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Determination of Manning's Roughness Coefficient in Bijayapur Irrigation Canal, Kaski, Nepal

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Abstract

The discharge in irrigation canal is to be determined for the proper allocation of water to the fields as per the crop-water requirement. Manning's roughness coefficient is one of the major important parameters for estimating discharge in open channel. The purpose of this research is to determine Manning's roughness coefficient in open channel flow by means of measuring velocity, cross-section, bed slope using Manning's equation. It also discusses how it varies along with various aspects of channel geometry and draws useful conclusion from the analysis. The investigation was carried out in the Bijayapur Irrigation System which is situated in Kaski district of Nepal. The velocity was measured using current-meter and discharge was calculated from the area velocity methods. Roughness coefficient was calculated using the Manning's equations for the uniform flow in open channel. The average value of Manning's roughness coefficient at Sakneri and Bijayapur computed from this study was found 0.028 and 0.037, respectively. The roughness coefficient, however, being a parameter representing the integrated effects of the channel cross-sectional resistance, the result of this study shows the higher value of roughness coefficient for the material (cement rubble masonry) used in the construction of canal. The higher value of roughness coefficient might be due to uneven bed and poor condition of banks as observed during the study. The greater value of roughness coefficient definitely reduces discharge which leads to the tail end deprivation in the command area.

Keywords: Current Meter, Discharge, Floats, Uniform Flow, Velocity.

1. Introduction:

Measurement of discharge is important in the irrigation project for the equitable distribution of water in the command area. Discharge is measured in the various sections of the main as well as branch canal of the irrigation project for the proper allocation and its distribution. Mostly, open channels are used for the supply of water to the field. There are several equations for determining the discharge of the channel such as Manning's equations, Chezey's equation, and Kutter's equation. The resistance formula proposed by an Irish engineer Robert Manning, can be calculated using uniform flow in open channels, is $V = 1/n\ (R^{2/3} \times S^{1/2})$ where n = a roughness coefficient known as Manning's n. This coefficient is essentially a function of the nature of boundary surface which is acceptable in a variety of practical applications and widely used uniform flow formula in the world [1]. For reaches of channel where the bottom slope, cross-section shape, and/or cross-section size change, non-uniform flow occurs while the flow condition is maintained uniform if these parameters become constant in a downstream reach of the channel [2]. The degree of roughness depends on several factors, the most important of which in open-channel flow are surface roughness of the bed material, channel section, size and shape of channel, stage and discharge, obstruction to flow, type, density and distribution of vegetation, among others [3]. But the roughness coefficient mainly depends on the bed slope and surface roughness [4]. In general, all factors that tend to cause turbulence and retardance of flow, and hence energy losses, increase the roughness coefficient; those that cause smoother flow conditions tend to decrease the roughness coefficient [5]. The incremental effect of grass density on Manning's n depends on flow depth, type and arrangement of vegetation [6] whereas the high velocity which results smaller depth and low wetted perimeter has larger value of Manning's n [7]. The various experimental set up (Rectangular Notch, 90-degree V-Notch, 60-degree V-Notch) has shown that the Manning's n decreases with increase in velocity and increase in discharge [8]. And also depends on time showing seasonal variety, however, its changes over year is small [9].

The modern Irrigation System in Nepal was started in 1922 where as the first Irrigation Project was started distributing water after its construction in 1928 [10]. As the agriculture is the major sector in Nepalese economy, Irrigation Sector Development in Three Year Plan has set the objectives for the establishment of efficient, sustainable, effective and reliable irrigation system for the year-round irrigation in the agricultural land. The policy emphasized for the increase in ground water use and surface irrigation in Terai whereas micro irrigation and lift irrigation in hills and intended to implement 6000 numbers of irrigation programs including co-operative, small and groundwater [11].This study described the condition of the Bijayapur Irrigation System which is the largest with respect to area irrigated in Kaski district. To incorporate all the changes occurred in the canal geometry and materials property, it is necessary to study the open channel hydraulics for the existing canal to check and verify the discharge capacity. With the determination of velocity, discharge can be calculated which can be correlated with depth of flow that helps to operate the system. The Manning's roughness coefficient might be changed because of the various factors which determine the velocity of the flow in canal. Therefore, it is necessary to analyze the Manning's roughness coefficient in its present condition which is quite helpful for determining the discharge measuring the depth of flow only.

Effective use of water for crop irrigation requires that flow rates and volumes be measured and expressed quantitatively. The canal capacity is to be determined and verified time and again since the water requirement of the command area determines the productivity of the crops. Reduction in capacity leads the tail end deprivation and the farmer may not get the required quantity of water as per the demand. The deficiency of water at the time of crop sowing leads the decrease in crop yields. Therefore, the canal shall be maintained to carry the sufficient discharge as per the designed. The channel capacity may be reduced due to deposits of silts on bed and growth of vegetation on banks in the absence of regular maintenance which finally reduce performance of irrigation canal [12].

Measurement of flow rates in open channels is difficult because of non-uniform channel dimensions and variations in velocities across the channel.

It is not easy to determine the Manning's coefficient which is varying constantly and influenced by channel bed forms, the channel obstructions, the geometry changes between sections and the vegetation in the channel [9]. The degree of the *n* value for a selected channel type is related to the newness of the channel and degree of subsequent maintenance [13]. From periodic tests at various depths of channel, the relative effect of sides and bottom can be definitely determined [14]. The channel roughness is affected by a lot of factors which are difficult to translate into a single value [9]. Also, the Manning's roughness coefficient decreases with the increase in water depth [15]. The average value of Manning's roughness coefficient for Rubble masonry is 0.02 [16] whereas the value of rugosity coefficient *n* for the lined channel boundary surface of concrete bottom float finished and sides of cement rubble masonry with straight alignment are varied from 0.02 to 0.025 [18].

The previous research shows that the observed roughness coefficients are greater than the values reported in the literature as given by Manning's for watercourse of various materials and depends on the prevailing conditions of watercourse [19]. Therefore, it is indeed need of the time to measure the Manning's roughness coefficient. This research aimed at determining the Manning's roughness coefficient to help for establishing the depth-discharge relationship for the canal so as to identify the real time discharge in the canal. The specific objectives were to access the condition of canal geometry, measurement of discharge and to develop the rating curve and to determine the Manning's roughness coefficient.

2. Materials and Methods:

2.1. Study Area:

Kaski district has highly fertile area for paddy, maize, wheat as well as other product with access of irrigation facilities being irrigated largely by Bijayapur Irrigation Project and Pokhara Irrigation Project [20]. Among the major six irrigation system in the Kaski district, Bijayapur Irrigation System was completed in 1987 A.D., is the largest Irrigation System on the basis of its command area. It is entirely located in Kaski district. The research was carried out in some of the selected reaches of the main canal of Bijayapur Irrigation System. The capacity of the main canal is six m^3/s. The length of main canal is 4.32 km while length of four branch canal is 10.70 km [21], [22], [23].

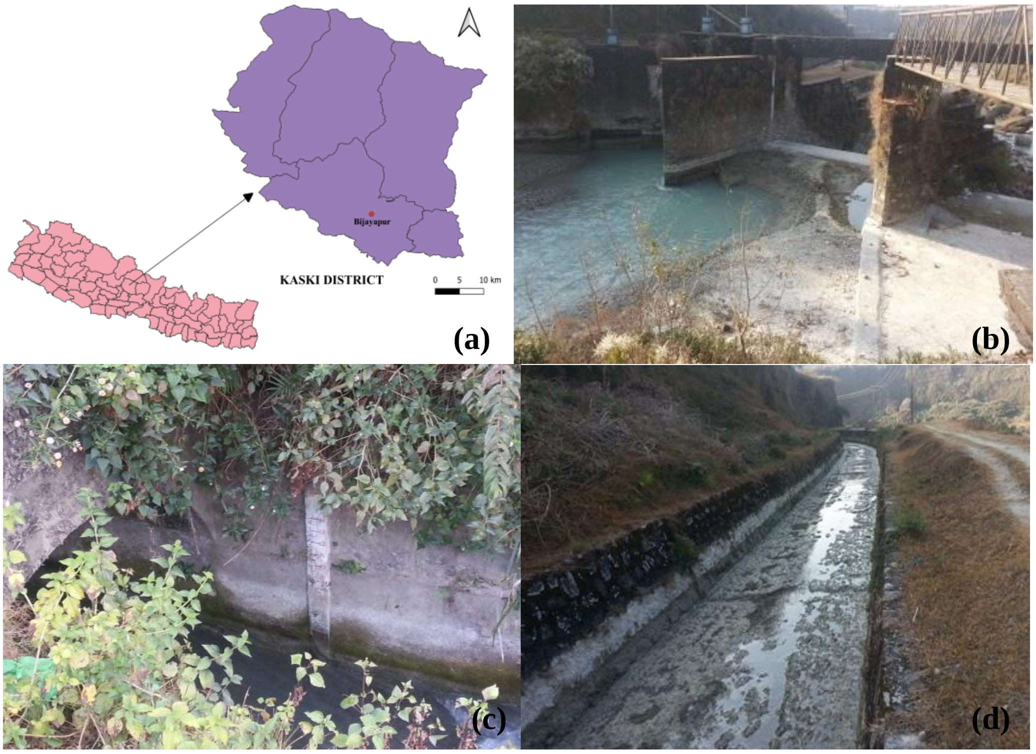

Figure 1: (a) Location map showing the location of canals under studied in Kaski District, Nepal; (b) Headworks of Bijayapur Irrigation System; (c) Scale for stage measurement in main canal; (d) Main canal downstream of headworks (Author, 2015)

Figure 1 (a) shows the location map of canals under studied in Kaski District; Nepal whereas Fig. 1 (b) shows the headworks of Bijayapur Irrigation System. Figures 1 (c) and (d) shows the arrangement for stage measurement of the canal which can be used for discharge calculation and the condition of main canal just downstream of the headworks, respectively. The flow was not under the control of the researcher; therefore, the study was carried out based on the three different depths available at different time interval. The channel was not in good condition of the specified materials and there were lots of deposit of debris and gravels in the bed of the canal. The data were taken in the existing condition of the canal.

For the observation of various data; the canal segment selected was of main canal at Bijayapur (east of Prithivi Highway) and the other section was on the way to Sakneri (west of Prithivi Highway), both of which are of trapezoidal shape. There is a sluice gate and Fall just downstream of the selected segments. Figure 2 shows the pictures of the selected sites of main canal at Bijayapur (left) and at Sakneri (right). For measuring the various parameters like channel geometry, longitudinal bed slope, depth of flow, velocity of flow; a reach of canal which was straight and uniform in cross section was selected in two locations as stated above.

Figure 2: Photographs of the main canal at Bijayapur and Sakneri

2.2. Research Design and Study Variables:

This research was based on the primary data taken by the researcher in the canal of Bijayapur Irrigation System. Some selected reaches of the canal of the Bijayapur Irrigation System at Budibazar in Lekhnath, Kaski District were taken for the determination of flow parameters.

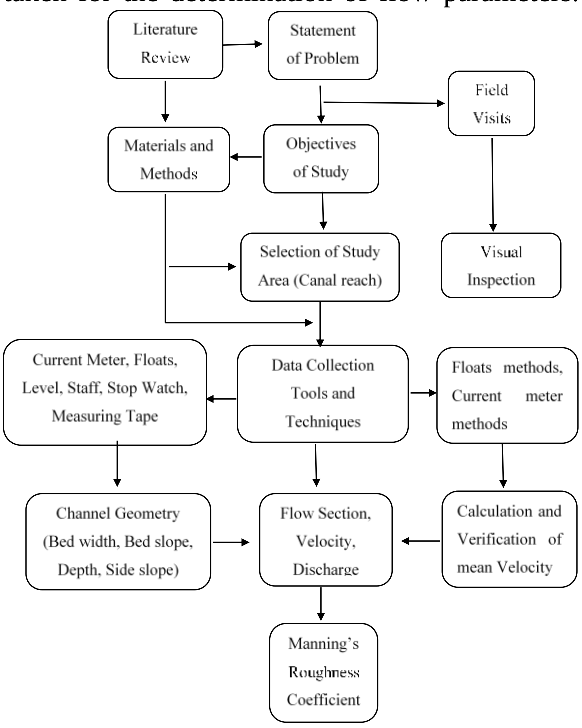

Figure 3: Methodological frame work for the research work

For the given sections and bed slope of the selected segments of the main canal; the variables are depth of flow, velocity and discharges of the canal. The study needed the variations of flow depths but the flow was not under the control of the researcher, therefore the observation and field works were done at different time for getting different depth and discharges as and when available in the canal. The research was based on the measurement of data at the two reaches (segments) of the main canal at Budhibazar (east of Prithivi Highway) and at Sakneri (west of Prithivi Highway). The canal was trapezoidal in shape and built by stone masonry. Figure 3 shows the methodological framework under which the research was carried out.

2.3. Data Collection Tools and Techniques:

Current meter, floats, stop watch were used for the measurement of the velocity while measuring tape and metal rod was used to measure the flow depth and other geometrical parameters such as depth, bed width, top width etc. The velocity was measured using current meter number of times dividing each reach into two segments (upper segments and lower segments) and the average was used for further calculation. The velocity was also simultaneously checked by suitable floats.

Frequency and types of floats was used as per the prevailing situation of flow condition.

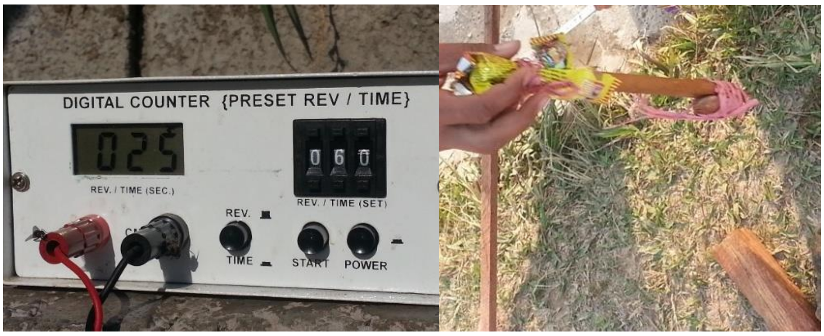

Figure 4: Current meter and wooden floats

Figure 4 shows the current meter which was used for measuring the velocity and the floats (wooden pegs) which were also used to measure the velocity. The current meter was calibrated and validated by the simultaneous data (velocity) measured by floats i.e., wooden pegs which were locally made and available.

The depth of flow was simply measured with a measuring tape with the help of straight metal rod. In a shallow depth (up to about three meter), the velocity measured at 0.6 times the depth of flow below the water surface is very close to mean velocity of flow in the vertical direction and can be taken as the average velocity of flow in the vertical direction i.e., average velocity = $V_{0.6}$. [16] [24], the surface velocity can be used as the average velocity of flow by the use of multiplication factor of K where the value of K lies in the range of 0.85 to 0.95 [24]. In this study also the velocity was measured at the depth of 0.6 times the depth of flow below the water surface.

The canal bed slope was measured using leveling. The Reduced Level (RL) of the canal bed at the interval of 5 m was taken along in the longitudinal direction (three reading in a section, centre line reading and both left and right corner of the bed) for the total length of 26 m at the Bijayapur.

In case of main canal at Sakneri the staff readings were taken at the interval of five meter in the longitudinal direction for the total length of 20 m. Figure 5 shows the use of level machine for taking staff reading held on the bed of the main canal at Bijayapur. For measuring the velocity of flow, a reach of canal, straight and uniform in cross section was selected.

Figure 5: Taking Staff reading form Level machine at main canal at Bijayapur.

Current meter of 0.05 m diameter cup assembly was used for the measurement of velocity. The values of the meter constants for them are of the order of a = 0.3 and b = 0.003. The velocity was also measured by floating which gives the tentative velocity and used as reference velocity. Knowing the area and velocity, the discharge was calculated. Figure 6 shows the depth measurement at the selected section and floats used to measure the surface velocity within the selected reaches of the canal. Finally, the flow parameters were calculated for the different depths of water observed during the various time intervals. The average velocity (V_{mean}) given by current meter was validated by using a reduction factor K as; $V_{mean} = K\ V_s$ where V_s is the surface velocity. The value of K is obtained from observation at lower stages and lie in the range of 0.85 to 0.95 and in this case the value of K is used as 0.9.

Figure 6: Depth measurement and velocity measurement using floats

The discharge was calculated as $Q = A \times V$ in m^3/s, A is area of the cross section in m^2; V is the velocity of the flow in m/s. The sections were selected just upstream of the fall and the gate. In the Manning's formula $V = 1/n\ (R^{2/3} * S^{1/2})$, the hydraulic radius R is the ratio of wetted area and wetted perimeter. The wetted area and wetted perimeter can be measured easily. S is the bed slope and it can be measured as the ratio of vertical difference to the horizontal distance between two points in the longitudinal section which can be measured with the Level machine when the channel is empty. Knowing the values of V, R and S the roughness coefficient known as Manning's roughness coefficient can be easily found out.

3. Result and Discussion:

3.1. Canal Geometry and General Conditions:

The canal geometry (dimension) is not uniform throughout the longitudinal direction. The shape of the canal in most of the portions is of trapezoidal shape and in some of the portion the canal is of rectangular shape. In the periphery of Budibazar there are many drop structures with 1.5 m fall. The channel was not in good condition of the specified materials and there were lots of deposit of debris and gravels in the bed of the canal. The canal bed was eroded and there were lots of scratches and pit holes in most of the portion. There was sharp demarcation of silt in the banks which indicates that the canal used to flow nearly half the depth of flow since the long time. The lining of the canal is not in good condition and also the bushy grass grown up in the banks of the canal.

3.2. Canal Bed Slope:

The bed slopes were measured for main canal at Bijayapur and Sakneri. The data were taken at the center as well as left and right side of the canal. Figure 7 shows the centerline bed slope of Bijayapur main canal at Bijayapur it was found 1 in 147 (1V in 147H) while the average of centre line and left and right corner of bed was found as 1 in 142.

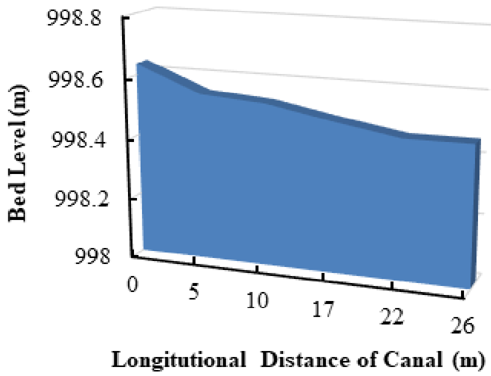

Figure 7: Bed slope of main canal at Bijayapur

Figure 8 shows the centerline bed slope of Bijayapur main canal at Sakneri and it was found 1 in 129 while the average of centre line and left and right corner of bed was found as 1 in 130.

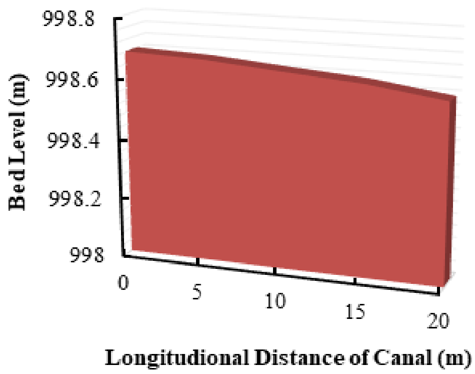

Figure 8: Bed slope of main canal at Sakneri

3.3. Velocity and Discharge:

As the channel has shallow depth, velocity measured at 0.6 times the depth of flow below the water surface represents the average velocity of the flow in vertical direction. The numbers of data were taken in the upstream and downstream segments of each reach under the study. The velocity was measured at the two different sections at Bijayapur and at Sakneri at the various depths. The measurement was carried out during the flow depth of 0.24 m, 0.35 m and 0.58m at Bijayapur site and the average velocity was found as 0.731 m/s, 0.903 m/s, 1.601 m/s, respectively. Whereas the same was calculated at the flow depth of 0.12 m, 0.18 m and 0.42 m at Sakneri and the average velocity was found to be 0.81 m/s, 0.84 m/s and 1.62 m/s, respectively. In each time the velocity was also taken by floats simply dividing the length by its travelled time. The surface velocity was corrected and compared with the velocity given by the current meter for the validation of the data given by the current meter. The data shows that the velocity increases with the increase in depth of flow.

Table 1: Discharge Calculation at Bijayapur Section

Bed Width (m)	Side Slope	Depth (m)	Area (m^2/s)	Velocity (m/s)	Discharge (m^3/s)
2.5	1	0.24	0.658	0.731	0.480
2.5	1	0.35	0.998	0.903	0.901
2.5	1	0.58	1.786	1.601	2.859

After the calculation of average velocity, the discharge was calculated with the respective flow depth. The Table 1 shows the computation of discharge from the area and velocity at different depths in the main canal sections at Bijayapur whereas the Table 2 shows the computation of discharge in the main canal sections at Sakneri.

Then, the velocity and discharges were used to develop the rating curve (depth-discharge relationship). The rating curve for the main canal at Bijayapur is shown in the Fig. 9 whereas for the main canal at Sakneri is shown in the Fig.10.

Table 2: Discharge Calculation at Sakneri Section

Bed Width (m)	Side Slope	Depth (m)	Area (m^2/s)	Velocity (m/s)	Discharge (m^3/s)
3	1	0.12	0.374	0.813	0.304
3	1	0.18	0.572	0.841	0.481
3	1	0.42	1.436	1.616	2.321

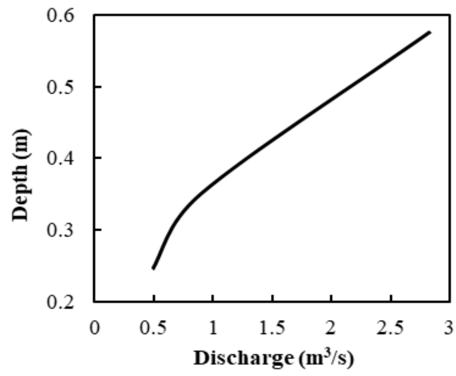

Figure 9: Rating Curve for main canal at Bijayapur main canal

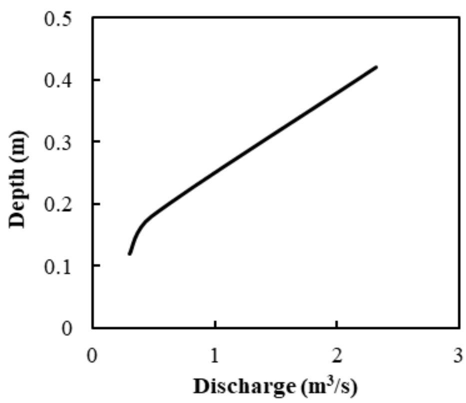

Figure 10: Rating Curve for main canal at Sakneri

3.3. The System of Operation and Maintenance in the Irrigation System:

The roughness coefficient was calculated with the help of canal geometry, bed slope and discharge observed during the study using the Manning's formula. Table 3 shows the calculation of roughness coefficient and it varies from 0.03 to 0.04 with average value of 0037 which is greater than the standard value of random stone masonry (varies from 0.02 to 0.025 [18]).

The average value of Manning's roughness coefficient at Sakneri and Bijayapur computed from this study is 0.028 and 0.037, respectively as shown as in Table 4. As the flow is not under the control of researcher, the data measurement was carried out only with the three different depths available randomly in the selected reaches of the canals. The result shows the high roughness coefficient than the standard values for the corresponding materials from which the canal was constructed and it may be because of uneven bed (as shown in Fig. 1(d), 2 and 5) and banks which the researcher observed during the low flow in the canal. There were silting (as shown in Fig. 5) in some cases while erosion in other cases with pit holes (Fig. 1(d)) though the bed is of concrete as observed during the study. The bed slope was not uniform and it creates the waves in the canal. The effect of poor condition of the bed (eroded with pit holes) and also due to the condition of the bank which was not in good condition increases the roughness coefficient. The Manning's roughness coefficient also varies in the two segments under the study and this indicates that the canal conditions also varied in different reaches of the same canal.

Table 3: Calculation Sheet for Roughness coefficient from measured Discharge (Bijayapur)

Depth (y)	**Wetted Pperimeter (*P*)**	**Area of Flow section (*A*)**	**Hydraulic Radius (*R*=*A*/*P*)**	**Discharge (*Q*)**	**Bed Slope (*S*)**	**Roughness Coefficient ($n=A\times R^{2/3}\times S^{1/2}/Q$)**	**Average Roughness Coefficient (*n*)**
0.24	3.179	0.658	0.207	0.480	0.00709	0.040	
0.35	3.490	0.998	0.286	0.901	0.00709	0.040	0.037
0.58	4.140	1.786	0.431	2.859	0.00709	0.030	

Table 4: Calculation Sheet for Roughness coefficient from measured Discharge (Sakneri)

Depth (y)	**Wetted Perimeter (*P*)**	**Area of Flow Section (*A*)**	**Hydraulic Radius (*R*=*A*/*P*)**	**Discharge (*Q*)**	**Bed Slope (*S*)**	**Roughness Coefficient ($n=A\times R^{2/3}\times S^{1/2}/Q$)**	**Average Roughness Coefficient (*n*)**
0.12	3.339	0.374	0.112	0.304	0.00769	0.025	
0.18	3.509	0.572	0.163	0.481	0.00769	0.031	0.028
0.42	4.188	1.436	0.343	2.321	0.00769	0.027	

4. Conclusion:

In this study, measurement of channel geometry and flow parameters were performed for the determination of roughness coefficient in the existing condition in the various segments of Bijayapur Irrigation System located at Lekhnath, Kaski, Nepal. The stage discharge curves were developed for the selected sites and finally the Manning's roughness coefficient was determined. The geometrical parameters, velocity and bed slopes were measured and used to calculate the discharge and roughness coefficient. The average value of Manning's roughness coefficient at Sakneri and Bijayapur computed from this study were found to be 0.028 and 0.037, respectively. The result shows the high roughness coefficient than the standard one for the materials used. The effect of poor condition of the bed (eroded with pit holes, deposits of silts) and also due to the condition of the bank (growth of weed and plant) increases the roughness coefficient as compared to the standard value of the given materials. The greater value of roughness coefficient decreases the velocity of flow and hence the discharge of the canal. Due to increase in roughness coefficient; canal could not carry the design discharge which leads to the tail end deprivation in the command area. To increase the carrying capacity of the canal the roughness coefficient should be reduced and for that the canal bed should be maintained smooth and even, the deposits of debris and gravel should be cleared regularly. For the efficient canal operation and to carry sufficient discharge as per design maintenance of canal should be carried out regularly.

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Conflicts of Interest:

The author declare no conflict of interest.

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