CHAPTER 8: SUMMARY AND CONCLUSIONS

The study area “Varanasi bend of River Ganga” (25˚ 20' N and 83˚ 7' E) is situated in the middle Ganges valley of North India, in the Eastern part of the state of Uttar Pradesh, the average length of the left crescent-shaped bank of the Ganges at Varanasi lies between 50 feet (15 m) and 70 feet (21 m) above the river. Varanasi is oldest city located on the concave bank of holy River Ganga. It is called the longest river of India as having a total length of 2525 Km from Gangotri to Ganga sagar. The complete arc length of river Ganga at Varanasi is about 7500 meters. The bend was alienated into14 cross-sections with help of hand GPS having length about 500 meters distance and also the cross-section to cross-section distance and average radius of curvature. Each cross-section has been marked by GPS for correct measurement of its coordinate so that in later studies it can be geo-referenced. The direction of river flow was marked along concave and convex side of bank. The measurement of discharge, velocity and depth at each cross-section was done with the help of ADCP (Acoustic Doppler Current Profiler). Data were obtained with the help of various analyses done after the data collected by using different type of software like SPSS, Sigmaplot, Win-River-II, Ky plot, Easyfit, Origin and XLSTAT. After the measurement process through the ADCP was completed (means, crossing of river completed with ADCP) the Data recorded in the instrument hardware were extracted from it with the help of the supporting software of ADCP named as Win-River –II.

The measured data were analyzed to establish the correlation between each measured parameter to develop a regression model to estimate discharge of the river. At each cross-section discharge, depth and velocity were checked for the multiple regressions. A strong correlation was obtained between discharge, depth and velocity data which provide a clear idea to develop a multiple linear regression model. For calibration of the regression model complete 55 data (63.95 % of total) were used for multivariate regression and remaining 31 data (36.05 % of total) were used for the validation of the model. A multiple linear regression model was proposed by using the discharge, depth and velocity data which is given below.

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

Where, Y_o, a and b are constants

The proposed model 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 100m^3/s out of which 6 data's give 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. 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 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, leaving the starting upstream station (M-14) the width of river is almost having decreasing trend till (M-6) cross-section. 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. 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 rating curve of River Ganga at M-1 cross-section was developed after using the total 88 days data of discharge of river, which were collected separately in the duration of 5 months i.e. from (Nov-2012 to March-2013). Out of these 88 data the 58 data (66% of total) was used for the development of the rating curve for River Ganga at M-1 cross-section and remaining 30 data (34 % of total data) were used for the validation of the generated rating curve equation. The proposed rating curve equation was obtained from the discharge & gauge data of the River at cross-section M-1 in arithmetic and logarthmatic scale respectively. The developed rating curve equation at arithmetic scale is s follow:-

- **$Y=787.06\ X^{0.8038}$**
- Where
  - Y= Discharge in m^3/s
  - X= (G-a) in meters
  - And R^2 value for the Rating Curve is 0.9495

It was observed that the discharge obtained from rating curve equation and measured discharge data are within the maximum error of ±10% which is within the limit of acceptance of the equation because it is very difficult to measure the discharge during flood condition of river Ganga at Varanasi. The proposed equation of rating curve is valuable for measuring the discharge of River Ganga at

Varanasi during flood condition. During flood condition after getting the gauge height the discharge of the river may be estimated effectively.

The 42 samples were collected from the three locations at each cross-section i.e. at left bank, middle and right bank at Varanasi bend from M-1 to M-14 sections. Grain size analysis were performed to determine the percentage of different grain size particle present within the collected samples. The mechanical or sieve analysis was done to determine the distribution of the coarse and fine grain-sized particles. The distribution of different grain size affects the engineering properties of soil. The complete measured Grain size distribution data for each cross-section i.e. M-1, M-2, M-3, M-4, M-5, M-6, M-7, M-8, M-9, M-10, M-11, M-12, M-13 and M-14 were tabulated. The graphical representation for each cross-section was studied with sieve size in μm is taken at X-axis for all cross-sections and percentage passing is taken on Y-axis. Grain Size analysis of sediments of River Ganga at Varanasi bend, reveals that size of the grain increases on left bank at section, M-3, M-6, M-7, M-8, M-10, M-12,and M-14. The grain size of sediments at M-1 and M-5 were large whereas the size of sediments at section M-2, M-4, M-9, M-11, and M-13 increased at right bank which is the sedimentation site of the River Ganga. The increase of grain size of sediments at M-3, M-6, M-7, M-8, M-10, M-12,and M-14 were responsible for the erosion of the left bank along the Ghat side of River Ganga. The erosion at these sections can be easily verify by the depth profile obtained at this section by ADCP thus it indicates that with increase of grain size the rate of erosion of sediments increases. The sand sample analysis reveals that the sample consists of sand, silt and clay grade particles. It is well known that soil contain high proportion of silt and fine sand are usually most erodible. Soil erodibility is mainly depends upon the particle size distribution and there texture, permeability and fibrous organic matter content. The ability of soil to absorb water or surface runoff is characterize by it permeability. The potential for erosion is reduced, if the soil tends to absorb water as this decreases the volume of water available to cause sheet or rill and gully erosion. The grain size also related to sedimentation at the bank of the river. Sedimentation is the deposition of soil particles held in suspension during flow of river. The sedimentation occurs at right bank of river due to reduction in the velocity flow and discharge of the river. Initially the larger particles settled out. As the flow velocity reduces further, the smaller particles settle, living only the clay finest particle, being the smallest, as the last to be deposited. Slope is also an important factor for the erosion at Varanasi bend along the Ghat side (left bank). The length and the inclination are critical factors with longer and steeper slope producing greater soil erosion. The shape of a slope also affect the potential of soil erosion, concave slopes will has inclination at the bank are generally less erodible than convex slope. The boundary condition of the Ganga site at the Varanasi is being guided by natural confluence of Assi and Varuna rivers. Moreover, the Ramnagar Fort is situated on the concave side of the upstream bend is causing and guiding the streamlines in the flow of Ganga entering into Varanasi bend. In spite of these boundary conditions the sedimentation process of the sand bed is continuous; therefore sedimentation and erosion process in the flood plain and in the mainstream adjacent to the flood plain is continuous and causing continuous sedimentation and change in cross-sectional shape of the river bank adjacent to the sand bed and resulted into the sinuosity of the River Ganga at Varanasi Bend. It was also observed that sinuosity of the River Ganga at Varanasi Bend is also influence by change of discharge, depth and flow velocity of the river.

The application of discharge, velocity, and depth on erosion, sedimentation and sinuosity has been summarized separately at each cross-section (M-14 to M-1) with the maximum depth from the concave bank and the maximum depth of the channel, maximum velocity, average depth of flow, average velocity of flow and the width of flow. The complete Varanasi bend have the arc length of 7476 meters, average radius of curvature is 4672 meters and the arc angle is 91.71^{o}. Total average area of the flow at complete bend is 3477.01, average width of flow at the bend is 435.21

meters, average velocity of flow is 0.4510 m/s, average depth of flow is 8.31 meters, average discharge of flow is 1270.68 m^3/s and sinuosity of bend is 1.598, which shows the bend is highly sinuous and the erosion and sedimentation takes at very high rate due to its sinuous nature and high discharge, depth and velocity. As we move forward from the middle section the erosion increases at high rate because the average width of flow is very high and the average area of flow is also very large so the discharge is also very high.