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Flow Measurement for Ungauged Kakayini and Kodadwen Streams in Support of Local Rice Production in the Ashanti Region of Ghana

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Abstract:- Local farmers especially in the Ashanti Region of Ghana depend on many ungauged streams for rice cultivation in the rainy season but are unable to do so during the dry season due to water shortage. This paper concentrated on some hydraulic and hydrological properties of ungauged Kakayini and Kodadwen streams in the Ahafo Ano South District of the Ashanti Region of Ghana. The float and current meter were used to measure stream discharges based on the area-velocity method. Roughness coefficients for the two streams were determined using the Manning's, Strickler, Limerinos and Jarrett procedures. The Boyer's procedure was used to derive rating curves for the ungauged streams using the measured streamflow and depth data. Discharges, as expected, were in response to rainfall events and there were some time lags between the rainfall events and the resulting discharges. The Kakayini and Kodadwen streams recorded the highest measured discharges of 0.172 m^3s^{-1} and 0.043 m^3s^{-1} respectively for the period the measurements took place. The hydraulic gradients determined using laser range for the Kakayini and Kodadwen streams ranged between 0.0001- 0. 0003. Derived rating curves were $Q = 0.162(H - 0.02)^{0.97}$for Kakayini and $Q = 1.25(H - 0.0137)^{1.36}$ for Kodadwen respectively with r values of 0.938 and 0.957 respectively. Farmers could be supported to use water for farming activities in these localities more sustainably based on seasonal flow variability and how much water is potentially available for downstream use.

***Keywords**:- Ungauged Stream, Roughness Coefficient, Discharge, Earth Canal, Rating Curve.*

I. INTRODUCTION

Ghana is well endowed with both underground and surface water. The quantity of available water from these sources changes by season and from year to year. Factors such as increase in population, high environmental degradation, water pollution and changes in rainfall pattern affects the available water for use. There is uneven water distribution between the northern and southern part of the country. The south-western (rain forest zone) part has better distribution compared to that of the savannah, coastal and northern regions (Water Resources Commission, 2012). The semi-arid part of the country records small amount of rainfall due to climatic conditions and hence must be used profitably (Anschütz *et al.*, 2003). The negative impacts of climate change on water sources have resulted in the demand for effective water management practices.

Paddy fields are essential in the practice of conserving water as well as for rice production. The increase in level of groundwater by paddy fields also goes a long way to limit the occurrence of flood (Wu *et al.*, 2001). Production of rice therefore rest on efficient water use practices thus putting in place appropriate strategies (Abdul-Ganiyu *et al.*, 2015). Areas with low level of rainfall may result in a reduction in groundwater which will not be favourable to the growth of crops. The kind of paddy fields found in Africa is characterized with earth canals which are often prone to water erosion. To minimize the occurrence of water erosion associated with earth canals, basic knowledge on all the elements of the local weather, landform, type of soil and condition ought to be available for applicable measures to be put in place (JIRCAS, 2011). To measure and evaluate earth canal functions, stream flow and discharge, slope (surface water gradients) and roughness coefficient need to be estimated. The estimation of stream flow is mostly indispensable for water management purposes which include prevention of pollution, flood control and water resources planning. According to Opoku-Ankamah & Forson (2009), available data on discharge for evaluating surface water resources in the country are limited.

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In Ghana, rice production at various irrigation schemes is done under the practice of continuous flooding, a system that requires large amounts of water (Ofori *et al*, 2015). However, the country is faced with significant variability in water resources, both spatially and temporally, such as sporadic downpours and droughts, and uneven distribution of annual precipitation. Rainfed agriculture for cultivating main staple crops has yielded adequate food for some years now. However, seasonal food shortage and insecurity is very common (Hope *et al*., 2010). The changes in precipitation and temperature as well as climatic conditions greatly affect surface runoff and discharges of water in all major river basins. A report on water resources and climate change by the Water Research Institute (2000) projects a fall in Ghana's annual river flows by 15-20 % for the year 2020 and 30-40 % for 2050, fall in ground water recharge of 5-22 % for 2020 and 30-40 % for 2050. Also, a rise in irrigation water of 40-150 % for 2020 and river basins will by the year 2020 be vulnerable, thus acute water scarcity in the entire nation. Ghana is to experience substantial amount of precipitation within short periods of time (EPA, 2012). This implies there would be drought caused by longer dry periods which would be preceded by a shorter period of rainfall with profound rise in surface runoff.

Excess streamflow can create hazards if mechanisms are not put in place to ensure resilience. Unpredictable weather, for instance the delayed start of rainfall period or shorter rainy season has driven the majority of Ghanaian farmers, thriving mainly on rain-fed farming, to conform to befitting technologies and water conservation techniques for the supply of water (Djagbletey *et al*., 2012). These coping strategies include but not limited to irrigating crops with water from streams and boreholes, cultivating around streams, construction and use of farm dugouts (Earthen excavation) close to a moving water course which are either filled by the use of a pump or re-directed from the watercourse. Because the risk associated with rice farming taking into consideration situations like drought and flooding, investment made by farmers in agrochemicals is very little (Alcantara *et al*., 1984). Estimation of hydrological parameters of streams therefore becomes necessary for water resources management. However, there are ungauged streams in Ghana, some of which are used by farmers to cultivate crops and particularly rice. Because these streams are ungauged, it is difficult to assess water availability at such sources in order to plan any irrigation activities. Local farmers, especially in the Ashanti region of Ghana, have over the years depended on these seasonal streams for rice cultivation during the rainy season but are unable to grow the crop during the dry season. The design of water storage and supply systems especially for the dry season depends largely on available information on stream discharge, flow and drought periods. This study seeks to measure the daily discharge for ungauged Kakayini and Kodadwen streams to enable future planning of water usage from these streams. Therefore, the main objective of this study is to determine the hydraulic and hydrological parameters of ungauged Kakayini and Kodadwen streams in the Ashanti region. Specifically, the study seeks to the hydraulic gradient and roughness coefficient of the streams and finally to derive the rating curves from depth-discharge measurements for the streams.

A. Study Area Description

The Kakayini and Kodadwen (also known as Dotem stream) streams are both located at Biemso No.1 community in the Ahafo Ano-South District of the Ashanti Region. The Kakayini is between longitudes 1o 51'58.32"W to 1o 50'20.88"W and latitudes 6o 52'59.88"N to 6o 52'33.6"N. The Kodadwen is also located between longitudes 1o 51'8.64"W to 1o 50'37.68"W and latitudes 6o 52'45.12"N to 6o 52'20.6"N. The discharge measurements of Kakayini and Kodadwen streams with catchment area, 205.62 km2 and 137.24 km2 respectively were specifically carried out at latitudes N 06o 52.717' and N 06o 52.045' and longitudes W 001o 51.413' and W 001o 50.226' respectively. The catchment of both streams is as shown in Figure 1.

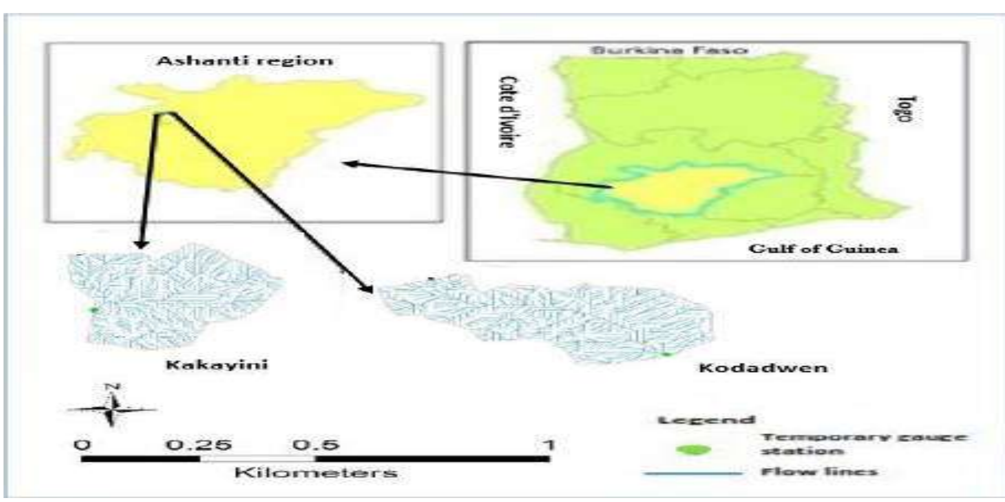

Fig 1:- Watershed of the Study Area

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B. Climate and Hydrology

The climatic condition in the district is wet semi-equatorial. The area experiences two rainfall seasons thus, major (March-June) and the minor (September-November). The mean annual rainfall and temperature range between 1500-1700 mm and 28-30 ºC respectively. The number of rainy days average about 100-120 days a year' with 75% of these occurring during the major season. The relative humidity is high especially in the rainy seasons (90 percent) and early mornings. The harmattan period (dry season) usually starts in December and ends in March with relative humidity ranging between 70-75 percent (GSS, 2014).

C. Vegetation and Geology

The district lies within the semi deciduous forest belt. The typical vegetation is basically determined by rainfall and ground water supplies. The topography is generally undulating; the most prominent feature is the range of hills which stretch from the west to the northeast. The highest elevation is about 763 meters above sea level. The geology of the study area forms part of rock of the Lower Birimian formation specifically, greywackes, phyllites, schists and gneiss whiles the soils fall under the Akumadan–Bekwai/Oda Complex association (Baffour *et al*., 2012).The geology of the district has a positive influence on the drilling of wells and boreholes as compared to other places where drilling becomes difficult because the nature of the land is sandy without rocks.

D. Economy

The economy of the study area is basically agrarian with production of cash crops, food crops and vegetables as their main economic activities. Biemso No. 1 has a total population of 2595 (GSS, 2014). About 76 percent of this working population is estimated to be engaged in the agricultural industry. The district is endowed with arable land. About 80 percent of the land is suitable for crop cultivation with around 60% of the arable land being under cultivation. Maize, rice, cassava, yam, cocoyam and plantain are the main food crops cultivated. The soils and the rainfall regime do support different types of agricultural produce such as citrus, cocoa, oil palm, plantain, cassava, tomatoes, maize and rice. In most of the settlements, sheep, goats and birds are also reared (MoFA, 2017).

II. METHODS

A. Discharge Measurements

Flow can be determined by several methods. Some of these methods provide flow measurement directly while others measure flow velocity which is used to compute for the discharge using particular equations (Michaud & Wierenga, 2005). Some methods are suitable for low flows while others are used for a wide range of flows. The technique selected to measure site discharge is dependent on a variety of factors including type of flow system, expected range of flow rates, configuration of the site, desired accuracy and overall cost. The streams understudies were shallow and as such the float and current meter methods were used for the flow measurements.

A 6 m straight course distance measured and cleared of all weeds. The 3-4-5 transecting method was employed using the tape measure and marked out with wooden pegs to set out the reach. The float and an electromagnetic current meter were used to measure stream discharges based on the area-velocity method. The electromagnetic current meter was used to measure the flow velocity in cm/s. The current meter was set at 0.6d (required for shallow streams), where *d* is the depth of that section. The width was measured and divided into equal intervals for the current meter readings. The velocity displayed digitally on the current meter was then recorded for discharge computation. The discharge was computed using Equation (3).

B. Flow Channel Characteristics Measurement

➢ *Measurement of Flow Area*

The width at each of the three sections were measured and divided at regular intervals for depths to be taken. The depth at regular intervals was measured using tape measure. The width and depth at each of the section were used to compute the cross-sectional area using Mid-section method. The daily stream discharge was then computed using Equation (3).

➢ *Measurement of Water Surface Gradient using Laser Range*

Laser range (LR) is an instrument that measures distance without contact. The LR measures a distance by phase difference between a laser generated by LR and a laser reflected by the object. Two PET bottles were stuck into the stream at a known distance along the flow. Openings (holes) are made to the PET bottles to synchronize the water surface inside and outside the tube. A float (a board of styrene foam) was floated in the tube, so that LR can catch the water surface to measure the height 1 and 2 respectively as shown in Figure 2. The hydraulic gradient was then calculated by dividing the change in height of the water surface by the distance between the two PET-bottles. The roughness coefficient (coefficient to indicate runny) of a canal was calculated through measuring hydraulic gradient using Manning's roughness equation as shown in Equation (10). Stream bed sediments were taken at two different locations of both streams for laboratory determination of the particle size using both the sieve and hydrometer method.

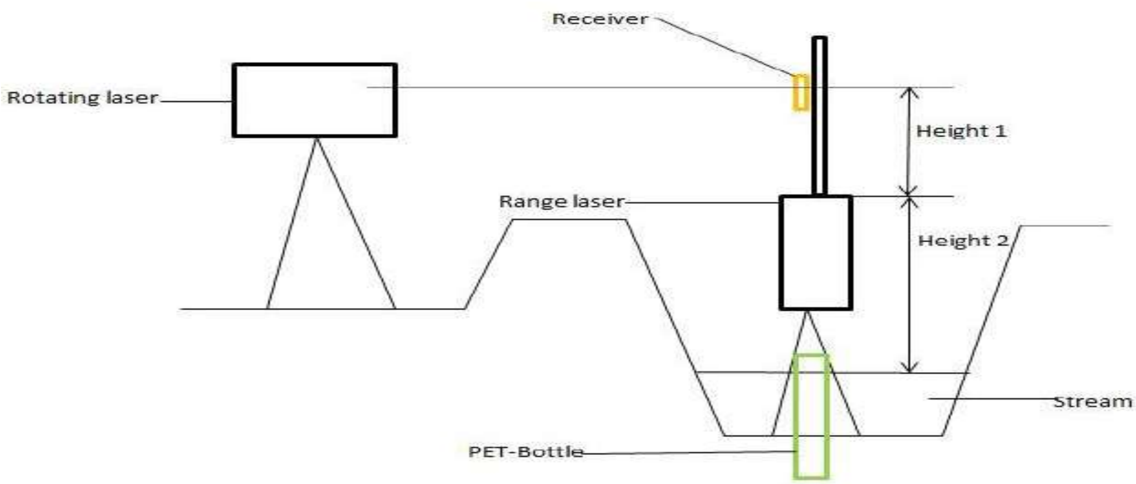

Fig 1:- Laser range setup

➢ *Equations for the Computation of Flow Velocity, Discharge, Canal Roughness Coefficient and Rating Curve Equation for the two Stream*

• *Computation of Flow Velocity and Discharge*

The float method is quite simple to use provided discharge from a particular location runs through an unsealed channel (Michaud & Wierenga, 2005). It demands knowing the travel time of a floating object over 6 m distance along the selected reaches and the cross-sectional area. The float velocity and flow velocity were computed using Equations (1) and (2) respectively

$$\text{Float velocity (Vf)} = \frac{\text{Distance(m)}}{\text{Time(s)}} \quad (1)$$

$$\text{Flow Velocity}\left(\frac{\text{m}}{\text{s}}\right) = \text{Float Velocity} \times \text{Correction factor}(C_r) \quad (2)$$

$$C_r = 0.7136d^{0.0689}; (d \geq 6.1,\ C_r = 0.8)$$

$$\text{Discharge} = \text{Area}\ (\text{m}^2) \times \text{Flow Velocity}\left(\frac{\text{m}}{\text{s}}\right) \quad (3)$$

• *Transforming Depth-Discharge Data into a Standard Rating Curve*

A rating curve is basically the representation of stage-discharge relationship graphically either on logarithmic plotting paper or rectangular-coordinate after a number of concurrent observations of stage and discharge over a period of time covering the range of stages at the river gauging stations. Stage-discharge relation, rating, rating curve and stage rating are normally used interchangeably to mean the same thing. It is recommended for many discharge measurements to be taken to define the rating for a new gauge station (HP Training Module, 1999). A simple orthogonal plotting of the measured depth against its corresponding discharge enables the need for a particular type of rating curve. The initial plot of the depth discharge relationship generated a looped curve called hysteresis indicating unsteady flow unlike single-valued relationship for steady flow. The unsteady flow is related to steady flow by developing a discharge rating expressed in the form known as the Boyer formula (Rantz, 1982) approach as shown in Equations (4).

$$Q_m = Q_r\left(1 + \frac{1}{S_r V_w}\frac{dh}{dt}\right)^{1/2} \quad (4)$$

Where;
Q_m is the measured discharge
Q_r is the rating discharge
$\frac{dh}{dt}$ is the change in depth with time
$\frac{1}{S_r V_w}$ is the slope factor where S_r and V_w represent the energy slope for steady flow and wave velocity respectively.

The water level at which the flow is equal to zero is referred to as the datum correction. Datum correction may vary between different controls as well as different segments of the rating curve. The arithmetic, trial and error and the computer- based optimization procedures are normally employed to assess the datum correction. The measured depth and discharge data are plotted and a curve drawn. Two points (Q_1 and Q_3) are selected from the upper and lower range of the curve and the point Q_2 then computed using Equation (5)

$$Q_2^2 = Q_1 Q_3 \quad (5)$$

Using the h_1, h_2 and h_3 thus the corresponding depths to discharges Q_1, Q_2 and Q_3 that satisfy Equation 5 , the depth (h_o) at which zero flow was recorded is computed using Equation 6

$$h_0 = \frac{h_1 h_3 - h_2^2}{h_1 + h_3 - 2h_2} \quad (6)$$

Using the least square method as shown in Equations (7) and (8), the k and n constants for the depth-discharge rating curves were determined. The r coefficients for both streams were determined using Equation 9.

$$\log k = \frac{\sum Y - n \sum X}{N} \quad (7)$$

$$n = \frac{N\sum(XY) - (\sum X)(\sum Y)}{N(\sum X^2) - (\sum X)^2} \quad (8)$$

$$r = \frac{N(\sum XY) - (\sum X)(\sum Y)}{\left(\sqrt{N(\sum X^2) - (\sum X)^2}\right)\left(\sqrt{N(\sum Y^2) - (\sum Y)^2}\right)} \quad (9)$$

Where,
$\sum X$ is the sum of all values of log Q
$\sum Y$ is the sum of all values of log ($h-h_o$)
N is the total number of measurements

The k and n constants were then used to establish the discharge formula for the derived rating curve in the form as shown in Equation 10.

$$Q = k(h - h_o)^n \quad (10)$$

- *Computation of canal roughness coefficient and uniformity coefficient of stream bed material of the two streams*

The roughness coefficient (coefficient to indicate runny) of the canal was calculated using measured hydraulic gradient of the streams in Manning's and Jarrett (1985) roughness equations as shown in Equations 10 and 11 respectively.

$$Q = AV = \frac{1}{n}A(R)^{2/3}S^{1/2} \quad (10)$$

$$n = 0.39S_f^{0.38}R^{-0.16} \quad (11)$$

where;
A represents flow Area in m^2
V is the flow velocity in m/s
Q is the stream discharge in m^3s^{-1},
R is Hydraulic Radius in m
n is the value of Manning's Roughness Coefficient
S is the Channel Slope

The roughness coefficient using the particle size from stream bed material gradation curve was determined using Limerinos (1970) and Strickler (1923) as shown in Equations 12 and 13 respectively.

$$n = 0.0926R^{\frac{1}{6}}/(1.16 + 2.0\log(\frac{R}{d_{84}}) \quad (12)$$

$$n = 0.039d_{50}^{1/6} \quad (13)$$

Where;

R represents hydraulic radius, d_{84} and d_{50} are particle size (m) of finer particles 84 and 50 percent than d respectively. The uniformity coefficients (C_u) of the stream bed material of both streams were also determined using Equation 14 as shown;

$$C_u = \frac{d_{60}}{d_{10}} \quad (14)$$

C. Data Collection

The research and data collection was conducted over a period of ten months covering the two major seasons in Ghana; the wet and dry seasons. The stream flow data collection began from November, 2015 to October 2016. The stream flow measurement discontinued because the streams were running dry.

D. Statistical Analysis

Correlations of flow velocity and discharge using the float and current meter methods for the two streams were plotted.

III. RESULTS AND DISCUSSION

A. Hydrographs

The hydrographs (Figures 3 and 4) show a depleting discharge with respect to time in the streams. Figures 3 and 4 also show the daily amount of rainfall recorded at the Biemso weather station for the study period. There was longer period of days without or with little (0.2 mm) amount of rainfall which affected the stream flow and eventually farming activities at the locality. The highest daily amount of rainfall recorded was 75 mm. The streamflow for the two streams were generally low recording even zero flows during the dry seasons. The dry season extended beyond the month of March, this according to the Ghana hydrological year usually marks the end of the dry season in Ghana. It took the Kakayini stream a longer period to record zero flow than the Kodadwen stream. The stream discharge was small with varied area of flow. Kodadwen stream dried up completely during the dry season. The Kakayini and Kodadwen streams recorded highest discharges of 0.172 m^3s^{-1} and 0.043 m^3s^{-1} respectively.

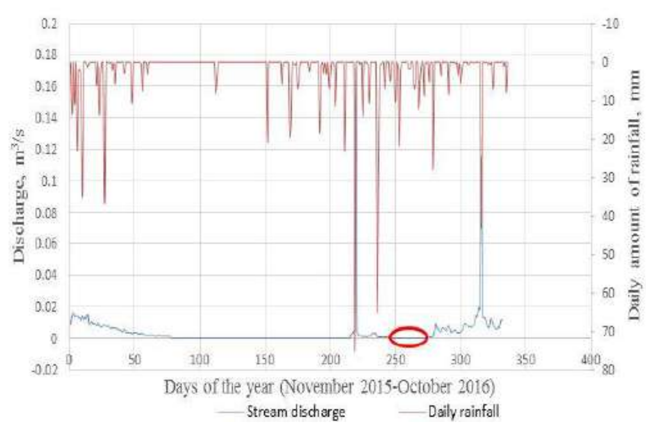

Fig 3:- Discharge (float method) and rainfall distribution with time of Kakayini stream

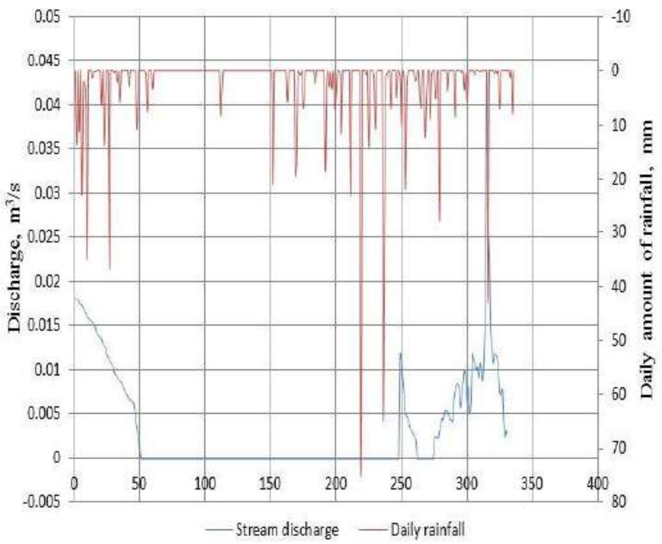

Fig 4:- Discharge (float method) and rainfall distribution with time of Kodadwen stream

These streams are associated with inland valleys where farmers traditionally grow rice by taking advantage of the seasonal waterlogging situations. Some farmers also make use of the residual soil moisture during the dry season when the streams cease to flow in order to grow vegetable crops. An attempt at harvesting the flow in micro-reservoirs as a stop gap for ensuring supplementary irrigation has not shown any satisfactory result. Changes in the rainfall pattern affected the flow of the streams. It can be noticed from Figure 3 that, even though rainfall occurred in July and August, little or no flows were recorded (as marked in a red circle on the diagram). This was an unusual occurrence. This period, the flow was intercepted by cocoa extension officers to create temporary storage on the stream. They did this to collect sufficient water to raise cocoa seedlings for farmers. This meant that until such reservoirs filled up, stream flow could not occur. Stream flow measurements resumed after that period as shown in Figure 3. Some of the rice farmers also planted very close to streams with some of the seeds eventually ending up in the streams. The germinated seeds and the weeds in the streams also increase the roughness of the channels. The dry season was longer than anticipated with little or no rainfall from December to September. It is however clear that even in the dry season; some quantity of water can be tapped from Kakayini stream for farming activities. The Kakayini stream has better flow and discharge in the dry season than the Kodadwen stream. The correlation between the current meter discharge and float method discharge are r^2=0.91 and r^2=0.99 as shown in Figures 5 and 6 for Kakayini and Kodadwen respectively. There is a strong correlation between the current meter discharge and float method discharge of both streams.

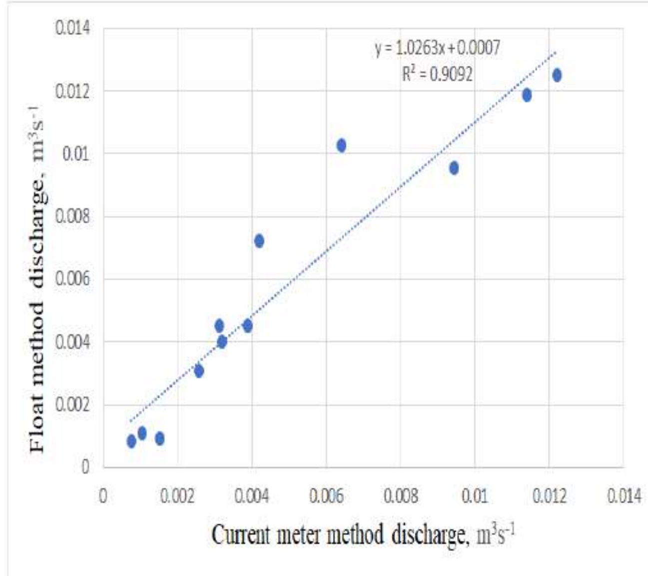

Fig 5:- Float method discharge against current meter discharge-Kakayini stream

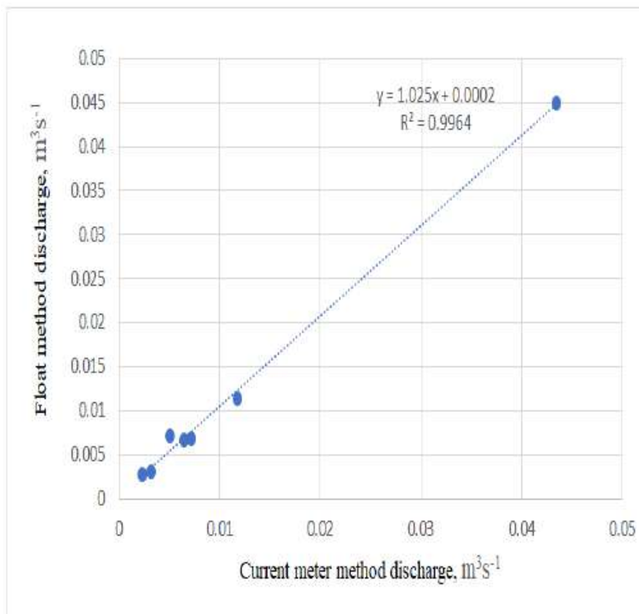

Fig 6:- Float method discharge against current meter discharge-Kodadwen stream

B. Derived Rating Curves from Depth-Discharge Data

Rating curves for the two streams were derived using the procedure described in Equations (4) to (6) and the results presented in Figures 7 and 8. The calculated coefficient of correlation (r) values for both streams were 0.938 for Kakayini and 0.975 for Kodadwen. The coefficient of correlation (r) of the derived rating curves for both streams showed strong relationships.

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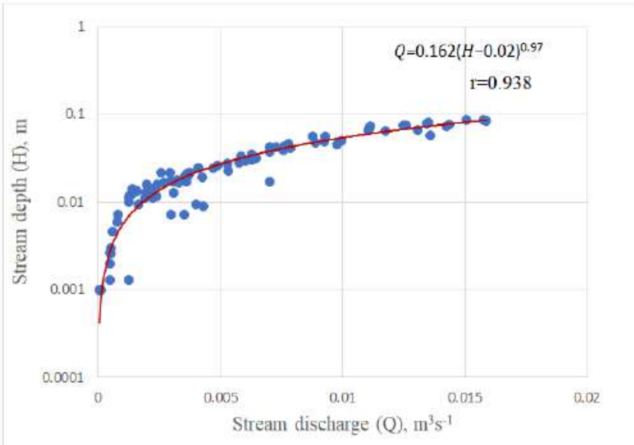

Fig 7:- Depth-discharge rating curve for Kakayini stream

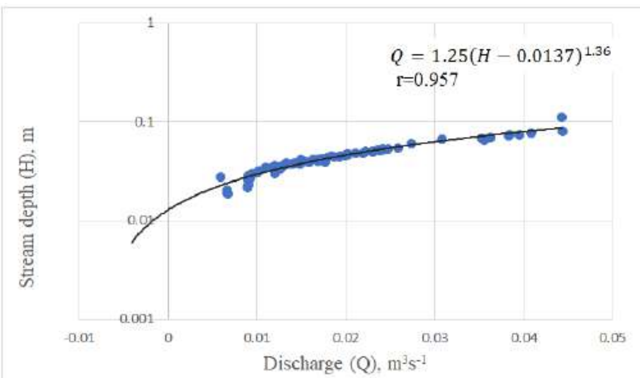

Fig 8:- Depth-discharge rating curve for Kodadwen stream

C. Canal Roughness Coefficient

The roughness coefficient combines many elements that add to the loss of energy in a stream channel. The main consideration is channel-surface roughness, which is determined by the size, shape, and distribution of the grains of material that line the bed and sides of the channel (the wetted perimeter) as cited in (Coon, 1998). The results of the hydraulic gradients and wetted perimeter measurement are as presented in Table .1

Date	Kakayini stream Wetted perimeter (m)	Kakayini stream Stream gradient x 10^{-4}	Kodadwen stream Wetted perimeter(m)	Kodadwen stream Stream gradient x 10^{-4}
22/07/16	0.41	1.2	0.44	3.4
29/07/16	0.29	1.6	0.42	3.2
23/09/16	0.51	1.8	0.49	3.3
30/09/16	0.58	1.17	0.56	2.8
14/10/16	0.91	3.0	0.53	3.0
21/10/16	0.57	2.14	0.55	2.0
29/10/16	0.61	1.12	0.46	2.1

Table 1:- Slope of both Streams with Time

The stream bed gradation curves of the two streams are as shown in Figure 9. The bed material of the two streams constitutes largely fine sand which according to Limerinos (1970) has lesser retarding effect as they are suspended during high flows. The uniformity coefficient for Kakayini and Kodadwen stream bed soils determined were 13 and 20 respectively. The values obtained for uniformity coefficients for the stream bed soils are greater than 5 which indicate a well-graded soil (Davison &Springman, 2000). The Kodadwen stream was mainly of finer particles (clayey and silty) while Kakayini stream bed material constituted of medium sand particles. The two sites for the study were all free of larger particle materials like gravels, cobblers, pebbles etc.

For all the empirical formulas used in this study for estimating canal roughness, increasing particle size of channel bed material increases roughness.

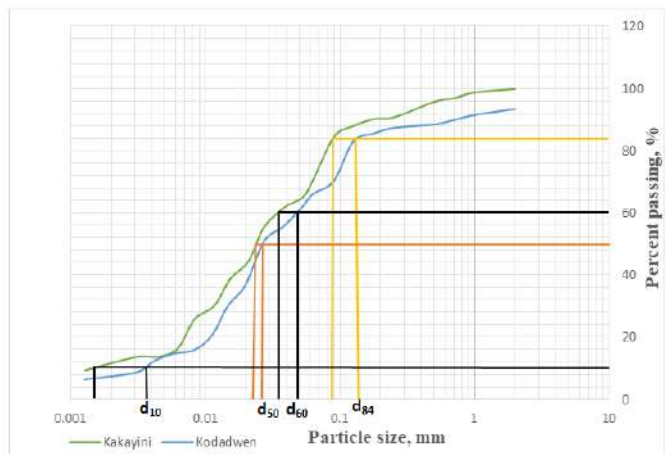

Fig 9:- Stream bed material gradation curve

The estimated values of roughness coefficient (Table 2) are within the range (0.025-0.06 $m^{-1/3}$ s) of n values for minor streams as cited in Boiten (2003). Roughness coefficients estimated using the Manning's equation and other procedures that required the determination of effective mean sizes of channel material had differences in values. For natural channels, flow characteristics are dynamic and therefore reflected by the roughness coefficient values. The Strickler formula is for streams with larger particles. The results of this study show that, the Limerinos Equation is also a better predictor of flow resistance over the range of flow conditions encountered in this study thus stream slope less than 0.002 with insignificant bed vegetation (Coon, 1998). The values obtained from the use of Jarrett's equation compared to that of Manning and Limerinos' were low. The range of the hydraulic gradients determined (0.0001- 0.0003) for both streams were not within the range of slope values (0.012 – 0.04) tested for using Jarrett's equation as given in Equation 3.5 for determination of roughness coefficient (Marcus *et al*, 1992).

Stream	Manning's	Limerinos, 1970	Strickler, 1923	Jarrett, 1984
	0.067	0.08	0.022	0.019
	0.068	0.09		0.021
	0.052	0.06		0.021
Kakayini	0.031	0.05		0.017
	0.029	0.04		0.021
	0.026	0.05		0.021
	0.026	0.05		0.017
	0.042	0.048	0.021	0.027
	0.062	0.051		0.027
	0.045	0.043		0.025
Kodadwen	0.052	0.044		0.024
	0.019	0.036		0.023
	0.032	0.041		0.021
	0.097	0.041		0.021

Table 2:- Roughness Coefficients

IV. CONCLUSION

The study revealed that, both streams recorded declining discharges as rainfall reduced and even zero flow during the dry season. Discharges, as expected, were in response to rainfall events and there were some time lags between the rainfall events and the resulting discharges. The discharge data of these two streams as determined in the study could be used in support of farmers to use water for farming activities in these localities based on seasonal flow variability and how much water is potentially available for downstream use; micro-reservoirs should be constructed for water storage for dry season farming especially for rice. Further studies on the hydrology of these ungauged streams should focus on groundwater flow measurements.

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