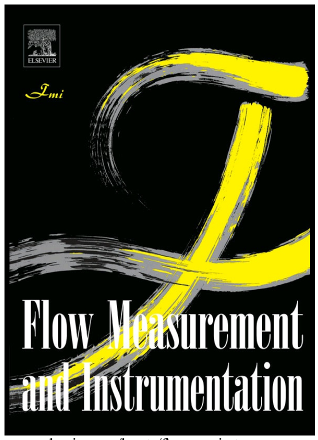

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HHAYNU MICRO HYDROPOWER SCHEME: MBULU - TANZANIA

Comparative River Flow Velocity and Discharge Measurement Methods

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Abstract

The objective of the study has been to determine the river discharge by measuring the river flow velocity using two different measurement methods together with the area method and compare the accuracy of the results.

Two river flow velocity measurement methods were used, the floating method and the use of current meter. In floating method a floating object was used to determine the water flow velocity on the surface by allow a float to move a distance of 1 meter along the river and record the time it takes to travel that distance in seconds. Ten readings were taken and manually recorded and the flow velocity was determined by taking the distance travel by the float (1m) divide by the time taken by the float (in seconds). On the other hand, the current meter method measure directly the average flow velocity across the river depth, twenty readings were taken and recorded manually and the average velocity were calculated. The use of current meter display flow velocity directly without the need of calculations.

The result shows that both methods produce very close value, but the floating method have displayed higher value of around +2% than current meter method which is a good value, despite the fact that floating method measures the surface velocity and the use of calculation. Many literature highlighted the accuracy of flow velocity measurement using current meter due to the fact that it measures the average velocity across the river, but from the findings when the floating method flow velocity measurement is properly applied it will produce as accurate results as the current meter with a fraction of cost in terms of instrument cost and expertise requirement in measurements.

The floating method flow velocity measurement method could be applicable as alternative to current meter in micro hydropower projects river flow measurements in rural areas of developing countries with limited funding and local expertise.

Keywords: Micro hydropower, river velocity, discharge, flow, scheme

Note:
The authors declare that there is no conflict of interest regarding the publication of this paper.

1. Introduction

Energy is one of Tanzania's priorities for development as stipulated in the National Energy Policy 2003. Many of the people with access to electricity live in urban areas while the majority of Tanzanians live in rural areas. Even in urban areas not all the people have access to electricity. According to Energy and Water Utilities Regulatory Authority – Tanzania (EWURA), electricity is available to only about 11% of the population by first quarter of 2007, with more than 80% supplied in the urban areas. Therefore, providing better access to electricity technologies will enhance development in rural as well as urban areas on a sustainable basis [1].

In Tanzania there are several potential sites for micro hydropower development and majority of them have not been studied and also have not been developed. One among the potential site for micro hydropower development is at Mbulu district – Manyara region in Tanzania as shown on Figure 1. The site area is located about 200 km from Arusha City (Northern Tanzania) in the remote rural areas of Mbulu district which is surrounded by several wards and villages. From the feasibility studies done by Arusha Technical College [2], the locality has a small river called Hhaynu which have the potential to develop a micro hydropower and supplying electricity to the local community. The area has tropical climate with a lot of sunshine so, there is also abundance of solar radiation for the development of solar power technologies which can be integrated with the micro hydro system to make it more energy efficient system [2].

2. Materials and Methods

2.1 Stream flow velocity and discharge measurement

In order to calculate the water flow instreams, the velocity and cross-sectional area need to be determined. The flowrate measurement methods include measuring the average water flow velocity and the cross-sectional area of the river and at the end calculating the flowrate using the following formula [3]:

$$Q(m3/s) = A\ (m2)\ x\ V\ (m/s)\text{..}(1)$$

2.2 Mean flow velocity measurements methods

2.2.1 Floating method

The floating method is a simple method to estimate the flowrate of a river by estimate the flow velocity and cross-section area. The velocity is estimated by measuring the time taken fora floating object to travel a measured distance downstream along the river. On the river profile the water flow velocity is usually not the same across the river, it is usually slower at the river sides and river bottom and flow faster close to the river surface [4].

See the Figure 2.

In this case the floating object is put on the surface of the water on a pre-defined distance and use stopwatch to record the time taken for the floating object to travel a pre-defined distance. This type of flowrate measurement method is mainly suitable for straight rivers on fairly even and regular water flows. SeeTable1 for the velocity and area measured values;

The velocity can be measured by a floating object, which is located at the surface of the river flow. The time (*t*) in seconds elapsed to travel a certain length (*L*) in meter is recorded and the surface speed (m/s) is given as:

$$Velocity\ (m/s) = \frac{\text{distance travelled } (m)}{\text{time travel } (\text{sec})}\text{...}(2)$$

To estimate the average flow speed (V_m), the above value must be multiplied by a correction factor that may vary between 0.45 to 0.85, depending on the water course depth and their bottom and river bank roughness (0.65 is a well-accepted value). [5]

Then, the flow rate can be calculated as:

$$V_m = 0.65\ x\ V_{surface}\ \text{..}(3)$$

Then the flow rate can be calculated as follows;

$$Q(m3/s) = A\ (m2)\ xV_m\,(m/s)\text{...}(4)$$

Where: Q = water flow rate (discharge) of the river or stream

This velocity and discharge measurement method have been tested using pre-define flow structure with known width, length and height (know volume). The flow length has pre-define unit scale in meters from 0 m which is the initial start point to 1 m which is the end point. The floating object was used to determine the time it take from the start point i.e. 0 m to end point at a distance of 1 m and the time taken for the flow to reach a length of 1 m is the surface flow velocity of the water in m/s. Several readings have been recorded and since the volume is known (length x width x height) then the discharge could be calculated by dividing the volume with the time taken for the floating object to reach the length of 1 m. See Figure 3.

The dimension of the structure is a small rectangular channel with the following dimensions: width 0.4m, height 0.6m and length 1 m with the pre-defined discharge of volume of 69.4 liters/second as shown on Figure 4.

Where: b = t = width = 0.4m, d = wetted height = 0.6m and the overall channel length is 1m.

The area of the above channel can calculated as follows;

A = W x H = 0.4m x 0.6m = 0.24m^2

And the Volume;

V = A x L = 0.240m^2 x 1m = 0.240m^3

Since the discharge have been pre-determined to be 69.4 l/s using the normal bucket with scale, then the velocity and time could be calculated using the following discharge formula;

Q = V x A

So; V = Q/A = 0.0694m^3/s/0.24m^2 = 0.289m/s which is the velocity of the water flowing through the given channel.

Thus the water flow duration could also be determined using the following relation;

V = Length/Time

Time = Length/Velocity = 1m/0.289m/s = **3.46 seconds**

The testing results with similar channel dimensions and discharge amount have been conducted using the floating object and the results for the floating object to travel a distance if 1 meter are shown on Table 1.

2.2.2 Current meter method

The current meter consists of a propeller which points upstream and is turned by the flowing water on the stream as shown on Figure 5 and Figure 6. The current meter method measures the water flow at different points across the river width and in this method several measurements points are used to calculate the average water flowrate. In this case the propeller is connected to a counter which records the number of complete revolutions the propeller makes in a set time.

In this method the cross-section of the stream was measured to be 6 meters and was divided into 20 strips of equal width of 30 cm as shown on Figure 2. The average water flow velocity for each sub-section strip was estimated from the mean of the velocity measured at 0.2, 0.6 and 0.8 of the depth in that strip which provide a more accurate value of the mean velocity [6].

2.2.2.1 One-point measurement

In one-point measurement, the average velocity for each strip is estimated from the mean of the velocity measured at 60% of the depth (0.6D) of the depth in each strip. In this case the average velocity in a river is measured at 0.6D of the stream depth.

$$V_{mean} = V_{0.6} \qquad (5)$$

This is usually applicable in shallow water where the water depth is limited and cannot accommodate the two or three-point measurements.

2.2.2.2 Two-point measurement

In order to make a reasonable accurate estimate, the average velocity is found by taking two readings in each sub-section measured at 20% depth (0.2D) and 80% depth (0.8D) in each section and V_{mean} is calculated using the formula below;

$$V_{mean} = 0.5(V_{0.2} + V_{0.8}) \qquad (6)$$

In this case the mean velocity (V_{mean}) is calculated by taking average of the flow velocity readings at 0.2 and 0.8 of the depth.

2.2.2.3 Three - point measurement

This involves measuring velocities at $0.2D_r$, $0.6D_r$ and $0.8D_r$ of the depth of each strip as shown on Figure 7 and the mean velocity is calculated using the following formula;

$$Vmean = 0.25\left(V_{0.2} + 2V_{0.6} + V_{0.8}\right) \qquad (7)$$

2.3 River Area measurements

Cross-sectional shape of the river varies with position in the stream and discharge as shown on Figure 8. The deepest part of channel occurs where the stream velocity is the highest. Both stream width and stream depth increase downstream because discharge also increases downstream. As stream discharge increases the cross sectional shape will also change, with the stream becoming deeper and wider.

As the depth of the river varies across the stream, the best method in area calculation is to divide the stream into sections of equal width and in this case 30cmand measure the depth of each section. The stream cross-sectional area for each section is calculated by multiplying width and height for each individual strip across the stream and the total area is the sum of individual strip areas [7] as shown on Figure 9 and 10.

Estimated area calculation on each strip is given by; Cross-sectional Area (m^2) = W (m) x H (m)

Accurateareacalculationoneachdividedstripisestimatedbydivingeachstripintorectangularand triangle shapes depending on the river profile on each stream section and then calculate the individual areas for each river strip from the river profile as shown on Figure 11.

During the site flow velocity measurement with the current meter, the type of instrument model used was Geopacks Advanced Stream flow meter Model - ZMFP126-S with serial number PGL-3610-B with the flow velocity measurement range of approximately 0.05 m/sec to 8.0 m/sec and measuring accuracy of around ± 7% as shown on Figure 6 and Figure 12.

The equipment was calibrated [8] using the pre-defined structure set with known flow velocity and discharge by the help of Manning's equation as shown in the diagram below;

In the case for the used Trapezoidal section which is shown in Figure 13 below;

The cross-sectional area, $A = bd + zd^2$and wetted perimeter, $W_p = b + 2dz$ So the Hydraulic radius,

$R = A/Wp = (bd + zd^2)/(b + 2dz)$ and top width, $t = b + 2dz$ or $T = b + 2Dz$

Note: $z = e/d$

The used Trapeziodal channel dimensions are as floows: b = 1.8m, d = 0.8m, D = 1.6m, e = 0.54m and z = 0.675m

So, from the Manning's equation, the average flow velocity (m/s) is given by;

$V = (1/n)\, R^{2/3} S^{1/2}$

where;

V = Average flow velocity, R = Hydraulic radius (0.650)

n = Manning's Roughness coefficient (Brick in cement mortar channel = 0.015)

S = Channel bed slope (0.05)

Substitute the values on the formula we get;

V = 66.667 x 0.141 x 0.025 = **0.235 m/s**

Thus, average water flow velocity for the above channel is **0.235 m/s** shown on Table 2.

2.4 River discharge determination

In calculating the flowrate, the measured mean velocities at each strip is multiplied with sectional areas of that strip which gives the flowrate for the strip [9]. The total flowrate is the sum of the individual strips as in Figure 9. Mathematically this could be expressed as $Q = V_m \times A_T$

3. Results and Discussion

3.1 Cross-sectional area

The results for the cross-section area calculation was based on the river depth and width and two area estimation methods were used and based on the results , the calculation based on the profile of the river produce 3% more accurate results than just simple area estimation method as shown on Table 3.

Note:

Calculation of the estimated area of 4.21 m^2 is based on the individual strip width multiply by strip height, assuming uniform rectangular shape, while the accurate area of value 4.09 m^2 is calculated by dividing the strips profile into rectangular and triangle shapes (trapezoidal rule) and then calculating the individual areas.

3.2. Flow velocity and discharge

3.2.1 Floating object

Ten readings were taken and time recorded for a floating object to move on the surface of a river for a distance of 3 meters.

The river discharge was determined by multiplying the mean flow velocity (distance x time) by the average cross-sectional area of the stream ($Q = V_m \times A$). An important drawback of this method is that the cross-sectional area may be difficult to determine, especially when the stream bank is not uniform. Further, since the flow velocity varies depending upon stream cross-section and position within the cross-section, velocity estimates may be subject to errors [10]

An average of several velocity measurements may improve accuracy of the estimated value. See Table 4 for the calculated results.

Note: Mean velocity $V_m = C \times V_{surface}$

where;

C = 0.65 for small stream with a smooth riverbed like Hhaynu river

The average discharge value of 0.92 m^3/s obtained above is very close to the site measured value in June 2016 which is around 0.90 m^3/s and also the historical and yearly average value of discharge of 0.98 m^3/s, so the method seems reliable in terms of its simplicity and cost effective.

It has been noted that the accuracy of this method is influenced by the human error and number of and also the river cross section area calculation method that has been used. To reduce this, the best way is to take more readings during measurements and average them and also make a reasonable distance for the floating object to travel from start to finish points.

3.2.2 Using current meter

3.2.2.1 Mean velocity

In the current meter measurements method twenty readings were taken and recorded manual at different depths and their mean velocity calculated at different water depth levels and the results is shown on Table 5.

Note: D = Stream depth (m)

3.2.2.2 Discharge

From the calculated results on Table 6, it is shown that the three point measurements with more strips areas across the stream width gives more accurate results compared to one-point measurement, two-point measurement and floating method as shown on Table 5.

Note: Discharge (m^3/sec) = Cross-sectional Area [width x depth] (m^2) x Average Velocity (m/sec)

In general comparison, the one point current meter measurement method produce +10% less accurate results than the three point measurement method and the one point measurement produce -6.7% less accurate results than the three point measurement [11]. In this case the error margin for the one point and the two point velocity measurement method compare the more accurate three point measurement is within ±10% [12].

This is also valid to the simple flow velocity measurement method by using floating object which in this case produce only +2% less accurate flow velocity results that the three point current meter measurement method [13]and [14].

Depending on the type river velocity and flowrate measurement required, both the simple and easy to set floating method and the use of equipment by the current meter method both measurement methods produce very close and almost similar results despite the fact that [15] and [16] claim that the current meter method is much more accurate than the floating flow velocity and discharge measurement method due to fact that with the current meter the measured flow velocity readings are averaged throughout the river cross-section.

4. Conclusion

Discharge measurements using the velocity-area method without the use of a weir provide a good estimate for streamflow and discharge. However, this method assumes several things, including a constant cross-sectional area (which is not always the case, as streams are erosive, dynamic systems), another thing is a strong relationship between stage height and discharge and also little human error in measuring flow velocity, stage height, and cross-sectional area.

The measured discharge for Hhaynu river for both methods resulted to almost similar value, 0.92m^3/s for the floating method and 0.90m3/s for the three point velocity measurement method respectively. The validity of these calculated values have been confirmed by the 23 years historical flow rate data (1985 to 2007) which reveal the average flow rate of 0.97m^3/s.

So, in mini and micro hydropower projects with limited budget and funding, the use floating method in velocity and discharge measurement could produce as better results without the need of an expert compared to the use of instrument like the current meter.

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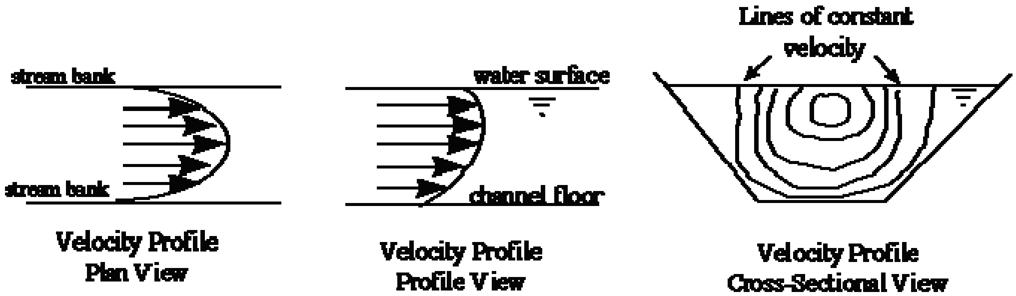
Figure 1. Hhaynu Micro hydropower scheme site location [11]

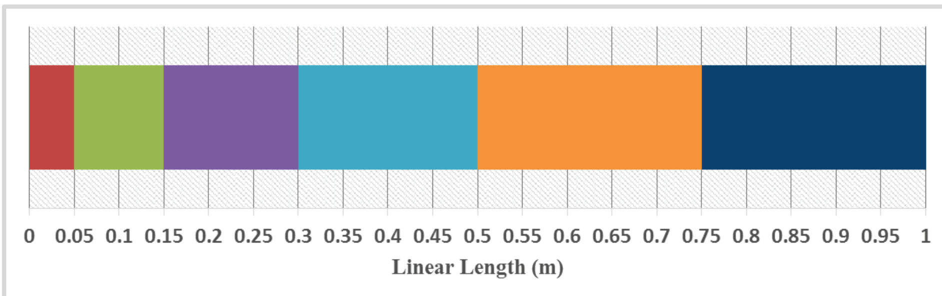
Map of Tanzania showing region distribution

Figure 2. Stream/river velocity profile



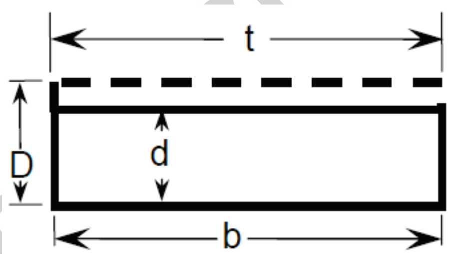
River cross-section profile showing water flow velocity

Figure 3. Distance travelled by the floating object



Linear measurement scale of a distance of 1 meter

Figure 4. Pre-defined flow channel dimensions



Rectangular channel section view

Figure 5. A propeller type current meter

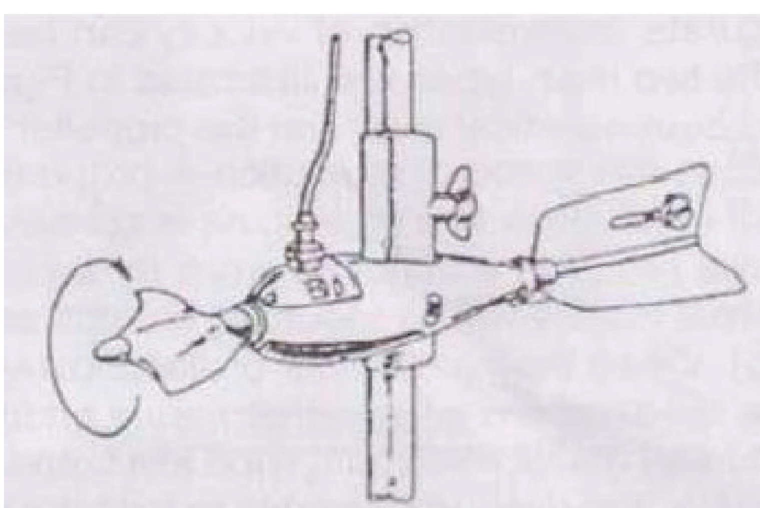


Figure 6. Flow velocity measuring instrument - Current meter

Figure 7. Velocity measurements depths

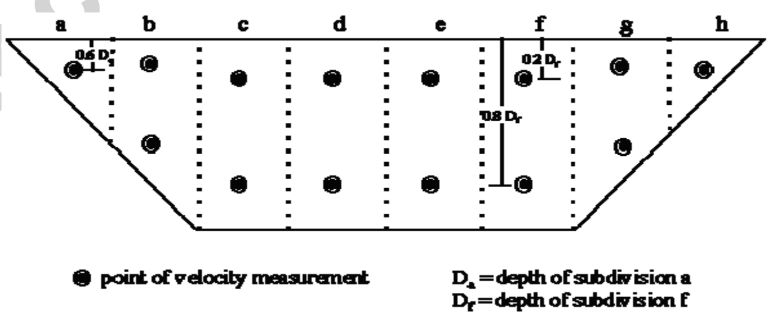
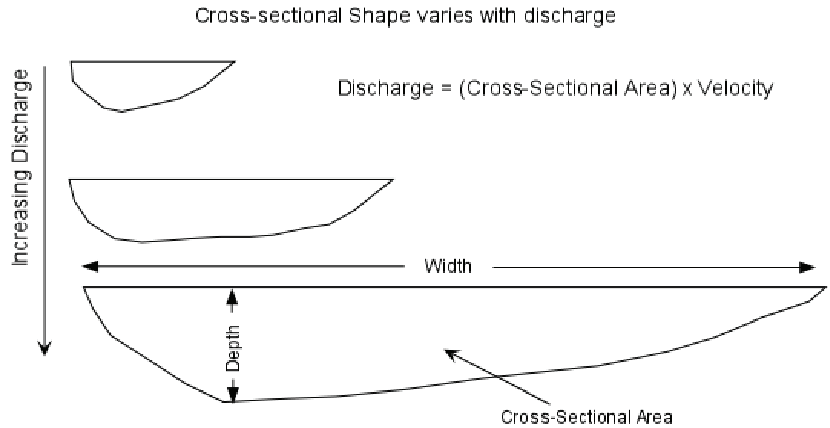


Figure 8. Stream cross-sectional shape of the river



River profile for cross-section area measurements

Figure 9. Model stream/river sub-divisions [19]

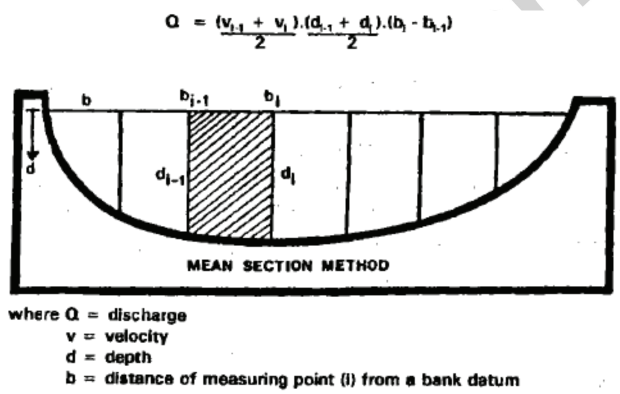
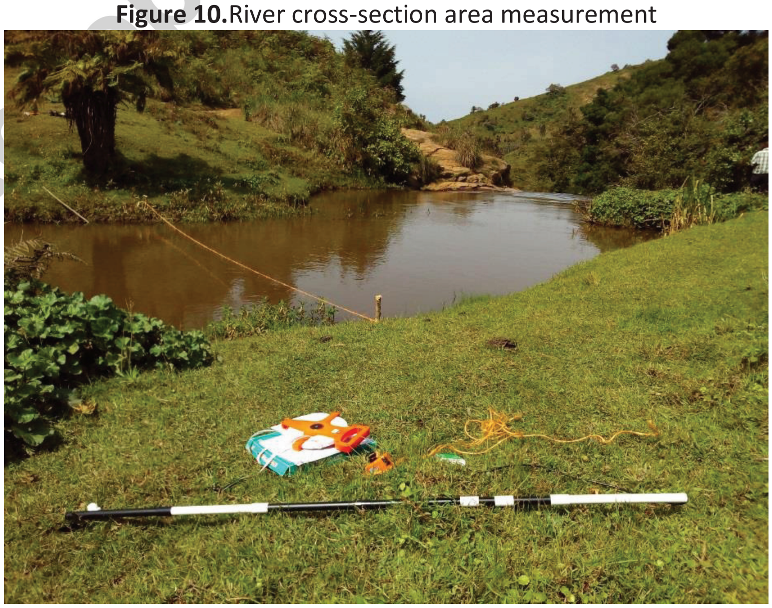
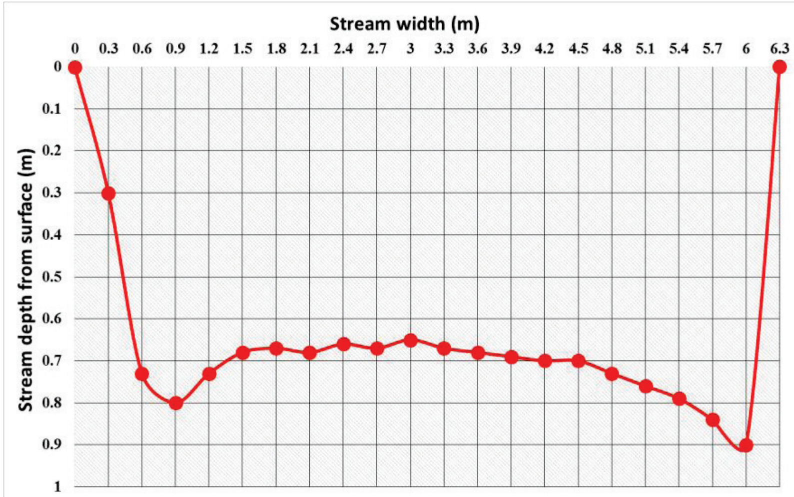


Figure 10. River cross-section area measurement



River section measurement point

Figure 11. Hhaynu river profile and width sub-section at the measurement location

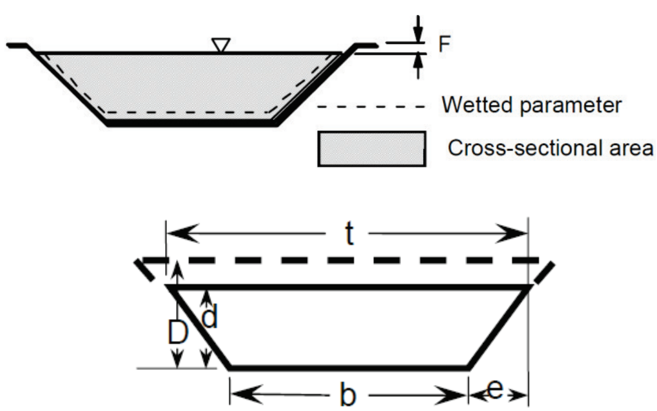


River profile with 0.3m strips

Figure 12. Flowrate recording on site - June 2016

Working on site for data collection

Figure 13. Pre-defined structure for flow velocity measurement using Manning's equation [20]



List of Tables:

Table 1: Recorded time for the floating object travelled a distance of 1 meter

Readings	Distance travelled (m)	Time taken (s)
1	1	5.25
2	1	3.18
3	1	2.60
4	1	2.53
5	1	2.69
6	1	2.97
7	1	3.08
8	1	3.43
9	1	3.67
10	1	5.18
Average		**3.46**

Table 2: Calibration results from the current meter

Readings	Flow velocity (m/s)
1	0.245
2	0.217
3	0.265
4	0.210
5	0.266
6	0.237
7	0.212
8	0.255
9	0.225
10	0.214
Average	**0.235**

Table 3: Hhaynu river cross-section area results

Section/strip	Stream width (m)	Strip width-W (m)	Strip height-H (m)	Section/strip estimate Area [W x H] (m^2)	Section/strip accurate Area (m^2)
1	0.3	0.3	0.30	0.09	0.05
2	0.6	0.3	0.73	0.22	0.15
3	0.9	0.3	0.80	0.24	0.23
4	1.2	0.3	0.73	0.22	0.23
5	1.5	0.3	0.68	0.20	0.21
6	1.8	0.3	0.67	0.20	0.20
7	2.1	0.3	0.68	0.20	0.20
8	2.4	0.3	0.66	0.20	0.20
9	2.7	0.3	0.67	0.20	0.20
10	3.0	0.3	0.65	0.20	0.20
11	3.3	0.3	0.67	0.20	0.20
12	3.6	0.3	0.68	0.20	0.20
13	3.9	0.3	0.69	0.21	0.21
14	4.2	0.3	0.70	0.21	0.21
15	4.5	0.3	0.70	0.21	0.22
16	4.8	0.3	0.73	0.22	0.23
17	5.1	0.3	0.76	0.23	0.23
18	5.44	0.3	0.79	0.24	0.24
19	5.7	0.3	0.84	0.25	0.26
20	6.0	0.3	0.90	0.27	0.22
TOTAL				**4.21**	**4.09**

Table 4: Discharge measurement results by floating method

Reading	**Distance covered (m)**	**Time (s)**	**Surface velocity (m/s)**	**Mean velocity (m/s)**	**Average river depth (m)**	**River width (m)**	**River cross section (m2)**	**Discharge (m^3/s)**
1	3	15.76	0.19	0.12	**0.85**	**5.40**	4.59	0.57
2	3	9.54	0.31	0.20				0.94
3	3	7.8	0.38	0.25				1.15
4	3	7.6	0.39	0.26				1.18
5	3	8.07	0.37	0.24				1.11
6	3	8.9	0.34	0.22				1.01
7	3	9.23	0.33	0.21				0.97
8	3	10.3	0.29	0.19				0.87
9	3	11	0.27	0.18				0.81
10	3	15.54	0.19	0.13				0.58
Average Discharge								**0.92**

Table 5: Hhaynu river mean flow velocities results by current meter method

Section/ strip	Flow velocity (m/s)			Mean velocity: 1 point measuring method	Mean Velocity: 2 points measuring method	Mean Velocity: 3 points measuring method
	0.2D	0.8D	0.6D	$V_{mean}=V_{0.6}$	$V_{mean}=0.5(V_{0.2}+V_{0.8})$	$V_{mean}=0.25(V_{0.2}+2V_{O.6}+V_{0.8})$
1	-	-	0.14	0.14	-	-
2	0.11	0.14	0.22	0.22	0.13	0.17
3	0.2	0.14	0.16	0.16	0.17	0.17
4	0.24	0.19	0.46	0.46	0.22	0.34
5	0.21	0.23	0.27	0.27	0.22	0.25
6	0.25	0.21	0.22	0.22	0.23	0.23
7	0.23	0.25	0.18	0.18	0.24	0.21
8	0.23	0.33	0.24	0.24	0.28	0.26
9	0.14	0.23	0.23	0.23	0.19	0.21
10	0.22	0.32	0.3	0.3	0.27	0.29
11	0.27	0.22	0.28	0.28	0.25	0.27
12	0.31	0.23	0.26	0.26	0.27	0.27
13	0.21	0.27	0.26	0.26	0.24	0.25
14	0.24	0.28	0.29	0.29	0.26	0.28
15	0.25	0.23	0.29	0.29	0.24	0.27
16	0.18	0.27	0.16	0.16	0.23	0.19
17	0.18	0.16	0.22	0.22	0.17	0.20
18	0.18	0.18	0.23	0.23	0.18	0.21
19	0.2	0.17	0.25	0.25	0.19	0.22
20	-	-	0.09	0.09	-	-

Table 6. Hhaynu river discharge measurement methods comparison using current meter method

Section/strip	Flow velocity (m/s)			Mean velocity: 1 point measuring method	Mean Velocity: 2 points measuring method	Mean Velocity: 3 points measuring method	Section/strip Area (m2)	Flowrate: 1 Point measuring method [0.6D] (m3/s)	Flowrate: 2 points measuring method [0.2D and 0.8D] (m3/s)	Flowrate: 3 points measuring method [0.2D, 0.6D and 0.8D] (m3/s)
	0.2D	0.8D	0.6D	Vmean=V0.6	Vmean=0.5(V0.2+V0.8)	Vmean=0.25(V0.2+2VO.6+V0.8)				
1	-	-	0.14	0.14	-	-	0.05	0.01	-	-
2	0.11	0.14	0.22	0.22	0.13	0.17	0.15	0.03	0.02	0.03
3	0.2	0.14	0.16	0.16	0.17	0.17	0.23	0.04	0.04	0.04
4	0.24	0.19	0.46	0.46	0.22	0.34	0.23	0.11	0.05	0.08
5	0.21	0.23	0.27	0.27	0.22	0.25	0.21	0.06	0.05	0.05
6	0.25	0.21	0.22	0.22	0.23	0.23	0.2	0.04	0.05	0.05
7	0.23	0.25	0.18	0.18	0.24	0.21	0.2	0.04	0.05	0.04
8	0.23	0.33	0.24	0.24	0.28	0.26	0.2	0.05	0.06	0.05
9	0.14	0.23	0.23	0.23	0.19	0.21	0.2	0.05	0.04	0.04
10	0.22	0.32	0.3	0.3	0.27	0.29	0.2	0.06	0.05	0.06
11	0.27	0.22	0.28	0.28	0.25	0.26	0.2	0.06	0.05	0.05
12	0.31	0.23	0.26	0.26	0.27	0.27	0.2	0.05	0.05	0.05
13	0.21	0.27	0.26	0.26	0.24	0.25	0.21	0.05	0.05	0.05
14	0.24	0.28	0.29	0.29	0.26	0.28	0.21	0.06	0.05	0.06
15	0.25	0.23	0.29	0.29	0.24	0.27	0.22	0.06	0.05	0.06
16	0.18	0.27	0.16	0.16	0.23	0.19	0.23	0.04	0.05	0.04
17	0.18	0.16	0.22	0.22	0.17	0.20	0.23	0.05	0.04	0.04
18	0.18	0.18	0.23	0.23	0.18	0.21	0.24	0.06	0.04	0.05
19	0.2	0.17	0.25	0.25	0.19	0.22	0.26	0.07	0.05	0.06
20	-	-	0.09	0.09	-	-	0.22	0.02	-	-
TOTAL								**0.99**	**0.84**	**0.90**