

CHAPTER 4: MODELING OF RIVER GANGA AT VARANASI BEND

4.1 INTRODUCTION

Flood is the most dangerous natural disaster, as worldwide known so far. It causes a huge economical impact as well as loss of life and livelihood. Estimation of discharge for open channel flow (most commonly natural rivers) is very vital hence it has been keen interest of the researchers for the decades. They have developed the methods for discharge measurement; however some enhances the accuracy of the previously observed method. Regression based models (Engeland and Hisdal 2009; Eslamian et al., 2010; Tayfur and Singh 2011; among others) and some goes through the soft computing methods (Zhu and Zhou 2009; Akbari et al., 2009; Chen et al., 2010; among others). 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 (Walter and Tullos, 2010). Regression based approach is commonly very useful for discharge estimation (Wharton et al., 1989; Wharton and Tomlinson 1999; Bhatt and Tiwari 2008) of the ungauged sites. Increasing the flow of any river is caused by the large volume of rainfall in its basin, would probably change the physical parameters of the river which involved the changes in the depth due to bank erosion takes place and width of flow (Andersson et al., 2006; Kamarudin et al., 2009; Jung et al., 2011; Hoyle et al., 2012). Schwendel et al., (2012) observed that the river hydrodynamic could directly affect the flow pattern of river and caused to the

change in river morphology. The main challenge of the researchers for decades is to study the hydrodynamics of meandering rivers. Chitale (1970), Allen (1982) and Howard (1992) state that the meandering is one of the most common pattern followed by large rivers. A lot of research work has 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. As it is clear to understand that the discharge of river is a direct function of river meandering wavelength and amplitude, as the higher the value of river meandering wavelength and amplitude higher will be the discharge and the vice versa. This clear understanding gives a way to go forward with this research in the direction that the river parameters must be naturally having a relationship with each other. For developing a correlation between the river parameters which are directly related to the physical parameters of river i.e. discharge, depth and velocity, Varanasi bend of holy River Ganga had been analyzed. Total measurement procedure was completed with the help of ADCP (Acoustic Doppler Current Profiler), complete bend was divided into the 14 separate cross-section for 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 of each cross-section had been completed.

4.2 DATA INTERPRETATION AND PREPARATION OF DATA FOR MODEL

In this section the complete data recorded in ADCP have to be changed for the analysis purpose. It may be completed by following:-

1. Data extraction from the ADCP hardware to Computer
2. Preparation of data for calibration of model

4.2.1 Data Extraction from the ADCP Hardware to Computer

As the data recorded in ADCP the complete data is in *.tff format, for analyzing, it is compulsory to convert it into Excel format. These are the following steps to convert the data set into the Excel format:-

- Firstly reprocess the transect (Figure 4.1 a.)
- Go through the ASCII Output (Figure 4.1 b.)
- Create the ASCII output Figure 4.1 c.)
- Select the variable between the data required (Figure 4.1 d.)
- Select the option to save the output in file (Figure 4.1e.)
- Select the saving location in computer (Figure 4.1 f.)
- Lastly reprocess the transect again to show it in window (Figure 4.1 g.)
- Now the text file is shown in window of Win River II (Figure 4.1 h.)

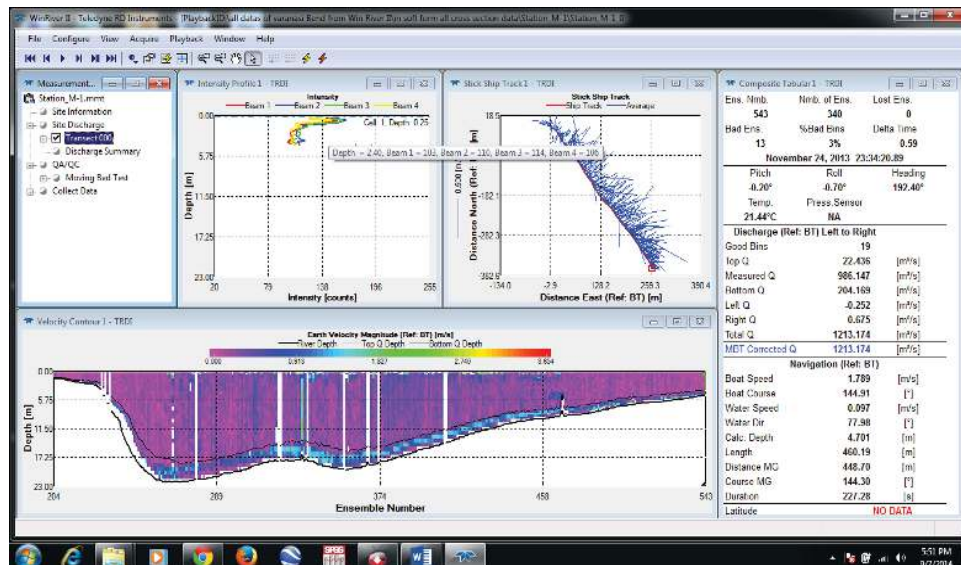


Figure 4.1 a. Showing the processing of the transect

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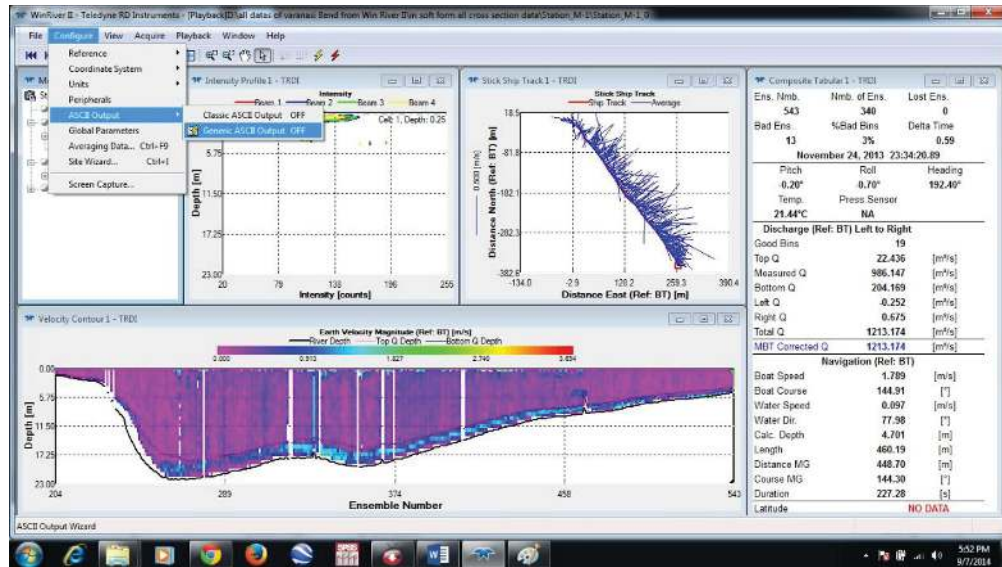


Figure 4.1 b. Showing the ASCII output in configuration option



Figure 4.1 c. Showing the creating ASCII output

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Figure 4.1 d. Showing the selection of variables



Figure 4.1 e. Showing the saving option

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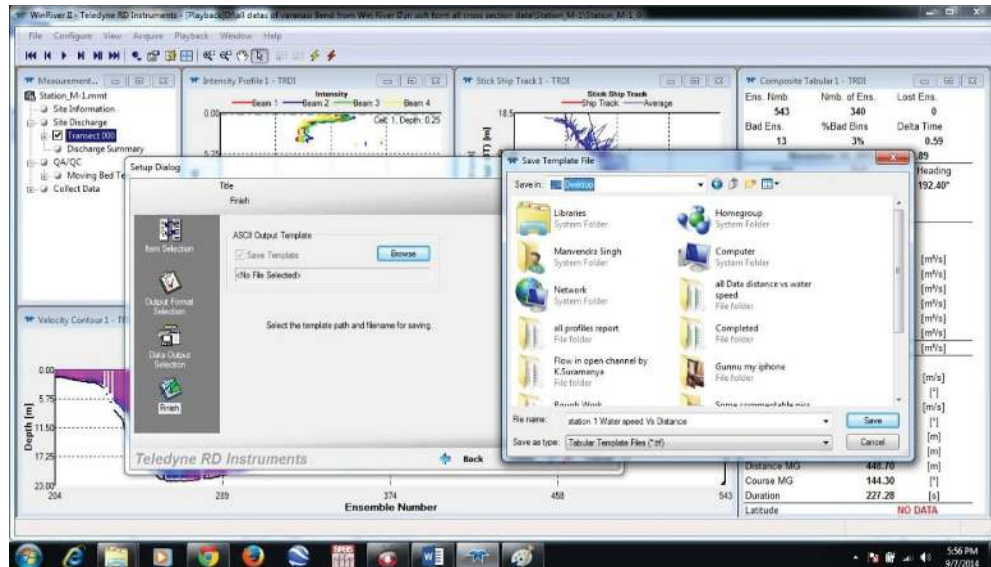


Figure 4.1 f. Showing the saving location to computer

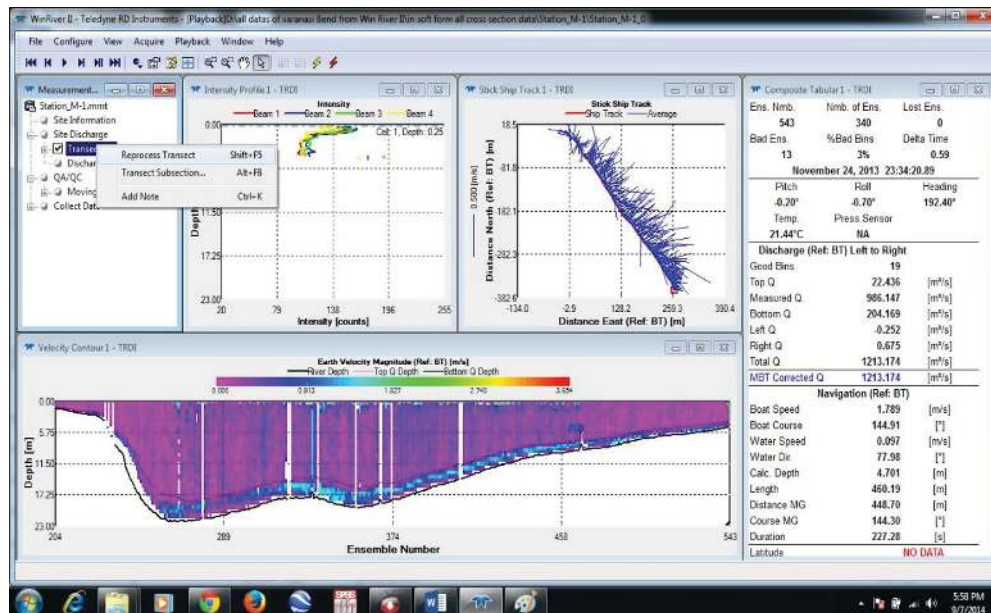


Figure 4.1 g. Showing the reprocess the transect again

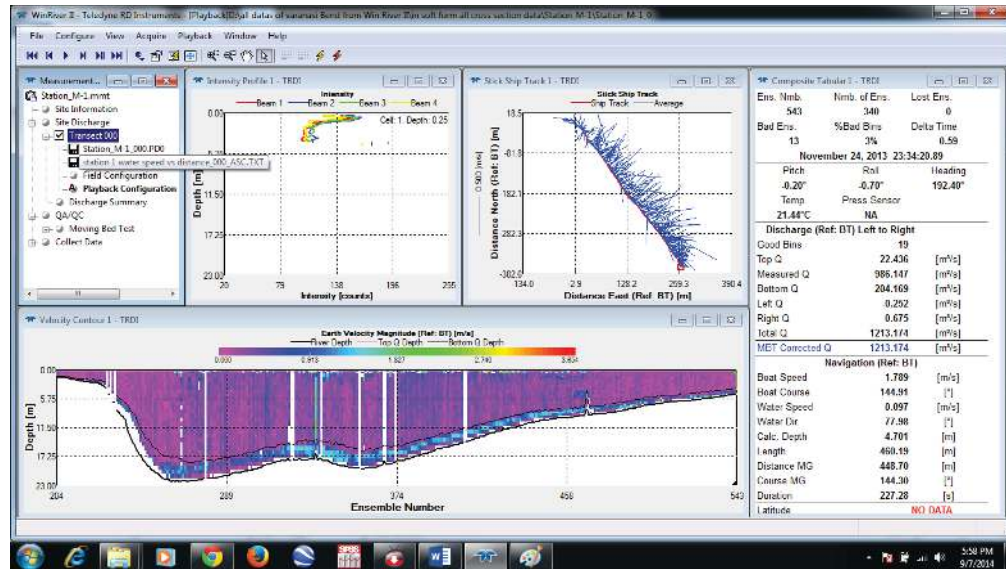


Figure 4.1 h. Showing the text file in Win River-II window

4.2.2 Preparation of Data for Calibration of Model

The data were extracted by using Win River II software, supporting software to ADCP. The excel sheets for each cross-section (from M-14 to M-1) distance, velocity and depth data were obtained, for calibration of regression based model. Data must be prepared as it is easy to understand, choose the shortest width cross-section and divide it into 4 uniform parts (width wise), the width of shortest cross-section was 297 meters after dividing it the resultant division width was 74.25 meters. It is essential to get average of velocity and depth parameters of each part as V1, V2, V3, V4 & D1, D2, D3, and D4 for the cross-section M-7. Area of each part has been calculated by using Auto Cad software termed as A1, A2, A3, and A4 respectively by applying this process on all the data of each cross-section, M-1 was divided in 7 parts having the average velocity from V1 to V7, average depth from D1 to D7 and the area from A1 to A7, M-2 was divided in 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 was divided in 5 parts having the average velocity from V1 to V5, average depth from D1 to D5 and the area from A1 to A5, M-4 was divided in 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 was divided in 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 was divided in 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 was divided in 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 was divided in 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 was divided in 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 was divided in 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 was divided in 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 was divided in 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 was divided in 10 parts having the average velocity from V1 to V10, average depth from D1 to D10. The average velocity, depth and area are given in the Table 4.1.

Table 4.1. Description of cross-sectional data for calibration of Model

Sr. No.	Profile No.	Total Width in (m)	No. of Division	Name of Average Depths	Average Depth in (m)/74.2 5m 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

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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
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

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				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
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

4.3 THEORETICAL BACKGROUND

This section is further divided into two subsections which contain the theoretical background behind the discharge estimation of open channel flow (natural rivers) and theory behind the regression analysis as given below :-

1. Theoretical background behind the discharge estimation of open channel flow (natural rivers)
2. Theory behind the regression analysis

4.3.1 Theoretical Background behind the Discharge Estimation of Open Channel Flow (Natural Rivers)

Flows in open channels (like natural rivers) are often represented by its cross-section. But in reality, river hydrodynamics is quite complicated because the river cross-sections and river bed are usually complex and do not meet assumption of one dimensional flow as in manmade open channel flow can. While the one dimensional approximation, it is important to assess the extent and the impacts of the approximations.

The flow rate or discharge of a river is the volume of water flowing through a cross-section in a unit of time and is usually expressed as m³/s. It is calculated as the product of average velocity and cross-sectional area but is affected by water depth, alignment of the channel, gradient and roughness of the river bed.

$$\text{Discharge (Q)} = \text{Area (A)} * \text{Velocity (V)}$$

Where, Q = Discharge in (m³/s)

A = Area of cross-section in m²

V = Velocity in m/s

Stream discharge can be measured using (1) volumetric gauging, (2) float gauging, (3) current metering, and (4) slope-area methods. The choice of method depends on the characteristics of the stream and on the application.

4.3.1.1 Volumetric gauging

Stream discharge (in m³/s) at one point in time (i.e., a 'spot discharge') can be measured directly with volumetric gauging, though this is only possible with small river-flows, or indirectly with the velocity-area methods of float gauging and current metering.

4.3.1.2 Float gauging

It involves measuring the velocity of a neutral buoyancy object (e.g., orange or dog biscuit) and multiplying this by the average cross-sectional area (using a tape and rule) of the river. These objects do, however, float close to the river surface, which is faster than the average velocity of the water profile and must, therefore, be reduced by a coefficient (e.g., a river 0.9 m deep has a coefficient of 0.7). Some rivers also have large changes in velocity across the river channel. This cannot be corrected, so the more accurate current metering method is recommended.

4.3.1.3 Current metering

With current metering the rotation of a current meter's impeller gives the local water velocity following application of a calibration equation (called a rating equation). To cope with the vertical distribution of velocity, measurements should be made at different depths (D) in the water profile. If only two depths are used for measurement, then an average of 0.2D and 0.8D gives a good representation of the profile velocity, or 0.6D if only one depth is used (Hewlett, 1982 p99). The transverse (i.e., 'across-river') distribution of velocity can be characterized by first dividing the channel cross-section into a number of 'segments'. The edge of these segments are called 'verticals' and these are the locations at which the measurements to calculate the profile-average velocity should be made. The 'Mean-Section Method' or 'Mid-Section Method' can then be used to calculate the discharge for each segment (Dingman, 1993).

Where the 'Mean-Section Method' is used to calculate discharge for each segment using:

$$Q_{seg} = 0.5(v_1+v_2) \times 0.5(d_1+d_2) \times b$$

where Q_{seg} is the discharge for each channel segment (m^3/s), v_1 and v_2 are the profile-average water velocities at vertical 1 and 2 respectively (either side of the segment), d_1 and d_2 are the depths of the flow at verticals 1 and 2 respectively, and b is the chosen width of each channel segment. The average velocity of the water in the two 'end segments' (adjacent to the river banks) are calculated by assuming zero depth and zero velocity at the water's edge. Current metering is an accurate method of river gauging except where the river is very shallow. Under such conditions, an alternative method of dilution gauging can be used.

4.3.1.4 Slope-area methods

Perhaps the most common slope-area method involves the use of the Manning Equation, i.e.

$$V = \frac{R^{2/3} S^{1/2}}{n}$$

and

$$Q = \frac{AR^{2/3} S^{1/2}}{n}$$

where V is the river velocity (or 'specific discharge'), R is the 'hydraulic radius' which is the cross-sectional area of the flow divided by the wetted perimeter, S is approximated by the downstream slope on the river surface, and n is Manning's roughness coefficient (which varies between 0.025 and 0.07 in natural channels). In other words, if the water-surface slope and the 'hydraulic mean depth' (hydraulic radius) increase so does the river's velocity, while if the channel roughness increases, the river velocity reduces (Hewlett, 1982).

Some other methods are also available to calculate the river velocity, by as many ways one can measure the river velocity these are the different methods (theoretical) to measure the discharge of any open channel stream.

4.3.2 Theory behind the Regression Analysis

In this study, the linear and multiple regression approach has been applied to develop a relationship between River discharge, depth and velocity. For this purpose, an introduction of regression equations for computing different parameters as dependent and independent variables is required.

Regression analysis is a statistical tool for the investigation of relationships between variables, which gives information on the relationship between a response (dependent) variable and one or more (predictor) independent variables to the extent that information is contained in the data. The goal of regression analysis is to express the response variable as a function of the predictor variables. The duality of fit and the accuracy of conclusion depend on the data used. Hence non-representative or improperly compiled data result in poor fits and conclusions. Thus, for effective use of regression analysis one must investigate the data collection process, discover any limitations in data collected, and restrict conclusions accordingly.

Once a regression analysis relationship is obtained, it can be used to predict values of the response variable, identify variables that most affect the response, or verify hypothesized causal models of the response. The value of each predictor variable can be accessed through statistical tests on the estimated coefficients (multipliers) of the predictor variables. Three broadly uses for regression analysis are prediction, model specification and parameter estimation.

Regression analysis equations are designed only to make predictions. Good predictions will not be possible if the model is not correctly specified and accuracy of the parameter not ensured. However, accurate prediction and model specification require that all relevant variables be accounted for in the data and the prediction equation be defined in the correct functional form for all predictor variables.

Parameter estimation is the most difficult to perform because not only is the model required to be correctly specified, the prediction must also be accurate and the data should allow for good estimation. For example, multi-collinearity creates a problem and requires that some estimators may not be used. Thus, limitations of data and

inability to measure all predictor variables relevant in a study restrict the use of prediction equations.

The main regression models used in the present study are:

4.3.2.1 Linear regression model

It is used to estimate the regression line between the river discharge, velocity and depth. Correlation analysis measures the closeness of the relationship between chosen independent and dependent variables. If the correlation coefficient is nearer to +1 or -1, it shows the probability of linear relationship between the variables x and y. The correlation between the parameters is characterized as strong, when it is in the range of +0.8 to 1.0 and -0.8 to -1.0, moderate when it is having value in the range of +0.5 to 0.8 and -0.5 to -0.8, weak when it is in the range of +0.0 to 0.5 and -0.0 to -0.5. This analysis attempts to establish the nature of the relationship between the variables and thereby provides a mechanism for prediction or forecasting. In this study, the relationship of river discharge, velocity and depth parameters on each other in data was determined by calculating Karl Pearson's correlation coefficient, R, by using the formula as given:

$$R = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{\sqrt{\sum(X - \bar{X})^2 \sum(Y - \bar{Y})^2}}$$

where, X denotes the values of x-variable, \bar{X} denotes the average values of X; and Y denotes the values of y-variable, \bar{Y} denotes the average values of Y represents two different river parameters.

To determine the straight linear regression, following equation of straight line can be used: $Y = a + bX$ where, Y and X are the dependent and independent variable respectively. a is the slope of line, b is intercept on y axis. The value of empirical parameters 'a' and 'b' are calculated with the help of the following equation:

$$b = \frac{\sum XY - \bar{X}\sum Y}{\sum X^2 - \bar{X}\sum Y} \quad \text{and} \quad a = \bar{Y} - b\bar{X}$$

In statistics, correlation is a broad class of statistical relationship between two or more variables. The correlation study is useful to find a predictable relationship which can be exploited in practice. It is used for the measurement of the strength and statistical significance of the relation between two or more river parameters. To study the correlation between various river parameters, the regression analysis was carried out using Sigma Plot version 10.0, Kyplot Version 5.0 and XLSTAT version 13.0.

4.3.2.2 Multiple linear regressions

It is a statistical tool for understanding between an outcome variable and several predictors (independent variables) that best represent the relationship in a population. The technique is used for both predictive and explanatory purposes within experimental and non-experimental designed.

Multiple linear regression models are used to study the linear relationship between a dependent variable and several independent variables by fitting a linear equation to observed data samples. The fitting is performed by minimizing the sum of the squares of the vertical deviations from each data point to the line that best fits for the observed data.

An example of a regression model is the linear regression model which is a linear relationship between response variable, y and the predictor variable, $x_i, i = 1, 2, \dots, n$ of the form

$$y = a_0 + a_1x_1 + a_2x_2 + \dots + a_nx_n + \varepsilon$$

Where

a_0, a_1, \dots, a_n are regression coefficients (unknown model parameters), and ε is the error due to variability in the observed responses.

4.4 ANALYSIS, BOUNDARY CONDITION, DEVELOPMENT, AND RESULT & DISCUSSION

In this section of the chapter, the analysis of data, Development of multiple regression model & partial regression model and explanation of the result outputs & discussion takes place in various subsections

1. Analysis of data
2. Boundary condition of the River model developed for the Varanasi bend
3. Development of regression models
4. Validation of regression model
5. Result & discussion

4.4.1 Analysis of Data

Before the development of the models of regression, it is the most important to analyses the data, whether these data have any correlation or not. For this, each cross-section data of discharge, depth and velocity were checked for the multiple regressions. 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 which shows there is a strong correlation between discharge, depth and velocity data, this analysis gives a clear idea to develop a multiple linear regression model.

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Table 4.2. Detail data analysis for each cross-section with R^2 , Adjusted R^2 and Standard error of estimates, standard error, t value and p value for each cross-section

Sr. No.	Profile	R	R^2	Adjusted R^2	Y_0	a	b	SEE	t	P	Std Error
1	M-1	0.99	0.98	0.97	-140.13	823.85	14.84	28.96	-4.72	0.01	29.66
									5.87	0.00	140.24
									5.51	0.01	2.69
2	M-2	1.00	0.99	0.99	-106.07	1451.22	-2.22	16.78	-3.37	0.04	31.52
									7.15	0.01	202.95
									-0.33	0.76	6.72
3	M-3	1.00	1.00	1.00	-232.01	1086.55	16.54	8.41	-12.73	0.01	18.22
									7.77	0.02	139.79
									8.06	0.02	2.05
4	M-4	1.00	0.99	0.98	-187.11	892.89	17.33	28.72	-3.45	0.07	54.18
									9.54	0.01	93.58
									3.46	0.07	5.01
5	M-5	1.00	0.99	0.99	-128.54	1178.47	9.07	27.89	-2.38	0.14	54.09
									8.24	0.01	142.98
									1.40	0.30	6.50
6	M-6	1.00	1.00	1.00	-121.95	1170.01	4.41	12.27	-4.41	0.14	27.67
									20.82	0.03	56.20
									1.21	0.44	3.65
7	M-7	0.98	0.96	0.87	-261.57	587.39	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	1.00	1.00	1.00	275.98	2038.62	-137.83	18.05	2.84	0.22	97.24
									6.18	0.10	329.67
									-3.69	0.17	37.36

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9	M-9	1.00	1.00	1.00	-126.31	78.11	73.45	6.34	-	0.01	12.59
									10.03		
									2.31	0.15	33.87
10	M-10	1.00	1.00	0.99	-132.19	258.62	46.33	17.09	28.23	0.00	2.60
									-5.64	0.01	23.44
									5.26	0.01	49.13
11	M-11	1.00	1.00	1.00	-203.78	306.82	50.42	6.32	14.97	0.00	3.09
									-	0.00	16.27
									12.53	0.01	53.61
12	M-12	1.00	1.00	1.00	-87.76	53.92	69.18	4.68	8.21	0.00	6.14
									-	<0.0001	6.96
									12.60	0.10	26.95
13	M-13	1.00	1.00	1.00	-103.66	202.29	37.94	3.72	16.86	<0.0001	4.10
									-	<0.0001	7.36
									14.09	<0.0001	17.55
14	M-14	0.92	0.85	0.80	-159.94	244.71	28.68	17.49	41.81	<0.0001	0.91
									-	0.02	55.97
									2.36	0.05	103.59
									6.19	0.00	4.63

4.4.2 Boundary Condition of the River Model Developed for the Varanasi Bend

1. Discharge measured during the month of Nov-2012.
2. Concave bank (inner bank) is rigid and convex bank (outer bank) is mobile.
3. The segment is assumed to be circular in nature with the average radius of curvature 4672 meter.
4. The flow entered to the bend is straight to curve and the exit condition is curve to straight.

5. The inflow of ground water is not been considered.
6. Impact of motor boat for the measurement of velocity and transverse distance was ignored.
7. Whatever discharge the instrument giving that discharge is passing through the cross-section.
8. Depth and velocity are assumed to be representing the cross-sectional area.

4.4.3 Development of Regression Models

4.4.3.1 Multiple regression model for 8 cross-sections:

For development of the regression model, the complete data set of all cross-section, analysed separately after that for model development choose the cross-section as three cross-section from both ends , and two cross-section from centre location as shown in figure clearly, this selection of cross-sections gives a complete picture of the Varanasi bend of River Ganga. For calibration of the regression model complete 55 data (63.95 % of total) and remaining 31 data (36.05 % of total) are used for the validation of the model. As shown in the table the value of R^2 is 0.8644 of the calibrated model which shown a strong correlation between discharge, depth and velocity data of the complete data set. The model equation generated is

$$\text{Discharge} = Y_0 + a*(\text{Velocity}) + b*(\text{Depth})$$

Where, Y_0 , a and b are constants

Table 4.3. Multiple linear model detail

Profile	R	Rsqr	AdjRsqr	Y_0	a	b	SEE	t	P	Std Error
8-C-S	0.934	.8723	.8674		519.233	27.3198	59.0513	-8.5517	<0.0001	23.9917

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				- 205.1 69				13.16 01	<0.00 01	39.45 51
								16.09 6	<0.00 01	1.697 3

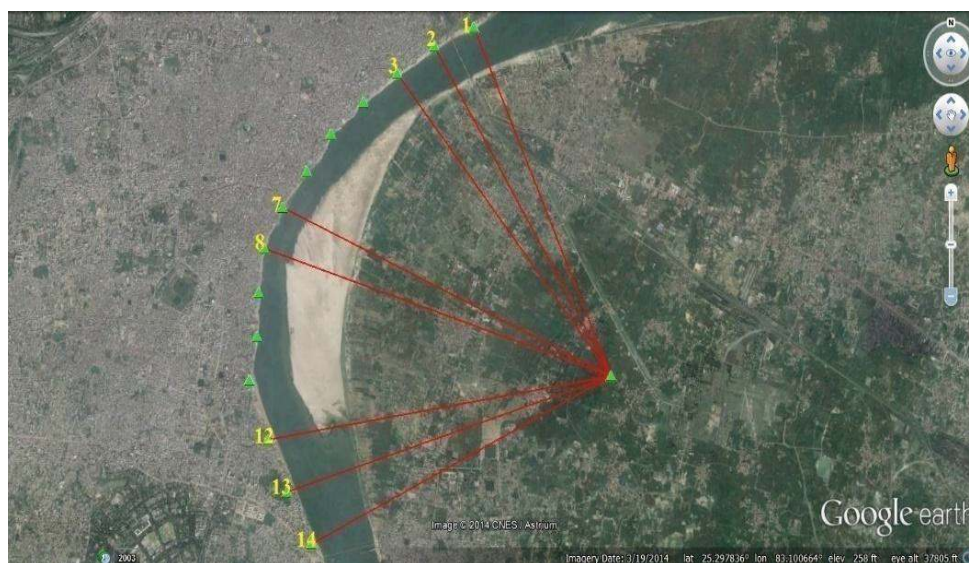


Figure 4.2. Showing the calibrated cross-sections

4.4.3.2 Partial regression model

For analyzing the fact that whether the discharge is more dependent on which parameter, Depth or velocity, a partial regression model studied by keeping depth and velocity constant. For the model (keeping depth constant) the data is shorted in a manner that the depth ranging in 1m-5m, 5m-10m, 13m-15m and finally 15m-20m, the model gives the R^2 value as follows 0.722,0.698,0.98 and 0.709 respectively. For the model (keeping velocity constant) average the velocity in previously shorted data, it ranged upto 0.36 m/s, 0.45 m/s and 0.5 m/s, the model gives the R^2 value as follows 0.95,0.98 and 0.963 respectively as listed in table below. These values conclude it to 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.

Table 4.4. Partial regression model

Sr.No.	R^2	Std. deviation	MSE	RMSE	Y_0	a	Range	Constant Parameter
1	0.82	36.26	1205.29	34.72	-44.44	342.20	1-5 m	Depth
2	0.80	59.93	3169.25	56.30	-35.17	633.19	5-10 m	
3	0.95	53.10	2115.02	45.99	62.66	769.01	10-15 m	
4	0.97	11.60	89.66	9.47	150.24	805.87	15-20 m	
5	0.90	45.31	1824.62	42.72	-60.38	22.61	0.31 m/s	Velocity
6	1.00	5.66	25.59	5.06	1.75	25.20	0.36m/s	
7	0.99	17.13	234.69	15.32	19.17	28.88	4.4 m/s	

4.4.3.3 Validation of Model

As the complete 86 data of the whole bend of Varanasi for River Ganga available out of which the 55 data used for the calibration of the model, remaining 31 data used for the validation of the model in the table below the detailed calculation for each data is clearly shown in understandable form,

Table 4.5. Showing the result obtained from Validation of model

Velocity	Depth	Discharge	a*Velocity	b*Depth	Measured discharge through model	error	% error
0.17	15.10	219.95	89.83	412.53	297.19	77.24	35.12
0.49	16.31	588.99	253.90	445.59	494.32	-94.67	-16.07
0.51	12.52	472.29	263.25	342.04	400.13	-72.16	-15.28
0.30	11.06	242.39	153.17	302.16	250.16	7.77	3.21
0.10	7.62	54.35	50.37	208.18	53.37	-0.97	-1.79
0.12	8.57	105.46	63.35	234.13	92.31	-13.16	-12.47

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0.48	17.87	634.09	248.71	488.20	531.75	-102.35	-16.14
0.54	15.75	628.81	278.83	430.29	503.95	-124.86	-19.86
0.25	15.41	283.96	128.77	421.00	344.60	60.64	21.36
0.10	8.31	66.84	52.44	227.03	74.30	7.46	11.17
0.50	13.88	531.70	261.69	379.20	435.72	-95.98	-18.05
0.64	13.10	680.85	332.83	357.89	485.55	-195.30	-28.68
0.31	12.71	297.35	162.52	347.23	304.59	7.24	2.43
0.14	6.51	66.97	71.13	177.85	43.82	-23.15	-34.57
0.90	9.05	610.20	466.79	247.24	508.87	-101.34	-16.61
0.87	6.47	418.34	453.29	176.76	424.88	6.54	1.56
0.68	3.46	174.79	355.16	94.53	244.51	69.72	39.89
0.51	2.25	85.93	262.73	61.47	119.03	33.10	38.52
0.33	1.45	1.75	170.83	39.61	5.27	3.52	200.73
0.68	10.10	516.41	352.04	275.93	422.80	-93.61	-18.13
0.80	6.02	357.18	414.35	164.47	373.64	16.46	4.61
0.78	4.00	268.78	402.92	109.28	307.03	38.25	14.23
0.58	3.11	132.79	301.67	84.83	181.33	48.54	36.56
0.41	1.90	58.86	213.92	51.91	60.66	1.80	3.06
0.28	1.12	3.56	144.87	30.60	-29.71	-33.26	-934.97
0.67	4.56	226.17	348.41	124.58	267.81	41.64	18.41
0.77	4.66	267.43	400.33	127.31	322.47	55.04	20.58
0.84	5.57	346.06	433.56	152.17	380.56	34.50	9.97
0.80	4.40	261.74	413.83	120.21	328.87	67.13	25.65
0.57	3.51	148.19	296.48	95.89	187.21	39.02	26.33
0.46	1.88	35.97	239.37	51.36	85.56	49.59	137.89

As shown in table 3.4 it is clearly visible that at very low discharge values, depth below 5 m and low velocities, the model doesn't work properly and it gives illogical results.

4.4.3.4 Results and Discussions

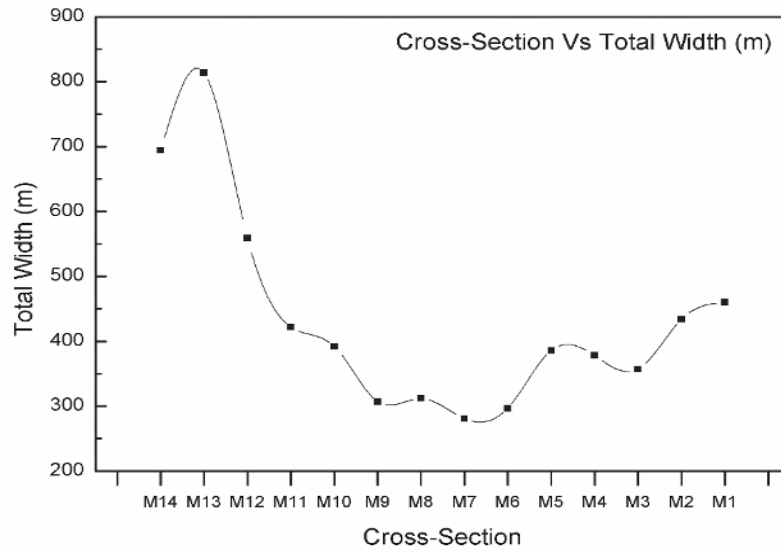
As we know that atmospheric and human intervention affects the hydrology of any area which influences the flow behavior of river. To understand these effects on

main governing parameters of hydraulics on river flow characteristics, 14 different cross-sections have marked along the river which lies between 7500m. 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 4.3 (b), leaving the starting upstream station (M-14) the width of river is almost having decreasing trend till (M-6) cross-section as also shown in Figure 4.3 (a). This shows a varying average depth and average width of flow at its different cross-section due to its meandering and sinusoidal characteristics.

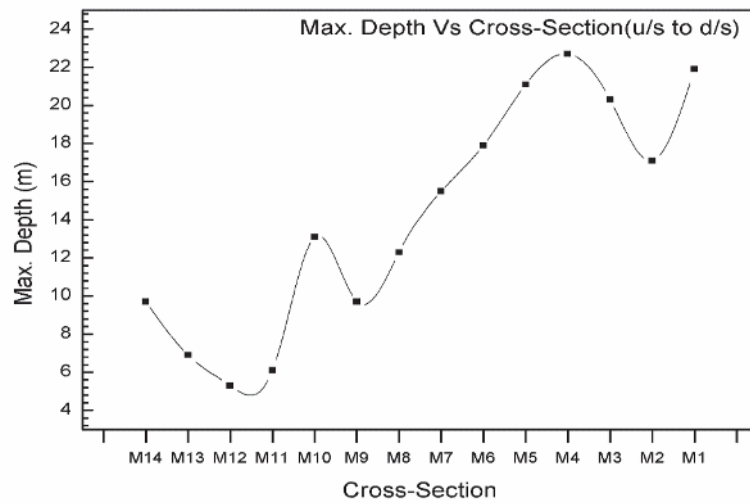
Generally long profile gradient of river is decreases in downstream due to increasing hydraulic radius (cross-section efficiency) but here at Varanasi bend the velocity is increasing up to M-12 cross-section after which the inconsistent bend for velocity obtained although from the M-7 cross-section the average velocity of flow is continuously decreasing as shown in Figure 4.3 (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.

A multiple linear regression model was developed by using the discharge, depth and velocity in required format. These shows a high correlation between the discharge, depth and velocity parameters with the R^2 value of 0.8624, from the validation set of 31 data's, 9 data's of discharge were of range of $100\text{m}^3/\text{s}$ out of which 6 data's gives more error. As well as the average velocity lies in the range of 0.101m/s to 0.279m/s in validation set which gives the more error in validation of model. The proposed model is validated for the average velocity greater than 0.279 m/s up to 0.899m/s . The developed model also shows variation when the depth of flow is less than 5m, so this model is suitable for the depth above 5m upto the maximum of 19.98m at the Varanasi bend of River Ganga.

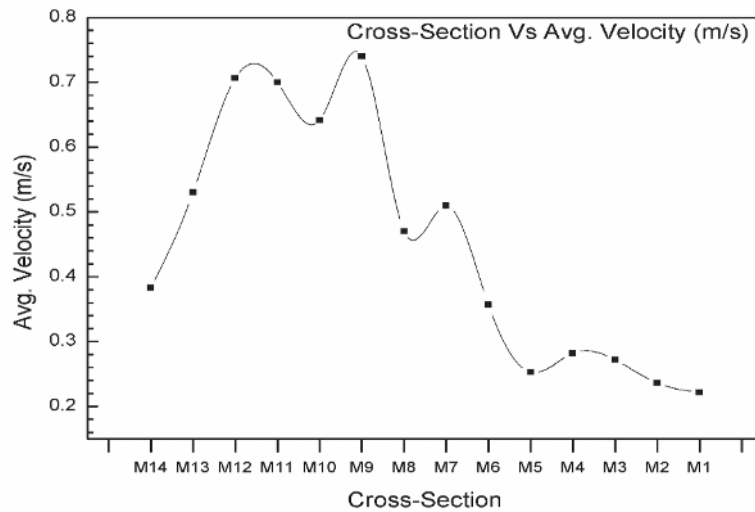
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a.



b.



c.

Figure 4.3 a. Width variation with cross-section, b. Depth variation with cross-section c. Velocity variation with cross-section

4.5 CONCLUDING REMARKS

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.