

Flow Measurement in Huma Tail distributary of Hirakud Command Area, India using Chiu's Equation

Ashutosh Rath¹, Sandeep Samantaray^{2*} and Prakash Chandra Swain¹

¹Department of Civil Engineering, VSS University of Technology, Burla 768018, Odisha, India

²Department of Civil Engineering, NIT, Silchar 788010, Assam, India

ABSTRACT

The present work provides a new methodology for the flow measurement in a lined canal Huma tail distributary of Hirakud canal system, Odisha, India. The acoustic Doppler velocity meter was used for the direct measurement of velocity over full area and the length of canal. The entropy based Chiu's equation is used in the present work to find out a constant ratio between the average and the peak velocity of the channel. The location for maximum value is found from the velocity profile. Applying the constant ratio, the mean velocity can be obtained at various sections. With the measured cross sectional area and the mean velocity the discharge can be found. The maximum velocity is a technically important parameter always consists of a single value regardless of the flow conditions, and a cross-sectional shape. Thus the maximum velocity can be applied to estimate the mean velocity. In this work a formula based on the entropy concept has been used to find out the maximum velocity. The accuracy was verified using 13 sets measured with the help of ADV flow tracker. A comparison of the velocity estimated with the value actually measured showed very high accuracy

Keywords: ADV flow tracker, Chiu's equation, discharge, entropy, natural stream

INTRODUCTION

The major challenges ahead of the Irrigation Associations, which are responsible for proper distribution of water, are to meet the farmers' demand as per their needs. The discharge measurements are considered seriously to ensure the availability of water for its proper distribution. Decisions are frequently made with less than adequate information. The water resource systems is

ARTICLE INFO

Article history:

Received: 04 April 2018

Accepted: 02 November 2018

Published: 24 January 2019

E-mail addresses:

samantaraysandeep963@gmail.com (Sandeep Samantaray)

erashutoshrath@gmail.com (Ashutosh Rath)

pswain.vssut@hotmail.com (Prakash Chandra Swain)

* Corresponding author

full of uncertainty so many times it is based on experience, judgment of the professional people, hit and trial methods and probabilistic methods. To describe the random behavior of water resource systems, in most cases, sufficient data are not available. To eliminate such problem and to find the least-biased probability distributions with inadequate data, the entropy theory can be applied effectively. The concept of entropy is highly acceptable in developing countries. In near past the entropy theory had been implemented to deal with various problems related to the water resources.

Chiu and Lin (1983) studied methods to compute the flow in three dimensional. Singh and Rajagopal (1987) made a study on application of the Principle of Maximum Entropy (POME) to obtain the derivation of some frequency distributions. Chiu and Chiou (1988) proposed the methodology to apply the entropy and probability concepts in hydraulic systems. Chiu (1989) research are based on finding the velocity distribution in various open-channel flow. Barbe et al. (1991) formulated the solution to find velocity distribution using entropy. Chiu and Murray (1992) made a study based on velocity distribution for a non-uniform open-channel flow. Chiu and Said (1995) studied methods to determine the peak and average velocities for a channel flow and to find the entropy in that flow. Moramarco et al. (2004) made a study on procedures to estimate the average velocities in natural streams basing on Chiu's entropy theory. Chiu and Hsu (2006) discussed about probabilistic approach for the modeling of velocity distributions in fluid flows. Marini et al. (2011) discussed the entropy approach for 2D velocity distribution in open-channel flow. Singh et al. (2013) made a study on 2D power-law velocity distribution with entropy. This study determined the discharge using the entropy based theory and comparison with the data measured using ADV. The Huma tail distributary of Hirakud canal system has been selected for the study. The canal system plays an important role for the supply of water in irrigation. Proper crop planning can be made by knowing the exact amount of flow available in canal during various seasons. Since the direct measurement of discharge in a canal is time consuming, the Chiu's equation can be applied with accuracy to find out the discharge in the canal. The people in the study area are mostly tribal and they depend on agriculture. The productivity rate of fields under consideration has decreased due to the rise in the ground water table caused by the flooding method of irrigation at the head reach of canal. Another problem is coming into consideration that people adopted a particular crop in a particular field. They were not adopting the crop rotation due to which the quality of soil decreased and thus crop losses faced by the farmers. Water is available but due to lack of irrigation management people were facing crop losses and leading to less efficiency in water use. Thus there is a scope of management of irrigation and getting of maximum yield from a particular field. This type of study will assist them for the proper crop planning and crop rotation.

MATERIALS AND METHODS

The velocity distribution as suggested by Chiu is based on Principle of Maximum Entropy (POME) to maximize the Shannon entropy. Chiu proposed another system ξ - η based on the velocity isovels against the Cartesian coordinates y - z to develop the entropy-based velocity distribution. Once the equation of ξ , which is a function of y and z is determined, the equation of η can be derived. The equation to determine the value of ξ value in the y -axis is given by

$$\xi = \frac{y}{D-h} \exp \left(1 - \frac{y}{D-h} \right) \tag{1}$$

The value of the y represents the vertical distance from the channel bed; D stands for the water depth along the y -axis; and h indicates the location of maximum velocity. The variations in velocity of flow with depth and width indicates the time-averaged and, therefore, time invariant velocity on an isovel, which is assigned a value ξ . The value of u is almost zero at ξ which corresponds to the channel boundary and u reaches u_{max} at ξ_{max} which may occur at or below the water surface. The value of u increases from ξ_0 to ξ_{max} monotonically. At any value of the spatial coordinate having value less than ξ , the velocity is less than u , which can be presented in the cumulative distribution function as

$$F(u) = \frac{\xi - \xi_0}{\xi_{max} - \xi_0} \tag{2}$$

The Shannon entropy of velocity distribution can be written as:

$$H = - \int_0^{u_{max}} P(u) \log P(u) du \tag{3}$$

Where u = value of velocity at a specified point, and u_{max} = the maximum velocity of the cross section. Chiu's velocity distribution is presented as

$$u = \frac{u_{max}}{M} \ln(1 + (\exp(M) - 1)F(u)) = \frac{u_{max}}{M} \ln(1 + (\exp(M) - 1) \frac{\xi - \xi_0}{\xi_{max} - \xi_0}) \tag{4}$$

u_{max} indicates the maximum velocity at, or below the water surface. The dimensionless parameter M is used as an index for characterization and comparison of various patterns of velocity distribution and state of flow systems. M is given as:

$$M = \ln \frac{P(u_{max})}{P(0)} \tag{5}$$

M can be used as a measurement of uniformity of probability and velocity distributions. The value of M can be determined by the mean and maximum velocity values derived from the following equation:

$$\frac{\bar{u}}{u_{\max}} = e^M (e^M - 1)^{-1} - \frac{1}{M} \tag{6}$$

With known value of M for a certain cross-section, the mean velocity can be estimated from the equation. It is natural that u_{\max} , the location for the occurrence is usually at the center of the cross section. In the present study the shape of irrigation canals is rectangular and symmetrical. So it is easy to establish the location of the y-axis in an irrigation canal is taken as with the help of constructing a set of isovels. Further in this study the discharge measurement is done with the help of ADV. Thus the maximum velocity and the mean velocity are determined using eq (6). The cross-sectional area of the channel can be estimated as:

$$A_{\text{est}} = WD \tag{7}$$

W, D represent the width and depth of the canal
 The discharge for the canal can be estimated as:

$$Q_{\text{est}} = u_{\max} WD \left[e^M (e^M - 1)^{-1} - \frac{1}{M} \right] \tag{8}$$

$$q_i = \left(\frac{v_i + v_{i+1}}{2} \right) a_i, \text{ where } a_i = d_i \times b_i \tag{9}$$

a_i is the cross sectional area of the segment i; the depth of water given by d_i where b_i is the distance from the reference point to the observed verticals i; q_i ; and v_i represent the discharge and the mean velocity at the observed vertical i.

$$A_{\text{obs}} = \sum_0^n a_i \text{ and } Q_{\text{obs}} = \sum_0^n q_n \tag{10}$$

The mean velocity on the vertical is:

$$\bar{v}_i = \frac{u_{\max}}{M} \int \ln \left[1 + (e^M - 1) \frac{\xi}{\xi_{\max}} \right] d\xi \tag{11}$$

Flow Tracker

Acoustic Doppler Velocimetry (Flow Tracker), SonTek/YSI (Figure 1) is the instrument used to measure the surface freshwater discharge in open channels. The principle on which the instrument works is it measures stream velocity by sensing the phase change caused by the doppler shift in acoustic frequency that occurs when a transmitted acoustic signal reflects off by the sediment particles in the flow. Measurements were performed by measuring the velocity of particles in a remote sampling volume based upon the Doppler shift effect. The ADV instrument consists of receivers to record the velocity components, strength of signals.

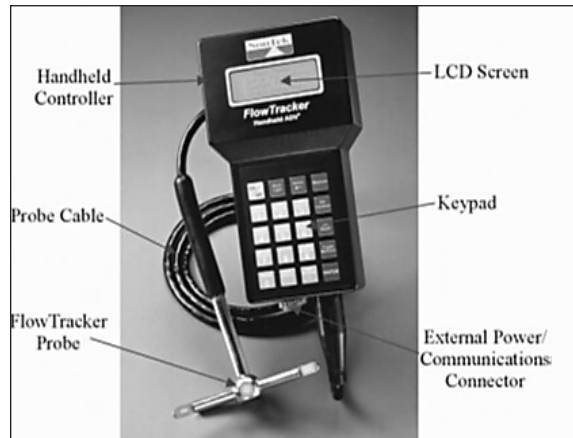


Figure 1. Various components of Flow Tracker with 2D Probe (Source: Google)

The ADV is a single point biostatic Doppler current meter. It provides 3-D velocity measurements in a remotely sampled volume. The ADV transmitter generates sound and the receivers are most sensitive to sound coming from a slightly broader angular range. The transducers are mounted such that their beams intersect over a sampling volume located some distance away. The size of the ADV sampling volume is mainly determined by two factors: the length of the transmitted pulse and receiving window. Both are controlled by the ADV software (within the limits of the transducer bandwidth). There are three types of ADV mainly 16-MHz Micro ADV, 10 MHz ADV, 5 MHz ADV. The standardized height of the sampling volume for the 16-MHz Micro ADV is 4.5 mm, for the 10 MHz ADV is 7.2 mm and for the 5 MHz ADV ocean probe is 14.4 mm.

The amplitude of received signal is also important for accurate velocity measurements although velocity measured by ADV is derived from phase. The strength of the signal return depends on the amount and type of particulate matter in water inside the sampling volume. If the water is too clear, the returned signal may not be stronger than the ambient electronics noise level thus reducing the accuracy of the velocity measurements. The discharge calculation have been done at 13 different sections of Huma tail distributary. The canal has rectangular cross section with partially lined. The velocity of flow is measured at different locations such as 0.2B, 0.4B, 0.6B and 0.8B from left side of the bank. The SENSOR was placed at different depth such as 0.2D, 0.4D and 0.8D. Total 12 readings in a cross section were taken in the channel. The average width of the canal varies from 1.5 to 1.65 meter and the depth of flow varies from 0.8 to 1.32 m.

Signal-to-Noise Ratio (SNR) are important for an accurate measurement of the flow velocity. SNR measures the intensity of the reflected acoustic with respect to the noise level of the instrument. It reflects the concentration of the water and size of sediment particles that reflect the acoustic signal. SNR was recorded for each beam with each 1s sample.

According to the manufacturer, the Flow Tracker can be applied to measure the velocity in a shallow water depth of about 3 cm with a velocity ranging from 0.001 to 4.50 m/ s with almost full accuracy.

Study Area

Hirakud Dam is built across river Mahanadi at about 15 km. upstream of Sambalpur town in State of Odisha. The project provides 155,635 hectares of Kharif and 108,385 hectares of Rabi irrigation of Sambalpur, Bargarh, Bolangir, and Subarnpur. The water released through power house irrigates further 436,000 hectares areas of Cultural command area (CCA) in Mahanadi delta. Installed capacity for power generation in 307.5 MW through its two power houses at Burla, at the right bank to and Chiplima at 22 km downstream of dam. Besides, the project provides flood protection to 9500 sqkm of delta area in district of Cuttack and Puri. Hirakud dam receives water from 83,400 sq. km of Mahanadi catchment. The reservoir has storage of 5818 million cubic meter with gross capacity of 8136 million cubic meter. In this study the command area of Huma tail distributary of Hirakud Irrigation system is selected for experimentation. The average annual rainfall of the command area is found to be approximately 1100 mm, out of which approximately 90% is received during monsoon season (mid-June to mid-October). The major crops are paddy, wheat, pulses like arhar, green gram and black gram, oilseeds like groundnuts, til and mustard, and sugarcane. Paddy is the most dominant crop. The study area is depicted in Figure 2.

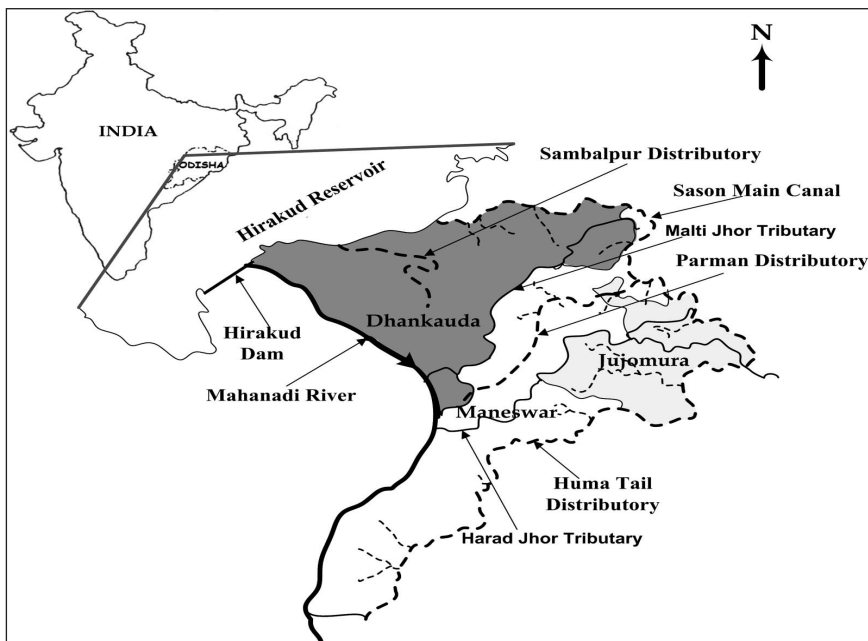


Figure 2. Ayacut Map of the Huma tail distributary system

RESULTS AND DISCUSSION

The accuracy of the entropy-based discharge estimation was established in this work by conducting various experimental and field data. Velocity data from various sections of Huma tail distributary were collected by flow tracker as depicted in Table 1. These data were used to build the velocity distribution curves as shown in Figure 3 and velocity isovels shown in Figure 4 at the measured sections.

Table 1
Discharge data at different stations as obtained from ADV flow tracker

Distance from start of canal distributary (m)	Discharge (m ³ /sec)	Distance from start of canal distributary (m)	Discharge (m ³ /sec)	Distance from start of canal distributary (m)	Discharge (m ³ /sec)
START	0.838	4850	0.618	9800	0.1792
700	0.807	5700	0.609	13500	0.1576
1500	0.799	6450	0.551	16000	0.0894
3000	0.728	7500	0.497	17000	0.0472
4300	0.687	7950	0.428		

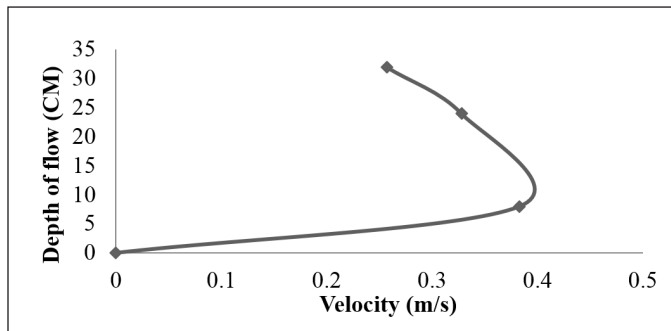


Figure 3. Velocity distribution of a section of canal along the depth of canal at R.D(0.560 Km from the start of canal)

The discharge calculations have been done at 13 different sections of the distributary. The canal has rectangular cross section with is partially lined with proper gradient. The velocity of flow was measured at different locations such as 0.2B, 0.4B, 0.6B and 0.8B from left side of the bank. The SENSOR was placed at different depth such as 0.2D, 0.4D and 0.8D. The average width of the channel is 3.2 m and the average depth is 0.9 m. Since it is a lined channel the contribution of sediments particle is not significant. From the velocity profiles plot at Figures 3 and 4, plotted with the help of MATLAB software. It is observed that maximum velocity occurs at depth of 0.2d to 0.4d. At depth near the surface (0.8d) velocity is minimum and near the bed (1.0d) it is zero. This is acceptable, since

the near bed region is more affected by the shear stress than the higher region. Generally, maximum velocity occurs at a certain distance below the water surface. This decrease in maximum velocity where surface velocities are less than the maximum velocity is due to secondary currents and is a function of the aspect ratio (ratio of depth to width) of the channel. Thus for a deep narrow channel, the location of the maximum velocity point will be much lower from the water surface than for a wider channel of same depth. This location of the maximum velocity point below the surface has nothing to do with the wind shear on the free surface.

Figure 4 shows the plot of velocity in the Huma tail distributary. It is clear that the maximum velocity occur at mid of the section.

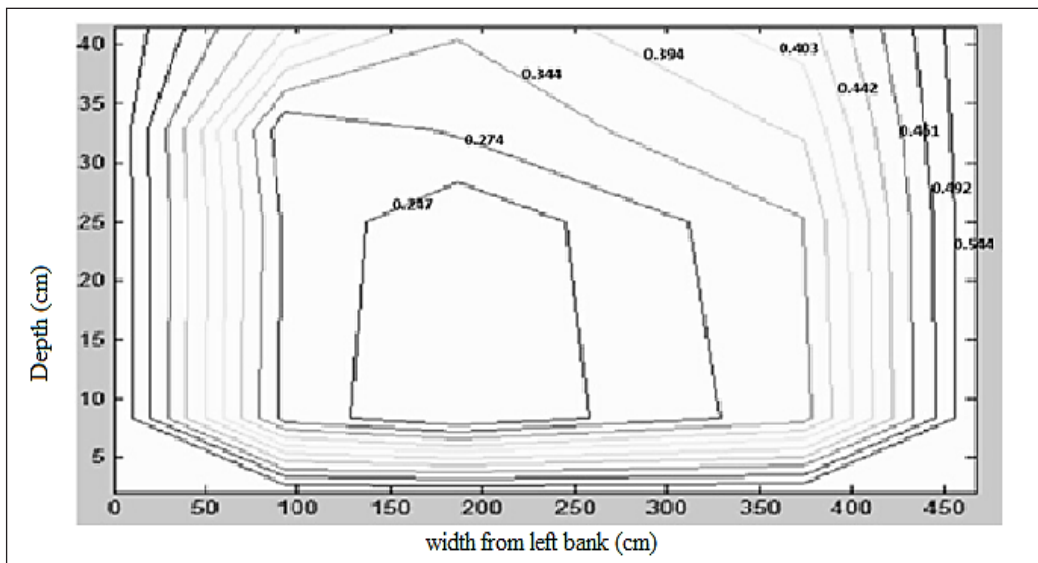


Figure 4. Isovels of the section of Huma tail distributary at RD. 0.560

Computation of Mean Velocity using Chiu’s Equation

Using data collected for each channel section the cross sectional mean velocity is calculated. The parameter of probability distribution M is calculated from the following equation. From the observed mean and maximum velocity the constant ratio Φ is first calculated and parameter M is calculated from the constant ratio.

$$\frac{\bar{u}}{u_{\max}} = e^M (e^M - 1)^{-1} \cdot \frac{1}{M} = \Phi \tag{12}$$

The variable ξ can be calculated from the eq. (1). The comparison between the maximum observed velocity and mean velocity obtained from the entropy theory are described in the Table 2.

Table 2
 Comparison of maximum observed velocity and mean estimated velocity in Huma tail distributary

Mean velocity of flow (u_{mean})	Maximum velocity of flow (u_{max})	Ratio between observed u_{mean} and u_{max} (Φ)	Parameter of probability distribution (M)	Variable's depends on depth (ξ)	ξ_{max}	u_{est}	$u_{\text{mean est.}}$
0.6751	0.7022	0.965	0.3532	0.971 0.8440 0.2921	0.9701	0.7020 0.6231 0.2390	0.5211
0.366	0.61	0.6	0.22	0.97 0.8 0.292	0.97	0.61 0.51 0.198	0.439
0.754	0.812	0.92	0.338	0.97 0.844 0.292	0.97	0.812 0.72 0.275	0.602
0.639	0.713	0.89	0.301	0.973 0.844 0.292	0.973	0.713 0.629 0.237	0.526
0.433	0.526	0.823	0.303	0.973 0.844 0.292	0.973	0.526 0.464 0.175	0.388
0.549	0.556	0.98	0.36	0.973 0.844 0.292	0.973	0.557 0.494 0.189	0.413
0.492	0.523	0.94	0.3	0.973 0.844 0.292	0.973	0.523 0.462 0.174	0.386
0.449	0.551	0.814	0.299	0.973 0.844 0.292	0.973	0.551 0.486 0.183	0.406

Figure 5 shows the plot between the maximum and mean velocity of cross sections of Huma tail distributary canal. From the graph it can be observed that a linear relationship occur between the mean and the maximum velocities with a constant ratio Φ . The result confirmed with the Chiu's theory as a constant ratio Φ , between the mean and maximum velocities are maintained throughout the section. The slope of the graph as indicated in Figure 5 is 1:1, with a very small variation, indicates the accuracy of the method. The velocity at the bottom of the channel is zero but it increases gradually again decreases at the top due to the effect of surface tension.

Figure 6 shows the plot between the mean velocity at various cross sections (at various depths and widths) of Huma tail distributary and the mean velocity computed by Chiu's equation. The slope of the line obtained from the graph between u_{obs} and u_{est} is found to be 1:1, with a very small error, that indicates the validity of the method in velocity calculation.

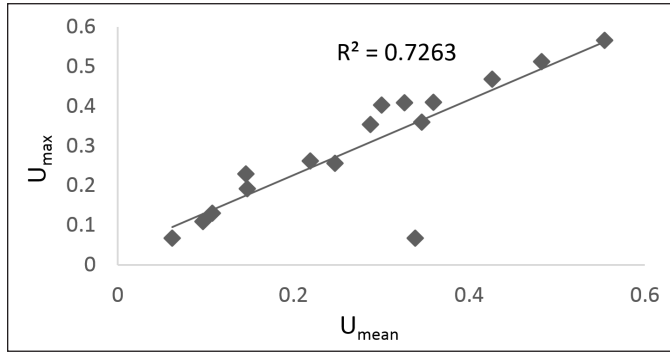


Figure 5. Graph between maximum and mean velocity estimated

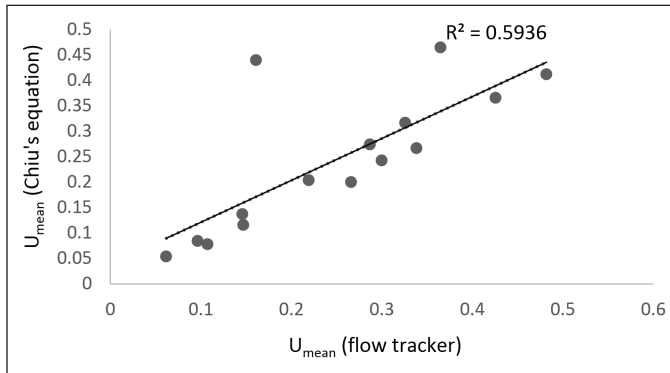


Figure 6. Graph between u_{max} calculated by Chiu's equation and u_{max} measured by flow tracker

The error in measurement is maximum at the near 0.2 and 0.4 from Chiu's equation due to not full coverage of the cross section and capturing boundaries of the channel is necessary to maximize the accuracy of discharge measurement.

Table 3
Data between the Discharge estimated and observed

Q_{obs} (m ³ /sec)	Q_{est} (m ³ /sec)	Error in %	Q_{obs} (m ³ /sec)	Q_{est} (m ³ /sec)	Error in %
0.5251	0.516	1.73	0.077	0.07	9.09
0.57398	0.5556	3.20	0.013	0.012	7.69
0.8071	0.773	4.23	0.301	0.285	5.32
0.0131	0.0122	6.87	0.008	0.006	25.00
0.751	0.737	1.86	0.172	0.164	4.65
0.039	0.036	7.69	0.14	0.132	5.71
0.13	0.124	4.62	0.091	0.079	13.19
0.023	0.02	13.04			

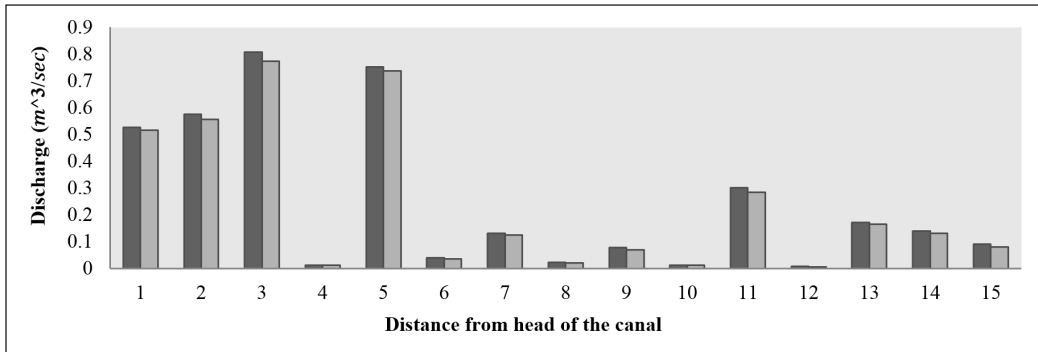


Figure 7. Plot between estimated discharge and observed discharge

The Figure 7 plot between estimated discharges and observed discharge, the discharge measurements made by the ADV. The average error as obtained from the Table 3 and Figure 7 is found to be 7.69 %. So it indicates the reliability and the accuracy of the Chiu's equation for the discharge measurement.

CONCLUSION

In this work an attempt has been made to develop a 2D velocity distribution by applying the Chiu's equation based on entropy theory at Huma tail distributary of Hirakud Irrigation system. The velocity was determined experimentally with the help of ADV flow tracker and the velocity that computed from the 2D distribution data is quite close. The mean velocity of flow is influenced by various parameters but the maximum flow velocity, remain constant at any cross section, irrespective of types of flow and the cross-sectional shape. So, it is a convenient to estimate the mean velocity by utilizing the maximum flow velocity without going for the direct measurements for the estimations of the mean velocity. In this work, a formula to determine the maximum velocity was applied. To establish the accuracy of the maximum flow velocity formula, the actual measurement data for the flow at 13 different cross sections were found out with the help of ADV Flow tracker. The results were compared with the maximum flow velocity estimated through the proposed formula. The results showed very high accuracy as the results obtained from the Chiu's equation, when compared with the value obtained from direct measurement, the error is found to be 7.69%. This methodology can also be applied to estimate the flow rate even in flood season.

ACKNOWLEDGEMENTS

The authors thank the District Civil Supplies Officer, Sambalpur, Deputy Director of Agriculture, Sambalpur, for providing Block-wise details of Sambalpur District, Odisha State and Hirakud Dam authority for their kind support to carry out the work

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