Comparative Analysis of Water Discharge Measurement Methods and Seasonal Trend Analysis of Taebayrongchu Sub-watershed, Punakha

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Abstract

Stream discharge can be measured using several methods and are influenced by the natural flowing characteristics of the stream. The study analysed the comparative measurement of stream flow using float area method and cup-type current meter with baseline data of propeller-type current meter. It also determined seasonal flow and lean flow trend analysis of stream in Taebayrongchu sub-watershed. The percentage difference and matrix technique were used for comparison of the discharge. The discharge data using cup-type current meter, propeller-type current meter and float area method were 0.912m^3/s, 0.876m^3/s and 1.654m3/s respectively. The percentage difference between propeller-type and cup-type current was 0.036. The cup-type current meter was used for lean flow measurement and Integrated Flood Analysis System (IFAS) modeling to determine the peak flow measurement. The Nash coefficient for the modeling was 0.598. The highest discharge in the stream was in the month of July (13.663m^3/s) and lowest in the month of February (0.876m^3/s). The trend analysis of lean flow showed decrease in the amount of water in the stream from the year 1998 to 2018. There was a variation in water discharge measurement in different months of the year. The IFAS modeling is less applicable for small streams.

Keywords: *current meter, discharge measurement, float area method, integrated float analysis system, lean flow*

Introduction

Watershed is a system of connecting streams where all the surface runoff originating within the area leaves in a concentrated flow through a single outlet at a lower elevation (Reddy, 2011; Brooks, Ffolliott, & Magner, 2012). It is a useful unit for natural resource management establishing relations between natural resources and human activities. One of the important aspects of watershed is the water discharge measurement for management of water resources (Bradley, Kruger, Meselhe, & Muste, 2002). The discharge measurement of a stream is the volume of water flowing through a single point within a channel at a given time (Whiting, 2003; Hirsch & Costa, 2004). The discharge measurement of water depends on natural characteristics of the stream and availability of measuring instruments.

Water discharge measurement is critical at present climate change scenario such as occurrence of floods, water flow in the lean season, agriculture activities, hydropower generation, and environmental management of aquatic ecosystem. Accurate measurement of volume flow is needed for computing estimation of water discharge in a stream (Antigha, Akor, Ayotamuno, Ologhodien, & Ogarekpe, 2014).

Stream discharge can be measured using several methods and has not changed for over centuries in many countries (Costa *et al.*, 2000). The most common traditional methods for water discharge measurement in open channels are cup-type current meter, and float area (Costa *et al*., 2000; Merz, 2000). The latest discharge measurement methods are salt dilution method (Sappa, Ferranti, & Pecchia, 2015), channel geometry (Sefick, Kalin, Kosnicki, Schneid, Jarrell, Anderson, & Feminella, 2015), and Acoustic Doppler Current Profiler (ADCP) method. The current meter work on the principle of rotating the cup and propeller with the velocity of water (Sappa *et al*., 2015).

Discharge measurement in a mountainous area with rugged water course depends on types of instruments and methods used (Calkins & Dunne, 1970). It is difficult for discharge measurement due to high variability of the flow and turbulent stream conditions that varies throughout the year (Adhikari, Dhakal, Dongol, & Merz, 2000). The selection of the most appropriate instrument and method in different flow conditions is the first step to provide accurate information on surface water conditions of a stream (Merz, 2010). Annual water availability in the streams is characterized by the low flows during lean seasons of the year (Adhikari *et al*., 2000). The quantity and variation of flows depend on precipitation pattern in the watershed (Merz, 2010).

In Bhutan, water discharge measurement is done by National Centre for Hydrology and Meteorology (NCHM) and Druk Green Power Cooperation (DGPC) for hydropower projects. They use different methods such as Automatic Water Level Station Sensor (AWLSS), cable way, and wading using current meter. The NCHM collects data on daily basis using AWLSS and Cable way in major rivers of Bhutan. The wading method using current meter is taken once in a year from January to March in small streams (NCHM, 2017).

Taebayrongchu watershed is valuable water resource for the local communities and contributes to the sustainability of water supply for irrigation and drinking water to the communities. Owing to the seasonal change, the stream shows variation in discharge; high during monsoon and low during dry seasons. The water becomes insufficient for paddy transplantation and drinking purpose during dry season (Gyelmo, 2015). Conversely, there are no clear scientific information depicting the actual discharge measurements for the stream during different seasons. The information generated will aid the farmers to better use and plan for cropping and irrigation at different seasons. The result will also help extension officials, municipality, local government and policy makers for planning and management. The data will be instrumental to hydropower project management as the contributions from streams to the main river, Punatshangchu can be generated with much ease.

The comparative study for flow measurement to establish the best method that will be feasible in mountainous areas, volumetric discharge in different seasons, and discharge trend of lean season in Taebayrongchu sub-watershed, under Punakha district were the premise of the study.

Methods and materials

Study Area

The study was carried out in Taebayrongchu (27^{o} 31”31’ N; 89^{o} 52” 03’ E) under Punakha district. Water discharge measurements were taken at Taebayrongchu Bridge. The watershed has an area of 114 sq.km with an elevation of 1250 to 3100 meter above sea level (masl) (NCHM, 2017). Water yield in a stream is mostly from rainfall and springs during summer. The water from all the springs on upper catchment meet at the lower elevation to form a stream because of steep slopes. The water in upper catchment flow with high turbulence due to steep slope and velocity decreases at lower elevation before forming confluence with Punatshangchu. The water flows from 3100masl passing through roads and human settlement. Some amount of water is also diverted for drinking and irrigation from the source. The watershed is more prone to landslide and soil erosion due to human disturbances.

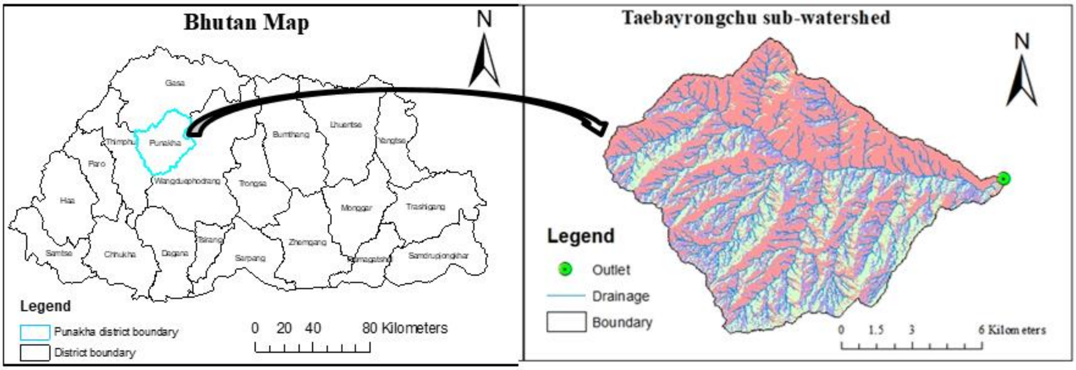

Figure 1: Taebayrongchu sub-watershed (Data source: National Centre for Hydrology and Meteorology)

Sampling Design

The data were collected through spot discharge measurement by wading method for six months (October 2017 to March 2018) during lean season using cup-type current meter. The discharge measurement was taken twice a month. The data were collected from only one station throughout the study period to reduce the error in accuracy and for the reliability of water discharge measurement as applied by Otuagoma (2015) and Sappa *et al*. (2015). The remaining 6 months data were predicted based on IFAS modeling during high discharge flow. The precipitation of seven surrounding meteorological station data was used as an input for discharge prediction for IFAS modeling.

For the effectiveness of water discharge measurement method, cup-type current meter and float area method was used. The data of propeller-type current meter method was used as baseline measurement data. The data from three methods were collected from same station at the same time. The data were analyzed using percentage difference in the reading and plotted against the bar graph. The lean flow data from 1998 to 2018 were used to analyse the discharge trend. Water discharge trend of lean season was done using Microsoft excel and Statistical Package for the Social Science (SPSS).

The rainfall data of 2016 from seven meteorological station (Punakha, Wangdue, Thinleygang, Gasa, Tashithang, samtengang and shelgana) were used as input for IFAS modeling. The only one meteorological station falls under the Taebayrongchu watershed and other six falls outside. The other six station's rainfall data from the surrounding area was include because of limited data. The discharge data of Wangdue Rapid is used for simulation correlation process in IFAS modeling. All the secondary data were collected from NCHM.

Results and Discussion

Cup-type current meter method

The area was calculated by measuring the width and depth of the sub-section of the stream. The velocity was determined using cup-type current meter. The total velocity and area were summed up to calculate the total stream discharge. The current meter method gives water velocity in each vertical section with the calibration equation of (v = 0.5826*RPS+0.0536) between stream velocity (m/s) and the number of spins (sec-1) with the rating range of 0.3m/s to 3.3m/s (Sappa *et al*., 2015).

Discharge (Q) = Velocity (V) * Area (A)

Table 1: Discharge measurement reading using cup-type current meter

SEGMENT	WIDTH (M)	DEPTH1 (M)	DEPTH2 (M)	TIME (SEC)	REV.	REV./ SEC	V=0.5826*RPS +0.0536(M/S)	AREA (M^2)	Q=V*A (M^3/S)
1	0.5	0	0.1	60	17	0.283	0.218	0.025	0.005
2	0.5	0.1	0.12	60	22	0.367	0.267	0.055	0.015
3	0.5	0.12	0.16	60	25	0.417	0.296	0.070	0.021
4	0.5	0.16	0.20	60	17	0.283	0.218	0.090	0.019
5	0.5	0.20	0.22	60	33	0.550	0.374	0.105	0.039
6	0.5	0.22	0.23	60	44	0.733	0.481	0.113	0.054
7	0.5	0.23	0.26	60	47	0.783	0.509	0.123	0.063
8	0.5	0.26	0.30	60	48	0.800	0.519	0.140	0.073
9	0.5	0.30	0.29	60	46	0.767	0.500	0.148	0.074
10	0.5	0.29	0.32	60	50	0.833	0.539	0.153	0.080
11	0.5	0.32	0.39	60	46	0.767	0.500	0.178	0.089
12	0.5	0.39	0.50	60	40	0.667	0.442	0.223	0.099
13	0.5	0.50	o.43	60	34	0.567	0.384	0.233	0.089
14	0.5	0.43	0.44	60	27	0.400	0.287	0.218	0.063
15	0.5	0.44	0.42	60	32	0.533	0.364	0.215	0.078
16	0.5	0.42	0.30	60	16	0.267	0.209	0.180	0.038
17	0.2	0.30	0	60	12	0.200	0.170	0.075	0.013
	Average velocity: 0.369 m/s				Total area: 2.344m²			Total: 0.912	

The discharge was taken during the lean season when the water level in the stream was low and does not show much fluctuation (Table 1). The total width of the stream at the station site was 8.2 meter. The cross section was divided into 17 sub-sections with 0.5 meter interval. The sub-section was determined based on width of the stream. According to Michaud and Wierenga (2005), more number of sub-section will have greater probability of discharge estimation. The time set was 60seconds at every cross section of the stream. The method used was 0.6 meter point measurement because the depth of water was less than one meter. More than one meter depth requires three point measurement at 0.2, 0.6, and 0.8 meter depth for the accuracy of velocity. Gees (1990) had set time for 60 seconds using conventional current meter set by United State of Geological Survey (USGS). The revolution per second was determined by time set by the total number of revolutions at each section. The discharge value calculated was Q = 0.912 m^3/s after summing up total velocity and area.

Float area method

The float area method is useful for streams which involve measurement of width, depth, and velocity. A pine cone was used as a floating object which was slightly submerged (Otuagoma, Ogujor, & Kuale, 2015) in the stream. The time 't' was taken by the float to cover a known distance 'd' was recorded. It measures surface velocity and correction factor is used to determine average velocity depending on stream bed rocks (Meals & Dressing, 2008). The cross-sectional area in the particular section of the river was calculated using the measuring tape for width and wading rod to measure average depth.

Three different measurements were made at the discharge station. The data collected from float area measurements were recorded and presented (Table 2). The discharge measurement using float area method was done thrice at a site to determine average velocity. The distance was maintained at 60 meter between start of the point and certain point downstream as done by Otuagoma *et al*. (2015). The K (Correction factor) 0.85 was used to find the average velocity of the stream based on river beds.

The surface velocity 'V' of the water is given by the relation:

V surface = travel distance/ travel time = d/t (m/s)

$$Discharge(Q) = Area(A) \times Velocity(V)$$

$$Vmean = \frac{d}{t} = k \times Vsurface \quad Where\ K\ \ (Correction\ factor) = 0.85$$

The equation to calculate the discharge: $Q = Ave \times Vsurface \times correction\ factor$

Table 2: Discharge measurement reading using float area method

Trial	Distance(m)	Time (s)	Area(m^2)	Velocity(m/s)	Discharge(m^3/s)
1	60	72	2.344	0.833	1.660
2	60	76	2.344	0.789	1.573
3	60	69	2.344	0.869	1.733
					Average: 1.654

In three different measurements; the time taken by the floating object to reach specific point were 72, 76, and 69seconds respectively. The three different velocities were averaged to get more accurate reading. The velocities of the stream were 0.833, 0.789, and 0.869m/s respectively. The total area of the cross section was 2.344m^2 and average discharge of the stream using float area method was 1.654m^3/s.

Comparison between current meter and float area method

Comparison of cross sectional mean velocity, area, and discharge using float area method and cup- type current meter method were observed (Figure 2). Results of the two methods for determining stream flow discharge at Taebayrongchu Bridge gauging station were compared with propeller- type current meter. The discharge values measured by the cup-type current was similar to values obtained by propeller type current meter. Propeller-type current meter method was the standard instrument and many stream flow measurements were taken throughout Bhutan during lean season (NCHM, 2015).

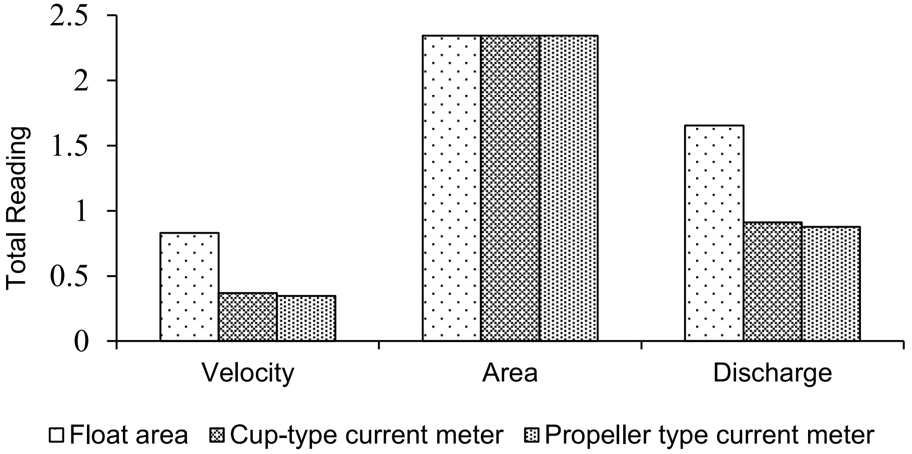

Figure 2: Measurement of velocity, area, and discharge using three methods

The highest mean velocity of 0.83m/s of water was recorded in float area method. There was a small variation of 0.036m/s in velocity measurements done by cup-type and propeller-type current meter. The area was 2.344m^2 in all three methods because the discharge measurement was taken at the same place. The discharge measurement using float area method is 1.654m^3/s, and cup-type current meter is 0.912m^3/s respectively. The stream measurement from cup-type current meter and float area methods were analyzed and compared with baseline data of propeller-type current meter. The difference in discharge measurement among three methods is primarily due to velocity difference as higher velocity value corresponds to higher discharge value (figure 2)

Comparison using percentage difference method

The percentage from discharge of propeller type current meter was used to compare between cup- type current meter and float area method.

Table 3: Percentage difference of three different methods

Date	Current meter (Propeller-type)	Current meter (Cup-type)	Float area method	Percentage difference
15/02/2018	0.876	0.912	-	0.036
15/2/2018	-	0.912	1.654	0.743
15/2/2018	0.876	-	1.654	0.779

The discharge measurement using propeller-type current meter was used as baseline data recorded by the NCHM. The propeller-type current meter was the standard method upgraded by United State of Geological Survey in a mountainous area. The discharge value using cup-type current meter and float area was 0.912 m^3/s and 1.655m^3/s respectively. The percentage difference between propeller-type and cup-type current meter is 0.036. The percentage difference for float area and cup-type current meter with propeller type current meter is 0.779 and 0.743 respectively.

According to Nolan, Shields, & Survey (2000), value of the cup-type current meter within 5 is considered good and float area greater than 8 is poor. The discharge measurement done in Ethiopia for comparative methods show that the current meter gives accurate result than float area method. The finding from Taebayrongchu shows that cup-type current meter is better and accurate than float area method. However, Merz and Doppmann, (2006) argued that in Bhutan, salt dilution method was appropriate and accurate, but this method could not be used due to lack of instrument. There is limited comparison with current meter with float area methods in the mountainous stream.

Matrix technique

Matrix of the techniques and methods and their use under certain stream conditions was used to observe the feasibility and advantages of current meter and float area method. Ticks and Crosses indicate where an advantage and disadvantage have been identified during discharge measurement in the field. Nolan *et al* (2000), used similar technique to look into effective methods based on field experience.

Table 4: Matrix techniques method

Stream condition	Cup-type current meter	Float Area method
Turbulent flow	√	×
Steady flow	√	√
Irregular channel	√	×
Regular channel	√	√
Low flow	√	√
Reversing flow	×	×

The stream condition such as turbulent flow, steady flow, irregular channel, regular channel, low flow and reversing flow was observed in both the methods. The tick mark indicate advantages and cross mark indicate disadvantages based on field observation. There are more advantages compared to disadvantages for stream discharge measurement using current meter in a mountainous area. The current meter was appropriate except in reversing stream condition.

In float area method, the floating objects were disturbed by wind that affected the velocity of water during measurement. The study on surface water flow measurement for water quality monitoring projects by Meals and Dressing (2008) found that wind was the main affecting factor for discharge measurement in float area method. The presence of aquatic plants and wooden materials that were washed away by flowing water also affected the velocity of water. The advantage of using float area method was fast and easy to take measurement. It is difficult to place cup-type current meter at different depth of water during velocity measurement. The advantage of using cup-type current meter over float area method was measuring the velocity of water across the stream at having measurement interval.

Integrated Flood Analysis System (IFAS) model setup

The IFAS modeling tool is was used for water discharge estimation of Taebayrongchu stream for peak discharge months. The data used were observed discharge records, rainfall, Digital Elevation Model (DEM) and land use as indicated in figure 3. Similar data were used by Sutikno, Handayani, Fauzi, & Kurnia (2017) for study of hydrologic modelling using TRMM-based rainfall products for flood analysis. The IFAS software ver. 2.0 and all data were downloaded directly from http://www.icharm.pwri.go.jp/research/ifas/ifas.html website.The observed discharge data are required to calibrate with simulation data of IFAS software to mimic the shape and follow the trend of the observed hydrograph (Sugiura, Fujioka, Nabesaka, Sayama, Iwami, Fukami, & Takeuchi, 2014).

Rainfall data of seven meteorological stations were used as input data to the IFAS model. IFAS reads rainfall point where location of the station and time of the measurements are specified (Sugiura, Fukami & Inomata, 2008). To handle rainfall data in IFAS format, there are four conditions to consider such as the format of the data, its chronological continuity, the no-data issue and if the calculation time step is smaller than the data time step and also the interpolation of rainfall data for each time step. Daily rainfall data of 2016 were collected from meteorological stations. Rainfall data from seven surrounding meteorological stations were used for accuracy and validity of model.

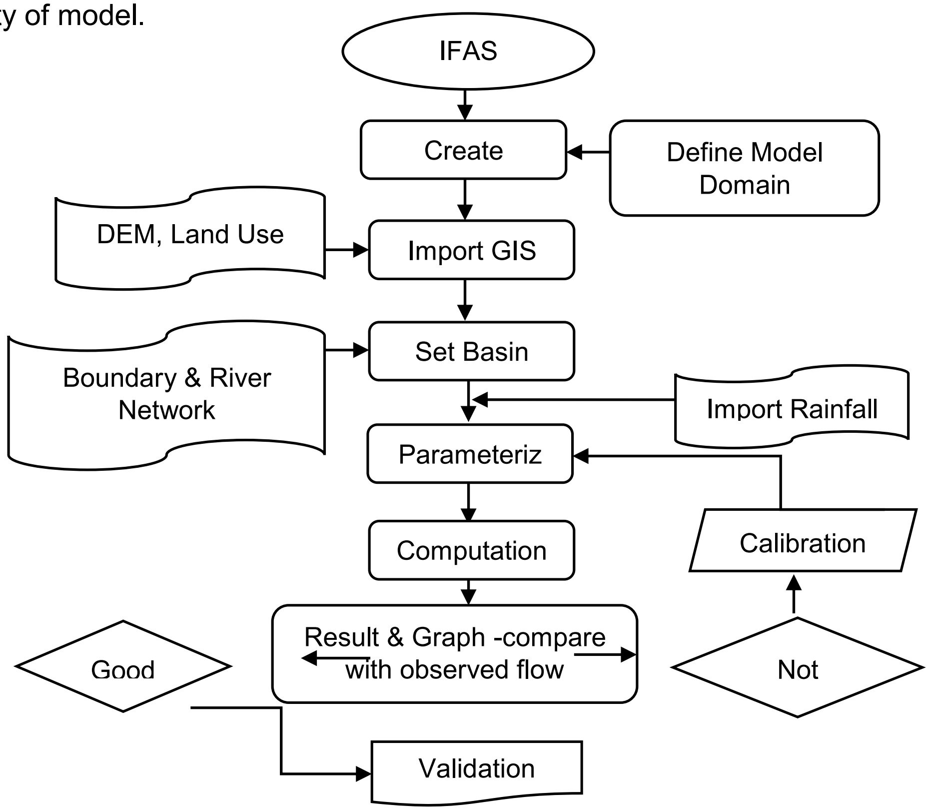

Figure 3: IFAS modeling procedure setup

Model calibration and validation

Model calibration is the process of optimizing the value of the parameters to improve the coherence between the hydrological discharge data (observed data) and simulated discharge. In this research, the IFAS model was calibrated using a reference of water discharge data of Wangdue rapids as there are no observed seasonal discharge data of Taebayrongchu. The hydrological parameters such as sub-surface, aquifer and river course were calibrated. These parameters were used in calibration by Sutikno *et al*. (2017) and Sugiura *et al*. (2014). At the beginning of the simulation, hydrological parameters were set default specified by IFAS based on satellite data input as shown in figure 3. The sensitivity of these parameters on the response of hydrological model calibration phase was examined.

Comparison between the simulation and measured hydrograph show the similar trend but the magnitude was not acceptable. The peak of simulation discharge of Wangdue rapid was significantly over estimate compared with the measurement peak discharge. To improve the accuracy and the correlation, calibration process was done by trial and error method on hydrological parameters so that the output discharge from the model was as close as possible with measured discharge. The calculated discharge produced by IFAS was compared to the observed discharge data from river at Wangdue rapid station. After calibration process, the simulation hydrograph is shown correlated with measured hydrograph.

Discharge trend of Taebayrongchu using IFAS modeling and manual measurement

Model calibration was used to simulate a discharge of Taebayrongchu of 2016. The model was simulated between rainfall data and discharge data. The Nash coefficient from modeling was 0.599 which simulation shows discharge trend of good correlation. According to Aziz, A. (2014), Nash coefficient above 0.5 is an acceptable error simulated for discharge prediction. The maximum simulated discharge in 2016 was about 13.66m^3/s and minimum were around 2m^3/s sing IFAS model.

The IFAS modeling using rainfall data can be used as an alternative for discharge analysis in the area with limited hydrological data. The simulations for data from Wangdue rapids station is similar to data collected from the study area. Sugiura *et al*. (2008) found high flow in beginning of simulation and overestimate during the peak flow. The discharge prediction showed an acceptable error with the Nash coefficient of *0.598.*

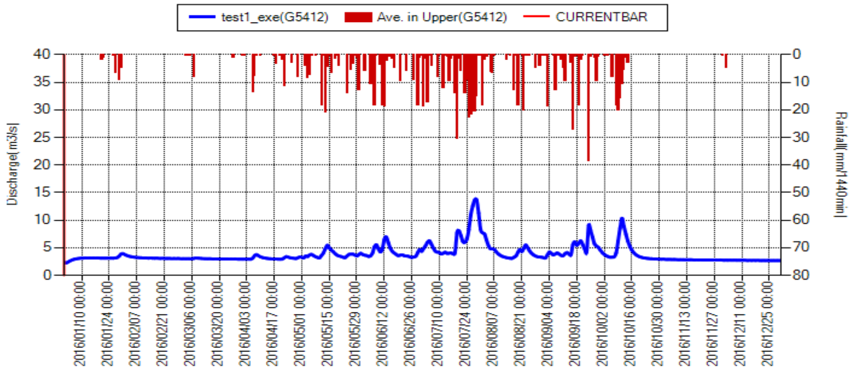

Figure 4: Peak discharge measurement using IFAS modeling

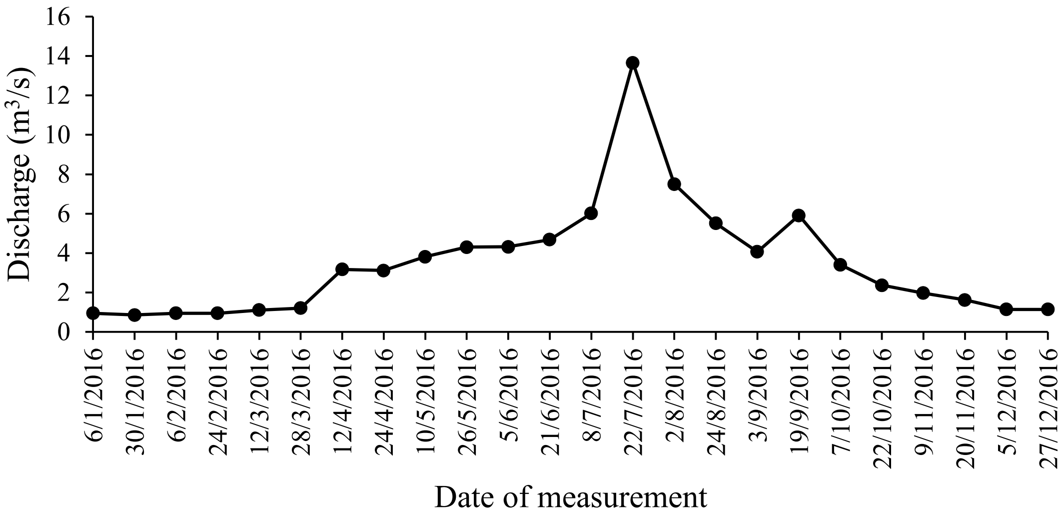

Figure 5. Discharge trend of stream using observed discharged and IFAS

The water discharge was measured using cup-type current meter for six months and remaining six months discharge was calculated using IFAS modeling (Figure 7). It indicates the variation of discharge as high during monsoon and low during lean season. The water discharge was low in February with 0.876m3/s and the highest in July with 13.66m3/s during monsoon season. The large variation in discharge is attributed to rainfall as recorded higher in monsoon than other seasons. The rivers and streams flow of mountainous area are the highest in the month of July and lowest in February (Water and Energy Commission Secretariat, 2011). The discharge measurement in a mountainous stream is 10-20 times higher than lean flow (Merz, 2010).

Water discharge trend of Taebayrongchu during lean flow

The lean flow discharge measurement was recorded by the National Centre for Hydrology and Meteorology from February to March every year. The trend of lean flow was analyzed for 21 years from 1998 to 2018 (figure 6). The minimum averaged discharge was 0.609 and maximum averaged was 1.294. The mean discharge of stream during lean season in the last 21 years was 0.869 with standard deviation of 0.211.

Table 5: Descriptive Statistics of 21 years lean season flow

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Discharge(m^3/s)	21	.609	1.294	.86881	.210681	.044
Valid N (list wise)	21					

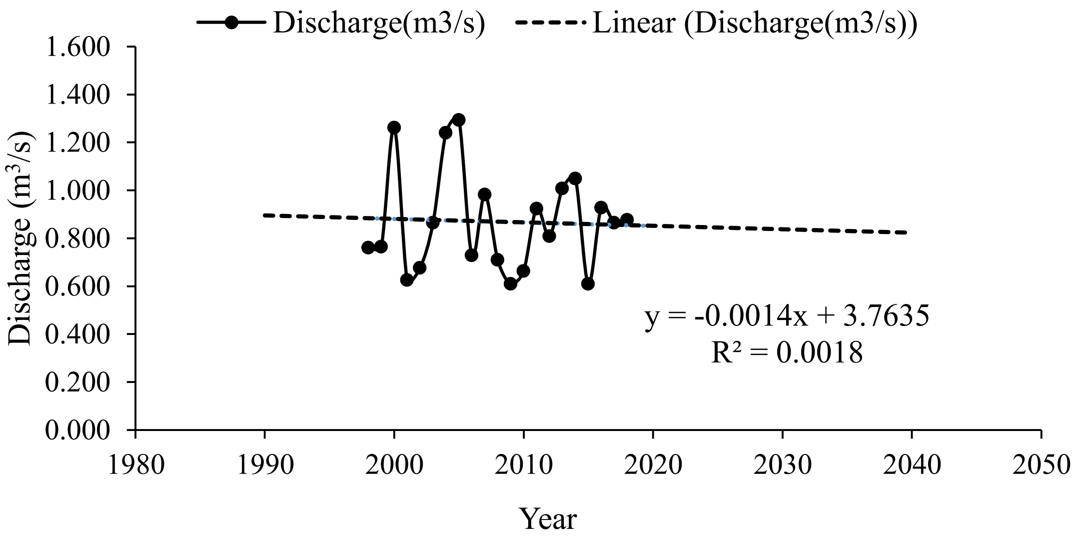

Figure 6: Lean season discharge trend of Taebayrongchu

The trend line showed that the water discharge in a stream is decreasing over the last 20 years (R^2 = 0.0018). The trend line indicated that 21 years from now water in the stream will continuously decrease during lean season. In the year 2040, the average water discharge will reach 0.80m^3/s from 0.89m^3/s in 1998. The factors that led to decrease of water are climate change (Armstrong, 2010; Beldring and Vokso, 2012; Khatiwada, Panthi, Shrestha, & Nepal, 2016), absence of rainfall (Devkota and Gyawali, 2015), forest type, soil characteristics and agriculture practices in the upstream which Taebayronchu stream is subjected to today.

Conclusion

The water discharge measurements of cup-type current meter and propeller-type current meter are similar. These two methods are more accurate than float area method for discharge measurement of streams in mountainous stream. The percentage difference between propeller-type current meter and cup-type current meter was 0.036, which is considered a good accuracy. Whereas, the percentage difference between propeller-type current meter and float area method was 0.779, which is a poor accuracy.

In the seasonal discharge trend of a year for Taebayrongchu, the highest flow was in July with 13.66m^3/s and lowest in February with 0.876m^3/s for the year 2016. The monsoon rainfall contributes to stream flow in the Taebayrongchu watershed. The lean season trend of past 20 years shows continuous decrease water level in the stream (R^2= 0.0018). The predictive linear line also indicated continuous decrease of water in the Taebayrongchu stream.

The limitation in this study are (1) Three discharge measurement methods were only used due to limited instruments for the comparison; (2) The IFAS modeling is used in small watershed in this study, which is less applicable, and (3) Only one site was selected for the discharge measurement in which the channel characteristics will change throughout the year. Study on different discharge measurement methods for accuracy and usage of particular instrument in future is deemed necessary.

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