landscape of this interface a ghat (steps and landings) lined by temples and other public buildings, pavilions, kunds (tanks), streets and plazas is layered and kinetic, and responsive to the river's flow. At Varanasi, where the Ganga reverses its flow northwards, the ghats describe a crescent sweep in a 7.6 km stretch.

The climate of the city, as of Northern India on the whole, is of tropical nature with extremes of temperature, varying from a minimum of 5˚C in winter to a maximum of 45˚C in summer. The annual rainfall varies from 680 mm to 1500 mm, with a large proportion occurring during the monsoon season, in the months of July to September.

3. Methodology

To achieve the objective of measuring velocity distribution and understanding the behavior of velocity distribution with depth of river in the river cross-section, an ADCP, was used. The whole study river length was divided into the 14 distinct cross-sections for discharge measurement, named as M-14 to M-1 respectively from upstream of flow to downstream of flow. Further with the help of ADCP, complete profiling for depth and discharge of each cross-section had been done. Recorded ADCP data have been extracted by using the supporting software of ADCP *i.e.* Win River-II, for analysis purpose. Excel sheets for each cross-section (from M-1 to M-14) of distance from bank, velocity and depth was prepared for calibration of regression based model. For preparation of data, shortest width cross-section was selected and divided it into 4 uniform parts (width wise), the width of shortest cross-section was 281 meters after dividing it, the division width was 74.25 meters, average the velocity and depth parameters of each part as V1, V2, V3, V4 & D1, D2, D3, D4 for the cross-section M-7. The area of each part was also calculated by using AutoCAD software termed as A1, A2, A3, and A4 respectively.

Similarly by applying this process on all the data of each cross-section from M1 to M14 was estimated and listed in **Table 1**. M-1 has been divided into 7 parts having the average velocity from V1 to V7, average depth from D1 to D7 and the area from A1 to A7 and Cross-sectional view with reduced level is also shown in **Figure 2**, M-2 has been divided into 6 parts having the average velocity from V1 to V6, average depth from D1 to D6 and the area from A1 to A6, M-3 has been divided into 5 parts having the average velocity from V1 to V5,

Table 1. Description of cross sectional data.

Sr. No.	Profile No.	Total Width in (m)	No. of Division	Name of Average Depths	Average Depth in (m)/74.25 m width	Name of Average Velocities	Average Velocity in (m)/74.25 m width	Area of each divided section in m^2	Discharge at each cross section
1	M-1	460	6.1953	D1	11.16	V1	0.113	1116.6769	126.18449
				D2	19.98	V2	0.221	1475.8199	326.1562
				D3	18.11	V3	0.3	1351.3572	405.40716
				D4	16.53	V4	0.34	1228.3031	417.62305
				D5	11.07	V5	0.34	830.8381	282.48495
				D6	6.95	V6	0.14	526.488	73.70832
				D7	4.82	V7	0.08	15.2103	1.216824
2	M-2	434	5.8451	D1	9	V1	0.192	879.809	168.92333
				D2	15.72	V2	0.43	1163.7889	500.42923
				D3	14.62	V3	0.371	1094.5191	406.06659
				D4	12.98	V4	0.252	967.9261	243.91738
				D5	9.7	V5	0.163	731.0454	119.1604
				D6	5.58	V6	0.098	210.2677	20.606235
3	M-3	357	4.8081	D1	15.44	V1	0.32	1226.6425	392.5256
				D2	18.22	V2	0.29	1349.0814	391.23361
				D3	14.97	V3	0.3	1112.5433	333.76299
				D4	12.86	V4	0.22	950.3806	209.08373
				D5	6.8	V5	0.17	391.39	66.5363
4	M-4	378	5.0909	D1	15.1	V1	0.173	1271.3793	219.94862
				D2	16.31	V2	0.489	1204.4832	588.99228
				D3	12.52	V3	0.507	931.5344	472.28794
				D4	11.06	V4	0.295	821.6697	242.39256
				D5	7.62	V5	0.097	560.2798	54.347141
5	M-5	386	5.1987	D1	8.57	V1	0.122	864.4567	105.46372
				D2	17.87	V2	0.479	1323.7853	634.09316
				D3	15.75	V3	0.537	1170.9607	628.8059
				D4	15.41	V4	0.248	1144.988	283.95702
				D5	8.31	V5	0.101	661.7477	66.836518
6	M-6	297	4	D1	13.88	V1	0.504	1054.9663	531.70302
				D2	13.1	V2	0.641	1062.1626	680.84623
				D3	12.71	V3	0.313	949.9967	297.34897
				D4	6.51	V4	0.137	488.8122	66.967271

Continued

7	M-7	281	3.7845	D1	11.5	V1	0.744	944.3512	702.59729
				D2	9.41	V2	0.75	707.7555	530.81663
				D3	8.54	V3	0.356	628.8874	223.88391
				D4	4.61	V4	0.111	252.4331	28.020074
8	M-8	312	4.202	D1	8.4	V1	0.656	728.3134	477.77359
				D2	10.27	V2	0.896	765.2419	685.65674
				D3	5.95	V3	0.344	443.2548	152.47965
				D4	2.9	V4	0.068	222.3736	15.121405
9	M-9	307	4.1347	D1	9.05	V1	0.899	678.7563	610.20191
				D2	6.47	V2	0.873	479.2026	418.34387
				D3	3.46	V3	0.684	255.54	174.78936
				D4	2.25	V4	0.506	169.8287	85.933322
				D5	1.45	V5	0.329	5.3285	1.7530765
10	M-10	392	5.2795	D1	10.1	V1	0.678	761.6668	516.41009
				D2	6.02	V2	0.798	447.5982	357.18336
				D3	4	V3	0.776	346.3682	268.78172
				D4	3.105	V4	0.581	228.551	132.78813
				D5	1.9	V5	0.412	142.8722	58.863346
				D6	1.12	V6	0.279	12.7513	3.5576127
11	M-11	422	5.6835	D1	4.56	V1	0.671	337.0713	226.17484
				D2	4.66	V2	0.771	346.8669	267.43438
				D3	5.57	V3	0.835	414.4396	346.05707
				D4	4.4	V4	0.797	328.4041	261.73807
				D5	3.51	V5	0.571	259.5272	148.19003
				D6	1.88	V6	0.461	78.0174	35.966021
12	M-12	559	7.5286	D1	4.19	V1	0.817	311.7137	254.67009
				D2	4.45	V2	0.79	330.417	261.02943
				D3	4.21	V3	0.8	313.0432	250.43456
				D4	4.55	V4	0.771	338.2732	260.80864
				D5	3.5	V5	0.704	257.2048	181.07218
				D6	2.66	V6	0.666	196.848	131.10077
				D7	1.81	V7	0.494	135.492	66.933048
				D8	1.2	V8	0.253	37.3966	9.4613398

Continued

13	M-13	814	10.963	D1	3.74	V1	0.524	279.8455	146.63904
				D2	4.48	V2	0.56	332.7477	186.33871
				D3	5.92	V3	0.526	436.2374	229.46087
				D4	6.12	V4	0.516	453.295	233.90022
				D5	4.48	V5	0.521	333.9429	173.98425
				D6	3.48	V6	0.497	255.3419	126.90492
				D7	2.27	V7	0.484	170.2859	82.418376
				D8	1.84	V8	0.534	135.8387	72.537866
				D9	2.2	V9	0.436	163.9797	71.495149
				D10	2.42	V10	0.356	179.3759	63.85782
				D11	2.38	V11	0.314	152.1876	47.786906
14	M-14	694	9.3468	D1	7.82	V1	0.287	594.5108	170.6246
				D2	7.566	V2	0.319	560.7728	178.88652
				D3	5.27	V3	0.337	392.2132	132.17585
				D4	3.71	V4	0.357	274.2688	97.913962
				D5	3.95	V5	0.354	291.6898	103.25819
				D6	4.14	V6	0.46	307.0175	141.22805
				D7	5.21	V7	0.459	386.965	177.61694
				D8	5.72	V8	0.455	424.994	193.37227
				D9	5.48	V9	0.43	410.8616	176.67049
				D10	4.5	V10	0.39	102.7781	40.083459

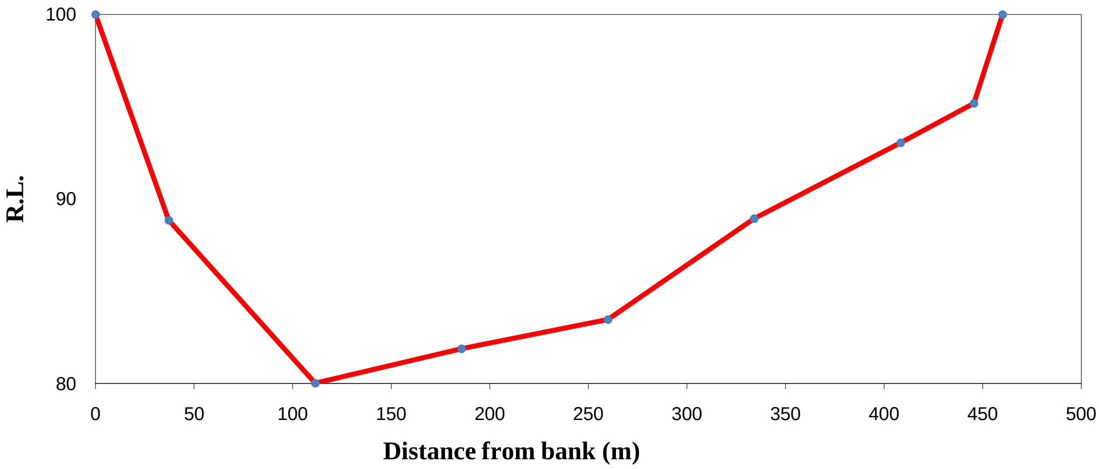


Figure 2. Typical behavior of river cross section w.r.t. Reduced Level (R.L.) at M-1.

average depth from D1 to D5 and the area from A1 to A5, M-4 has been divided into 5 parts having the average velocity from V1 to V5, average depth from D1 to D5 and the area from A1 to A5, M-5 has been divided into 5 parts having the average velocity from V1 to V5, average depth from D1 to D5 and the area from A1 to A5, M-6 has been divided into 4 parts having the average velocity from V1 to V4, average depth from D1 to D4 and the area from A1 to A4, M-8 has been divided into 4 parts having the average velocity from V1 to V4,average depth from D1 to D4 and the area from A1 to A4, M-9 has been divided into 5 parts having the average velocity from V1 to V5, average depth from D1 to D5 and the area from A1 to A5, M-10 has been divided into 6 parts having the average velocity from V1 to V6,average depth from D1 to D6 and the area from A1 to A6, M-11 has been divided into 6 parts having the average velocity from V1 to V6,average depth from D1 to D6 and the area from A1 to A6, M-12 has been divided into 8 parts having the average velocity from V1 to V8, average depth from D1 to D8 and the area from A1 to A8, M-13 has been divided into 11 parts having the average velocity from V1 to V11, average depth from D1 to D11 and the area from A1 to A11, M-14 has been divided into 10 parts having the average velocity from V1 to V10, average depth from D1 to D10 and the area from A1 to A10.

4. Data Analysis and Modeling

a) Data Analysis

Before the development of the models of regression, it is the most important to check whether the variables in data have any correlation or not. Therefore, each cross-sectional data of discharge, depth and velocity are checked for the multiple regression, the R^2, Adjusted R^2, Standard error of estimates, standard error, t value and p value for each cross-section are listed in **Table 2** which shows there is a strong correlation between discharge, depth and velocity data, this analysis gives an clear idea to develop a multiple linear regression model.

R-squared (R^2) is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determinations for multiple regressions. The value (R^2) should always between 0% and 100%:

- 0% indicates that the model explains none of the variability of the response data around its mean.
- 100% indicates that the model explains all the variability of the response data around its mean.

For any regression model first indicator of generalizability is the adjusted (R^2) value, which is adjusted for the number of variables included in the regression equation. This is used to estimate the expected shrinkage in (R^2) that would not generalize to the variable because our solution is over-fitted to the data set by including too many independent variables. If the adjusted (R^2) value is much lower than the (R^2) value, it is an indication that our regression equation may be over-fitted to the sample, and of limited generalizability.

The R^2 method is a useful linear regression tool for exploratory model building as it assists in finding subsets of independent variables that best predict a dependent variable in a given sample (SAS Institute, Inc., 1994). This algorithm examines all of the possible combinations of the independent variables and ranks them according to decreasing order of R^2 (fraction of the variance explained by the regression) magnitude for the given sample. Using this output of ranked R^2, the best combination of independent variables was selected for further testing for inclusion in the final regression equations. The type of regression equation that is most suitable to describe the relation depends naturally on the variables considered and with respect to hydrology on the physics of the processes driving the variables. Furthermore, it also depends on the range of the data one is interested in.

b) Development of Regression Models

(i) Multiple Regression model for 8 Cross-Sections: For development of the regression model, the complete data set of all cross-section were analyzed separately. Three cross-sections from both ends of the bend and two cross-sections from center location have been selected for model development (as shown in **Figure 3**). Selected cross-section gives a complete picture of the Varanasi bend of River Ganga. For calibration of the regression model complete 55 data (about 65% of total) and remaining 31 data (about 35% of total) are used for the validation of the model. As shown in the **Table 3** the value of R^2 is 0.8674 of the calibrated model which shown a strong correlation between discharge, depth and velocity data of the complete data set.

Thus developed discharge equation from regression analysis is $\mathbf{Q = Y_o + a \times V + b \times D}$, where Q is Discharge V is Velocity and D is depth, Y_o, a and b are constants which has to determined by regression analysis.

(ii) Partial regression model: For analyzing the fact that whether the discharge is more dependent on which parameter, depth or velocity, a partial regression model has been studied by keeping depth and velocity constant. For the modeling purpose (keeping depth constant) the data had shorted in a manner that the depth ranging in

Table 2. Cross-sectional data analysis.

Sr. No.	C-S	R	R^2	AdjR^2	Y_o	a	b	SEE	t	P	Std Error
1	M-1	0.9892	0.9784	0.9677	−140.1343	823.845	14.8447	28.9603	−4.72	0.01	29.66
									5.87	0.00	140.24
									5.51	0.01	2.69
2	M-2	0.9973	0.9946	0.991	−106.0717	1451.219	−2.2241	16.7843	−3.37	0.04	31.52
									7.15	0.01	202.95
									−0.33	0.76	6.72
3	M-3	0.999	0.9981	0.9961	−232.0105	1086.547	16.5426	8.4102	−12.73	0.01	18.22
									7.77	0.02	139.79
									8.06	0.02	2.05
4	M-4	0.995	0.9901	0.9802	−187.1077	892.8937	17.3317	28.7211	−3.45	0.07	54.18
									9.54	0.01	93.58
									3.46	0.07	5.01
5	M-5	0.9974	0.9948	0.9896	−128.5444	1178.466	9.0698	27.8852	−2.38	0.14	54.09
									8.24	0.01	142.98
									1.40	0.30	6.50
6	M-6	0.9997	0.9993	0.9979	−121.947	1170.01	4.4053	12.27	−4.41	0.14	27.67
									20.82	0.03	56.20
									1.21	0.44	3.65
7	M-7	0.9785	0.9576	0.8727	−261.565	587.393	40.15	106.93	−1.03	0.49	253.87
									1.23	0.44	479.24
									0.77	0.58	51.99
8	M-8	0.9994	0.9988	0.9964	275.978	2038.62	−137.83	18.05	2.84	0.22	97.24
									6.18	0.10	329.67
									−3.69	0.17	37.36
9	M-9	0.9998	0.9997	0.9994	−126.307	78.1056	73.449	6.3376	−10.03	0.01	12.59
									2.31	0.15	33.87
									28.23	0.00	2.60
10	M-10	0.9976	0.9953	0.9921	−132.187	258.619	46.329	17.09	−5.64	0.01	23.44
									5.26	0.01	49.13
									14.97	0.00	3.09
11	M-11	0.999	0.9979	0.9965	−203.784	306.824	50.422	6.3165	−12.53	0.00	16.27
									5.72	0.01	53.61
									8.21	0.00	6.14
12	M-12	0.9992	0.9984	0.9978	−87.7579	53.9182	69.184	4.6753	−12.60	<0.0001	6.96
									2.00	0.10	26.95
									16.86	<0.0001	4.10
13	M-13	0.9988	0.9976	0.9969	−103.664	202.286	37.935	3.7203	−14.09	<0.0001	7.36
									11.52	<0.0001	17.55
									41.81	<0.0001	0.91
14	M-14	0.9201	0.8465	0.8026	−159.944	244.71	28.683	17.493	−2.86	0.02	55.97
									2.36	0.05	103.59
									6.19	0.00	4.63

C-S: cross-section; R: Correlation constant; R^2: square of the correlation constant; Adj R^2: adjusted value of R^2, Y_o, a and b are the intercept constants; SEE: Standard error of estimate, t: test value for each constants; p: test value for each constants and Std Error: standard error for each constants.

Figure 3. Bifurcation of cross-sections at Varanasi Bend of River Ganga.

Table 3. Statistical parameters of the calibrated model.

Profile	R	Rsqr	AdjRsqr	Y_o	a	b	SEE	t	P	Std Error
8-C-S	0.934	0.8723	0.8674	−205.169	519.233	27.3198	59.0513	−8.5517	<0.0001	23.9917
								13.1601	<0.0001	39.4551
								16.096	<0.0001	1.6973

1 m - 5 m, 5 m - 10 m, 13 m - 15 m and finally 15 m - 20 m, the model gives the R^2 value as follows 0.816, 0.802, 0.947 and 0.966 respectively. For the model (keeping velocity constant) average the velocity in previously shorted data, it ranged up to 0.3168 m/s, 0.3645 m/s and 0.5 m/s, the model gives the R^2 value as follows 0.897, 0.998 and 0.988 respectively as listed in **Table 4** below. These values concluded that the discharge is more depending upon the depth of the flow as the R^2 value for the model when velocity is constant is more except once *i.e.* 0.897.

c) Validation of Model

From whole data set remaining 31 data used for the validation of the model. The detailed calculation for each data is shown in **Table 5**. From this it is clearly noticeable that at very low discharge values, depth below 5 m and low velocities, the model doesn't works properly and it gives unreasoned results.

5. Result and Discussion

River hydraulics is quite complex in natural channels and rivers. For practical and engineering purposes, the flows in river channel are often characterized by depth averaged or cross-sectional averaged properties. While these simplifications might be justifiable and necessary for practical reasons, it is important to be cognizant about the complex nature of the three-dimensional free-surface flows in rivers and open channels. A better understanding of the hydraulic properties in natural rivers would give rise to a more accurate approximation in practical applications. In this study, the velocity distribution in a river cross-section has been investigated in detail.

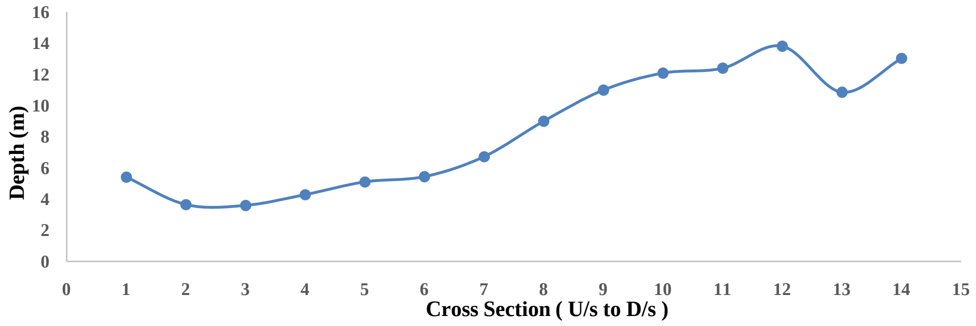
Also as we know that atmospheric and human intervention affects the hydrology of any area which influences the flow behavior of river. To understand these effects on main governing parameters of hydraulics on river flow characteristics, 14 different cross section shad marked along the river which lies between 7500 m. The river flow velocity, width and depth has been computed and plotted to compare each other and identified their relationship among the above said parameters. The results showed that river depth is almost having increasing trend except the cross section (M-2), second last from downstream as clearly shown in **Figure 4(a)**.

Table 4. Statistical parameters of the partial regression model.

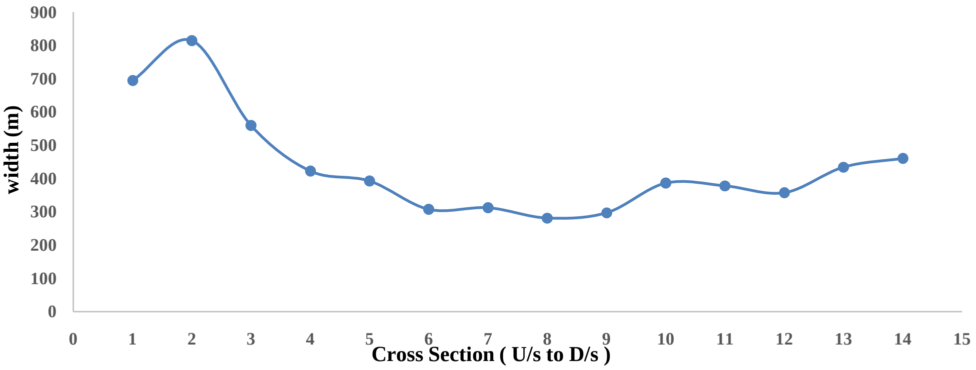
Sr. No.	R^2	Std. deviation	MSE	RMSE	Y_o	A	Range	Constant Parameter
1	0.816	36.261	1205.293	34.717	−44.442	342.204	1 - 5 m	Depth
2	0.802	59.932	3169.251	56.296	−35.172	633.193	5 - 10 m	
3	0.947	53.104	2115.015	45.989	62.655	769.011	10 - 15 m	
4	0.966	11.597	89.657	9.469	150.237	805.866	15 - 20 m	
5	0.897	45.307	1824.616	42.716	−60.380	22.605	0.3168 m/s	Velocity
6	0.998	5.656	25.593	5.059	1.750	25.202	0.3645 m/s	
7	0.988	17.128	234.689	15.320	19.174	28.876	0.5 m/s	

Table 5. Discharge data for validation of model.

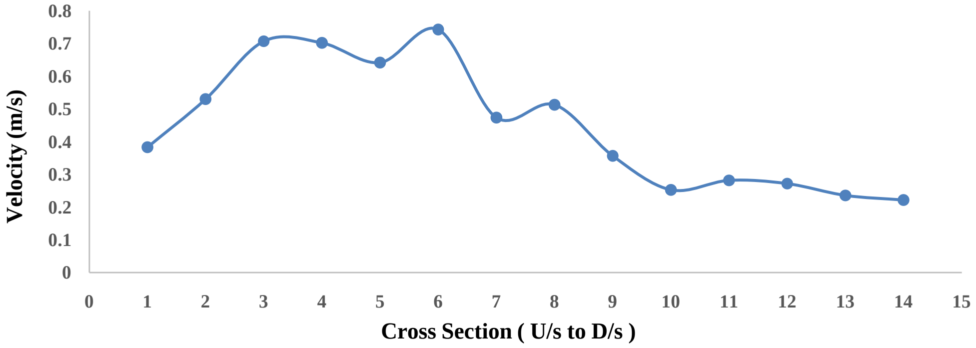
Sr. No.	Velocity	Depth	Observed Discharge	A × Velocity	B × Depth	Modeled discharge	% error
1	0.173	15.1	219.9486189	89.827309	412.529	297.186989	35.11655
2	0.489	16.31	588.9922848	253.904937	445.5859	494.321575	−16.0733
3	0.507	12.52	472.2879408	263.251131	342.0439	400.125727	−15.2793
4	0.295	11.06	242.3925615	153.173735	302.157	250.161423	3.205074
5	0.097	7.62	54.3471406	50.365601	208.1769	53.373177	−1.79212
6	0.122	8.57	105.4637174	63.346426	234.1307	92.307812	−12.4743
7	0.479	17.87	634.0931587	248.712607	488.2048	531.748133	−16.1404
8	0.537	15.75	628.8058959	278.828121	430.2869	503.945671	−19.8567
9	0.248	15.41	283.957024	128.769784	420.9981	344.598602	21.3559
10	0.101	8.31	66.8365177	52.442533	227.0275	74.300771	11.16793
11	0.504	13.88	531.7030152	261.693432	379.1988	435.722956	−18.0514
12	0.641	13.1	680.8462266	332.828353	357.8894	485.548433	−28.6846
13	0.313	12.71	297.3489671	162.519929	347.2347	304.585287	2.433612
14	0.137	6.51	66.9672714	71.134921	177.8519	43.817519	−34.5688
15	0.899	9.05	610.2019137	466.790467	247.2442	508.865357	−16.6071
16	0.873	6.47	418.3438698	453.290409	176.7591	424.880215	1.562434
17	0.684	3.46	174.78936	355.155372	94.52651	244.51258	39.88985
18	0.506	2.25	85.9333222	262.731898	61.46955	119.032148	38.51687
19	0.329	1.45	1.7530765	170.827657	39.61371	5.272067	200.7323
20	0.678	10.1	516.4100904	352.039974	275.93	422.800654	−18.127
21	0.798	6.02	357.1833636	414.347934	164.4652	373.64383	4.608408
22	0.776	4	268.7817232	402.924808	109.2792	307.034708	14.23199
23	0.581	3.105	132.788131	301.674373	84.82798	181.333052	36.55818
24	0.412	1.9	58.8633464	213.923996	51.90762	60.662316	3.05618
25	0.279	1.12	3.5576127	144.866007	30.59818	−29.705117	−934.973
26	0.671	4.56	226.1748423	348.405343	124.5783	267.814331	18.41031
27	0.771	4.66	267.4343799	400.328643	127.3103	322.469611	20.57897
28	0.835	5.57	346.057066	433.559555	152.1713	380.561541	9.970747
29	0.797	4.4	261.7380677	413.828701	120.2071	328.866521	25.64719
30	0.571	3.51	148.1900312	296.482043	95.8925	187.205241	26.32782
31	0.461	1.88	35.9660214	239.366413	51.36122	85.558337	137.8866



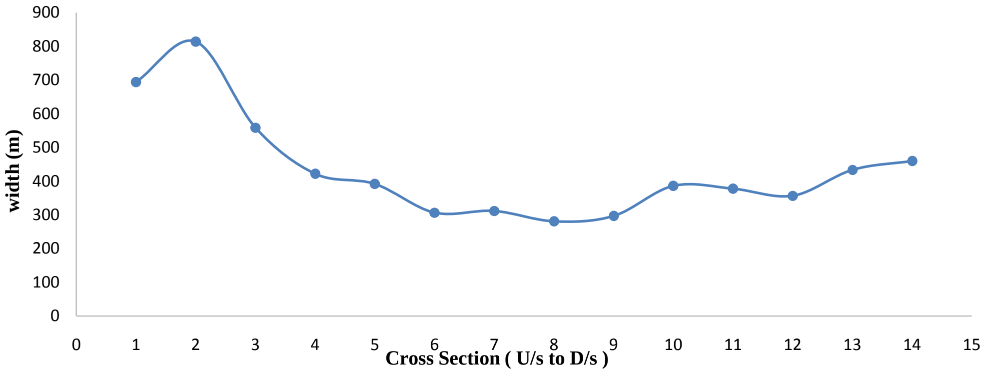
(a)



(b)



(c)



(d)

Figure 4. (a) Depth Variation along with cross section from M-14 to M-1; (b) Width variation with cross section from M-14 to M-1; (c) Velocity distribution with cross section from M-14 to M-1; (d) Discharge variation with cross section from M-14 to M-1.

Leaving the starting upstream station (M-14) the width of river is almost having decreasing trend till (M-6) cross section as shown in **Figure 4(b)**. This shows a varying average depth and average width of flow at its different cross section due to its meandering and sinusoidal characteristics.

Generally long profile gradient of river is decreases in downstream due to increasing hydraulic radius (cross section efficiency) but here at Varanasi bend the velocity is increasing up to M-12 cross section after which the inconsistent bend for velocity obtained although from the M-7 cross section the average velocity of flow is continuously decreasing as shown in **Figure 4(c)**. The above theory of increasing velocity in downstream seems to be not valid for River Ganga at Varanasi bend. The decreasing of velocity had resulted by the increasing the depth of flow in downstream consistency. Discharge variation with the cross sections is also shown in **Figure 4(d)**.

Any stream with having changing volume may assume a meandering course, alternatively eroding sediments from the outside of a bend and depositing them on the inside. This meandering characteristic and sinuosity along Ganga river course had showed non uniformity in the river width and uneven depth of water. The main cause of overall these parameters is heavy rainfall from which the runoff in term of river flow depends. The rainfall intensity mainly governs the amount of erosion and the geological parameters decide the deposition of eroded sediment in the river which leads to variation in the geometry of any river. Human activity is also the indisputable cause for high flow which involved of building of impervious structures, deforestation, and caused to the higher surface runoff and decrease the time of concentration by which even on small rainfall leads to change in depth of river flow. On the other hand, forestation such as pine tree and other tree which can increase infiltration so that time of peak can delay and its harmful effects can be reduced. To minimize the impact of surface runoff directly to the river flood mitigations concept should be undertaken and another river training work to be adopted along the Ganga River in order to minimize erosion as well as sedimentation enter to the river.

6. Conclusions

The monitoring of discharge and velocity distribution was conducted using consistent protocols designed to ensure the scientific validity of the data. These stream flow datasets will aid in the management of water resources in a sustainable manner for the benefit of water users and the environment.

A multiple linear regression model was developed by using the measured discharge, depth and velocity through ADCP of Varanasi bend of river Ganga. The regression equation shows a high correlation between the discharge, depth and velocity parameters with the R^2 value of 0.8624. Among the validation set of 31 data's, 9 data's of discharge were in the range of $100 m^3/s$ and out of which 6 data's gave more errors, as well as the average velocity lies in the range of 0.101 m/s to 0.279 m/s in validation set which gave more errors in validation of model. The proposed model is validated for the average velocity greater than 0.279 m/s up to 0.899 m/s. The developed model also shows variation when the depth of flow is less than 5 m, so this model is suitable for the depth above 5 m up to the maximum of 19.98 m at the Varanasi bend of River Ganga. The equations developed for this study are not applicable for ungaged sites in which the basin characteristics are not in the range of those used to develop the regression equations.

Acknowledgements

Authors are thankful to Department of Civil Engineering, Indian Institute of technology (BHU) for providing the infrastructure and computational facilities to complete this work.

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