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Low-cost Remote Rain and Stream Data Acquisition System for Mapping of Potential Micro-Hydro Sites

R. C. Pallugna[1], A. B. Cultura[1], C. M. Gozon[1], N. R. Estoperez[2]
[1]Mindanao University of Science and Technology
[2]Mindanao State University - Iligan Institute of Technology
Email: reuelpallugna@yahoo.com, acultura2003@yahoo.com, xozip_neutron@yahoo.com,
noel.estoperez@g.msuiit.edu.ph

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ABSTRACT

The stream and rain data acquisition system presented in this paper makes the mapping of hydro potentials in the region or of the country economically and practically possible. Moreover, it can also serve as a flood warning system.

Keywords: Stream Data Acquisition; Micro-hydro; Flood Warning System

1. Introduction

Stream flow and rain water information are essential to the design and operation of micro-hydro power plants. These are site specific data gathered for a considerable period of time [1]. According to [2], the Philippines is one of the countries with an abundant and widely spread micro hydro sites. **Figure 1** shows the map of the micro-hydro potential of the country and **Figure 2** shows the map of the potential of micro-hydro in Mindanao.

These sites are potential sources of clean electric energy like micro-hydro for rural and domestic electrification. However, most of these sites are not locally assessed and utilized [2]. Part of the problem is the high cost of gauging instruments, most of which are imported. This paper proposes the use of locally developed, low-cost Remote Rain and Stream Data Acquisition System (RRSDAS) to assess these resources. It is a microcontroller based system that employs the use of the tipping bucket rain gauge and the orifice stream gauging method for its data acquisition and a GSM module for its communications. Laboratory and field test can be used to validate the accuracy and reliability of such system. A block diagram of the system developed is shown in **Figure 3**.

2. The Rain and Stream Gauging

2.1. Common Types of Rain Gauges

There are two main types of rain gauges: the non-recording and the recording rain gauges [3]. The most common of the non-recording type is the Standard rain gauge (SRG) used for more than a century by the United States National Water service [4]. The recording type includes the Optical Rain Gauge which measures rain rate on the principle that it is proportional to the disturbance of done by raindrops on an optical beam. This type of rain gauge is expensive and used mainly for research purposes. Another type is the disdrometer. It can measure the size, velocity, and distribution of rain drops and other hydrometeors. This is a research oriented device and uses optical or acoustic technologies. One of the most common and relatively inexpensive recording types of rain gauges is the tipping bucket rain gauge. Like the

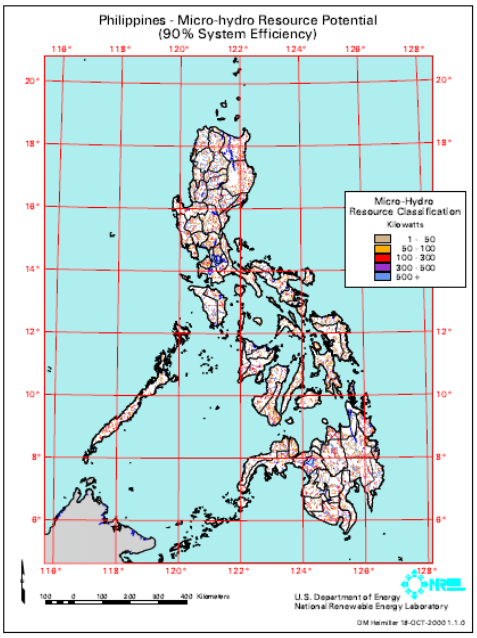

Figure 1. Micro-hydro potential in the Philippines.

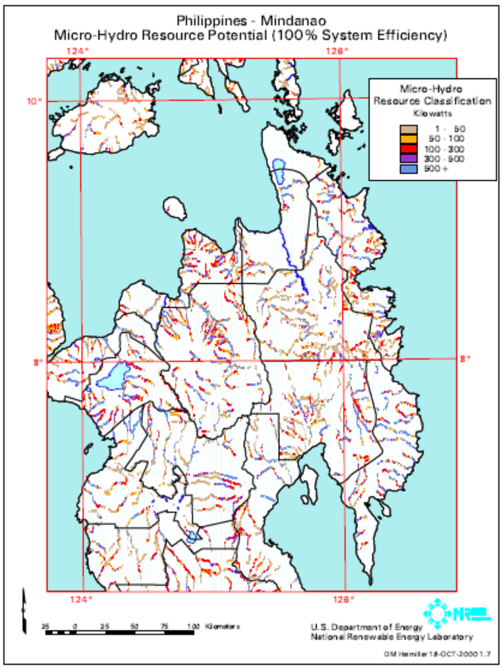

Figure 2. Micro-hydro potential in Mindanao.

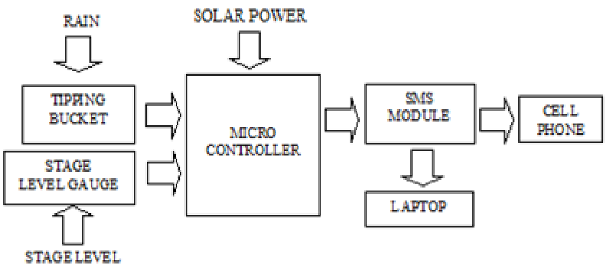

Figure 3. Block diagram of the rain and stream DAS.

SRG, tipping bucket rain gauge has an established history. Its mechanism is simple. It collects rain through a funnel into a see-saw like mechanism that tips whenever a fixed amount of rain volume is collected on one side. Every time a tip is made, a reed switch is activated and its signal is recorded as signifying a certain amount of rainfall. Usually each bucket hold 0.01 inch of rain. Thus the number of tips multiplied by the volume per bucket is the total amount of rainfall on a certain period of time. **Figure 4** shows the mechanism of a tipping bucket [5] and **Figure 5** a picture of a typical tipping bucket rain gauge [6].

2.2. Stream Gauging Methods Used in Assessing Micro-hydro Sites

Literatures on development of micro-hydro resources usually introduce fairly accurate but inexpensive stream gauging methods [7-9]. Commonly used methods include the weir method, the float method, the bucket method, the velocity-area method, and the staff gauge method. However these methods do not have data logging capacities and thus, have to be performed repeatedly on the site.

2.3. Microcontroller Technologies

One of the most important developments in computer and electronics industries is the microcontroller. Microcontrollers are very small computers, containing a processor, memory and input/output peripheral, which are mounted inside a single integrated circuit [10]. For application specific conditions, micro controllers have the advantages of being inexpensive, commonly available, and easily programmable [11]. For small Data acquisition systems, microcontrollers are ideally suitable. Even in developing countries, like the Philippines, microcontrollers are readily available. Reference [12] lists the commonly available microcontrollers in the country.

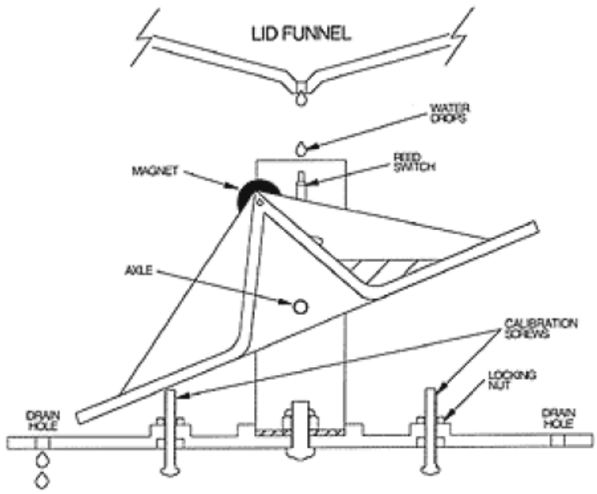

Figure 4. Tipping bucket rain gauge mechanism.

Figure 5. Typical tipping bucket rain gauge.

2.4. The Gizduino Microcontroller

The Gizduino microcontrollers are clones of the Arduino microcontrollers developed by a local company called eGizmo [12]. These are microcontrollers originally built for artists and designers but found much use by electronics and robotic hobbyists. Today, even engineers use them to develop small scale industrial applications. These devices have the advantage of a cheap and available hardware and open-source software. Moreover, they are easily programmable and have a lot of available libraries and support groups. Compared to other microcontrollers they have very short programming time.

2.5. The Communication Devices

Aside from microcontrollers, another very important development in communication technologies is the GSM modules. They employ cellular phone technologies which are very ideal for remote DAS. As compared to other communication devices, they are relatively cheap, easily configurable to most microcontrollers, and readily available. Reference [13] lists the commonly available GSM modules. The Telit GE 846 QUAD was used in this study.

2.6. Microcontroller Based DAS

Microcontroller based DAS are commonly used in renewable energy systems. Juca [14] summarizes a number of these systems and its applications. However, most of the applications involved photovoltaic, biomass, and other applications but not so much on micro-hydro data acquisition systems. Micro-hydro DAS are exposed to a more harsh environment.

3. The Development of the Rain and Stream DAS

The proposed system suggested the use of tipping bucket rain gauge, the application of the orifice method of stream flow, the Gizduino microcontroller for data logging, and the GSM module for communications link.

3.1. The Tipping Bucket Rain Gauge

This study uses the Tipping Bucket Rain gauge because they are easily developed: the materials are locally available and easily assembled, and easily interfaced to electronics. The entire gauge is housed in a plastic container with a frustum dimension: 12 inches diameter on top, 10 inches diameter at the bottom, and 14 inches high. The funnel, which is 10 inches in diameter, is made from a cut top portion of a 16 litters mineral water container connected to a plastic 4 inch diameter funnel (commercially available). Rain water is collected in the funnel and dropped to the tipping buckets. The buckets are made of one piece rectangular aluminum pipe mounted on a galvanized "L" supports and pivoted on a cabinet knob in two 3 mm bolt as axles. The bucket empties its 2 by 15 milliliters tip on each side into 1.5 inch PVC pipes that serves to contain the splashing of rain water. Each time a tip is made, a reed switch [15] mounted below the buckets detects it, that is, sense the number of tips of the buckets and micro-controller acts as counter and recorder. Furthermore, the information gathered are totaled and sent through a cellular phone based communication system interfaced to it to the researcher's cellular phone and computer. Such a system could be battery operated or solar powered. This system, which is based on low-cost and locally available electronics, can make the mapping of micro-hydro resources affordable and practical even in rural areas. Detailed pictures of the system are shown in appendix 1.

3.2. The Open Pipe Flow Measurement Method for Partially Filled Pipe

This study made use of Manning's equation (1) of discharge for partially filled open pipe given by Bengston [16]. **Figure 6** and **Figure 7** illustrates the open pipe flow measurement method. Due to its simple principle, this method can also be used in stream gauging of micro hydro sites, especially for long term site assessment. **Figure 6** illustrates the set up for the open pipe stream flow measurement method.

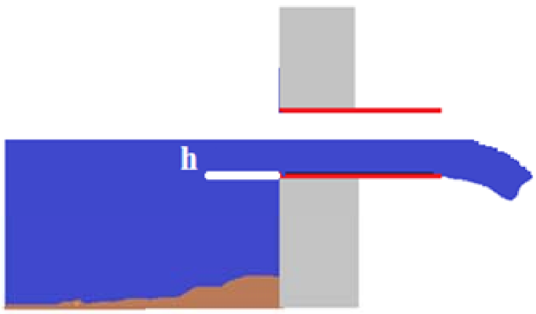

Figure 6. An illustration of the Open Pipe stream flow Measurement method.

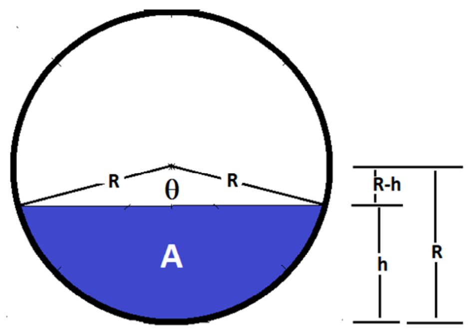

Figure 7. For h less than R, (h<R).

The discharge can be given by (1) through [16].

$$Q = \left(\frac{1.0}{n}\right) A\left(R_h^{2/3}\right) s^{1/2} \quad (1)$$

where:

Q = the discharge, m^3/s

n = 0.009 = Manning roughness Coefficient (Plastic)

R_h = A/P = Hydraulic radius, m

A = cross-sectional area of water in pipe, m^2, which varies with h; most of the time the pipe is not full.

P = Rθ wetted perimeter, m

S = slope of the channel, m/m

Figure 7 and **Figure 8** illustrates that the value of A is dependent upon h, which may vary from less than r to greater than r. Equation (2) gives the value for calculating A. If h is less than r the sign of the radical term is negative and positive for h greater than r. This means that if the pipe is more than half filled then the amount of water above its radius is added [17].

$$A_{water} = 0.5R^2\theta\left(\frac{\pi}{180}\right) \mp \sqrt{(R-h)^2(2Rh-h^2)} \quad (2)$$

where: R = 2.5 inches = 0.0635 m

The value of h can be determined using an infra-red sensor mounted on a stilling well. This is shown in **Figure 9**. A sharp GP2YOAO2 [18] distance sensor was used in this study, which can sense distance variation from 5-120 centimeters from its eyes, with an accuracy of 5 millimeter and a signal of 0 to 2.5 volts. These signals are then fed to the microcontroller which converts it directly into Q using (1). Every 6 hours, the microcontroller activates the IR sensor and records h an averages and logs every 4 values of h. In this way a daily value of Q is acquired.

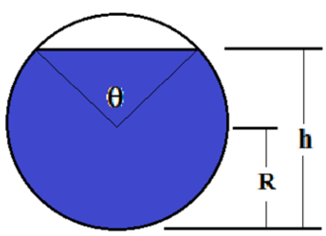

Figure 8. For greater than R, (h>R).

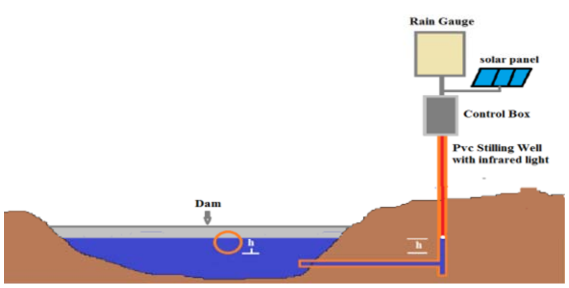

Figure 9. The proposed orifice method of stream DAS.

With the rainfall and stream data a rainfall-runoff relations can be established. Rainfall and discharge data are essential to the design and operation of micro-hydro power plants. The discharge data monitored over a period of time can be used to form the flow duration curve which will serve the basis for sizing, design, and operation of micro hydro sites. **Figure 10** shows a typical flow duration curve [19].

Figure 11 shows the Rain and Stream DAS developed. It is installed for field testing beside a natural regulation pond to monitor its rain fall and water level. The white object on top is the rain gauge. Below it is a solar panel to supply its power. Below the solar panel is the control box that housed the microcontroller, battery, solar charger and other components. The orange PVC pipe serves as a stilling well. The entire system adopts the Plug-and-play concept. This means that the entire system can be mounted easily and quickly.

3.3. Extension of the System Developed to Other Methods of Stream Gauging

The proposed stream gauging method and system can also be applied to other methods of stream gauging. It can be applied both to the weir and to the stage level method. In the weir method, if h is known, the Q can be determined. In the stage-level method, once the stream

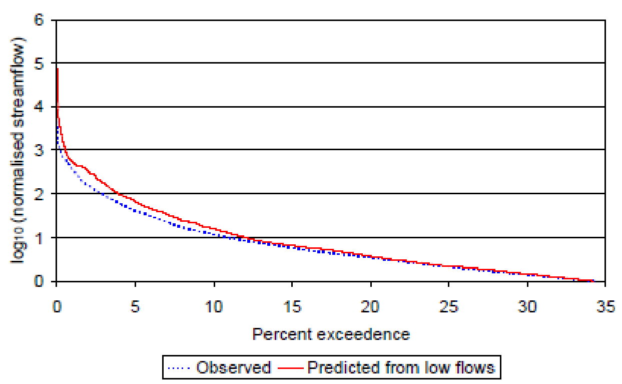

Figure 10. A typical flow duration curve.

Figure 11. Picture of the RRSDAS under field test.

rating is known and the stage-discharge relation is established then the discharge can be determined for every value of stage.

4. Results and Discussion

The proposed DAS was tested both in a laboratory set up and in on of the micro-hydro sites in the region. The results are shown in the next sections,

The Rain field test gauge results. **Table 1** shows the result of the rain gauge data logging.

The values of the loggings are further processed to obtain a graphical relation. This is shown in **Figure 12**. Equations (3) and (4) were used to calculate the rainfall [20].

$$R_{mm} = \frac{N\,x V_{ml}\,x 1000\,\frac{mm^3}{ml}}{A_{mm}} \tag{3}$$

$$A_{mm} = \pi \frac{d^2}{4} \tag{4}$$

where:

R_{mm} = the amount of daily rain fall inmillimeters

N = number of tips per day

V_{ml} = volume of rain per tip (ml)

1000 mm^3 /ml = conversion factor

A_{mm} = area of funnel (mm^2)

d = diameter of funnel (254 mm)

It can be seen from **Figure 12** that the month of February was a rainy month. Reaching up to the maximum of 9 millimeters of rain.

Table 1. Rain gauge data logging.

LOGGER01
STREAM FLOW, STREAM LEVEL, AND RAIN GUAGE
DATA ACQUISITION SYSTEM

Date & Time Started
2/21/2012 15:39:50

Date	Time	Water Level	No.of Tips	millimeter Water/day
2/21/2012	18:0:0	72.69	0	0.00
2/22/2012	0:0:0	107.89	3	0.95
2/22/2012	6:0:0	156.53	4	1.26
2/22/2012	12:0:0	103.79	4	1.26
2/22/2012	18:0:0	72.99	4	1.26
2/23/2012	0:0:0	83.18	4	1.26
2/23/2012	6:0:0	106.95	4	1.26
2/23/2012	12:0:0	577.98	4	1.26
2/23/2012	18:0:0	99.76	4	1.26
2/24/2012	0:0:0	179.27	4	1.26
2/24/2012	6:0:0	273.15	4	1.26
2/24/2012	12:0:0	133.92	4	1.26
2/24/2012	18:0:0	147.52	6	1.89
2/25/2012	0:0:0	215.51	7	2.21
2/25/2012	6:0:0	241.13	7	2.21
2/25/2012	12:0:0	193.46	7	2.21
2/25/2012	18:0:0	171.61	7	2.21
2/26/2012	0:0:0	274.24	7	2.21
2/26/2012	6:0:0	218.61	7	2.21
2/26/2012	12:0:0	181.63	7	2.21
2/26/2012	18:0:0	144.27	7	2.21
2/27/2012	0:0:0	259.71	10	3.16
2/27/2012	6:0:0	244.83	10	3.16
2/27/2012	12:0:0	130.92	10	3.16
2/27/2012	18:0:0	184.39	14	4.42
2/28/2012	0:0:0	320.68	14	4.42
2/28/2012	6:0:0	231.32	14	4.42
2/28/2012	12:0:0	101.05	15	4.74
2/28/2012	18:0:0	149.77	21	6.63
2/29/2012	0:0:0	278.69	29	9.16
2/29/2012	6:0:0	258.83	29	9.16
2/29/2012	12:0:0	99.15	29	9.16
2/29/2012	18:0:0	118.77	29	9.16

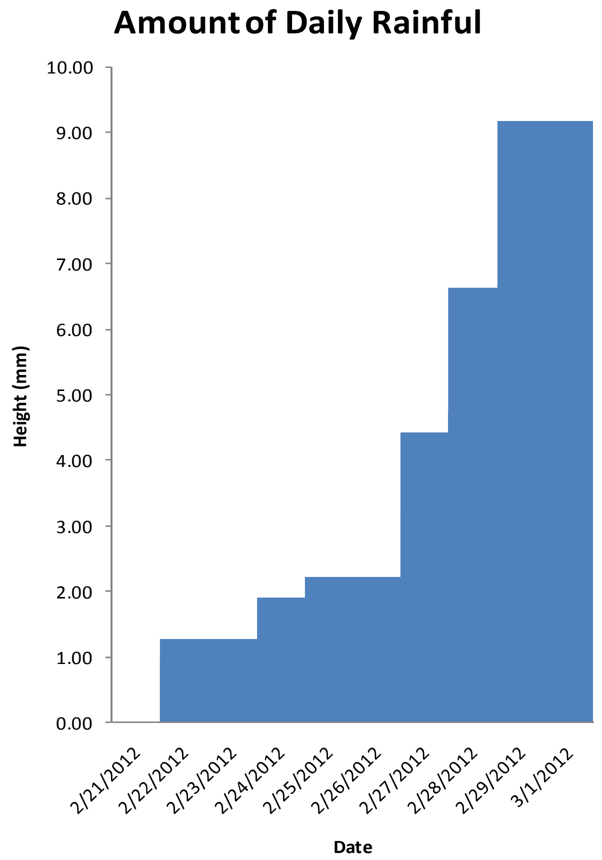

Figure 12. Graphical display of rainfall loggings.

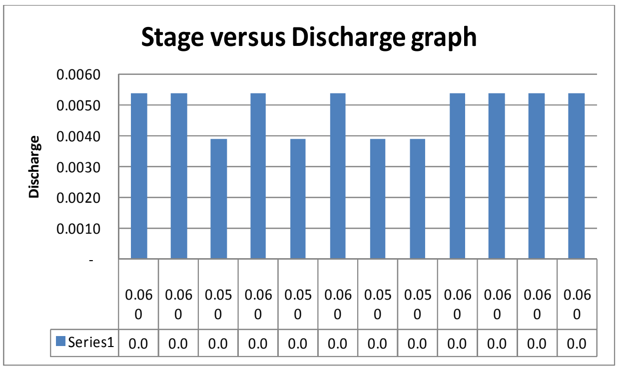

Figure 13. Stage versus discharge curve using the Open pipe Flow method.

4.1. The Result of the Stream Gauge Tests

The stream gauge was tested in comparison with a velocity-area method using a standard PRICE TYPE AA (Nakaasa model 8154) current meter and the bucket method. The results are recorded and illustrated in the graphical result in **Figures 13**, **14**, and **15**.

Results indicated the validity and accuracy of the orifice method and system. The average discharge of the three methods is consistent within three decimal values of 0.004 cubic meters per second.

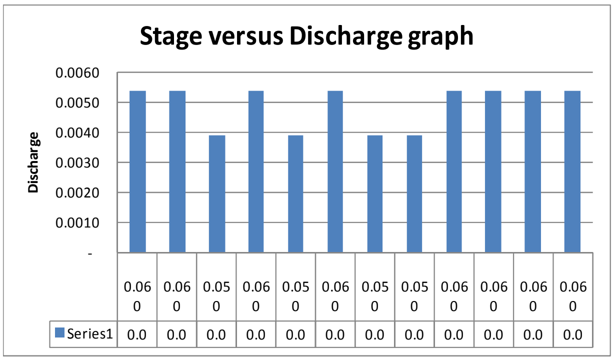

Figure 13. Stage versus discharge curve using the Open pipe Flow method.

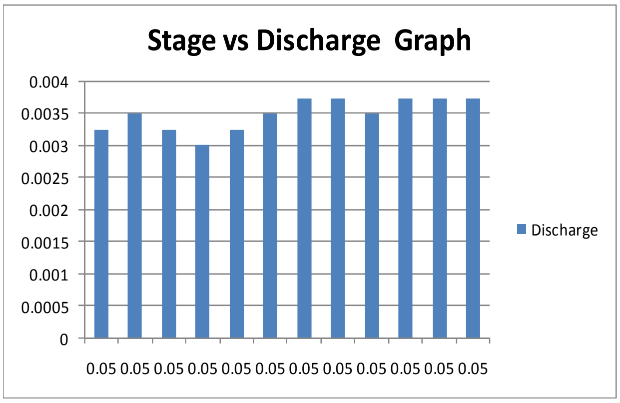

Figure 14. Stage vs discharge graph using the Velocity- Area method using Current Meter.

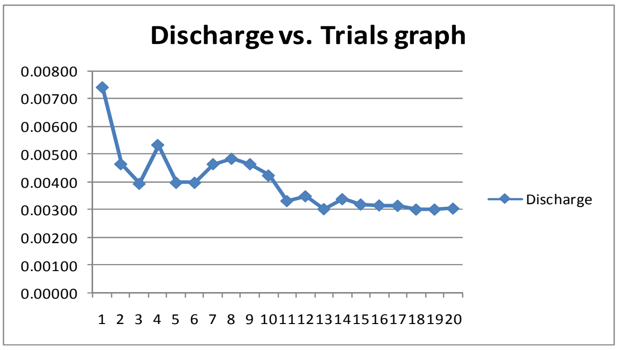

Figure 15. Discharge versus Trials graph using the Bucket Method.

4.2. The Result of the Stream Gauge Tests

The stream gauge was tested in comparison with a velocity-area method using a standard PRICE TYPE AA (Nakaasa model 8154) current meter and the bucket method. The results are recorded and represented in the graphical result in **Figures 13**, **14**, and **15**.

Results indicated the validity and accuracy of the orifice method and system. The average discharge of the three methods is consistent within three decimal values of 0.004 cubic meters per second.

4.3. The Computer Interface

A computer interface can be used to generate a graphical display of the results using Microsoft excel. This is a very convenient way of gathering and analyzing Rain and stream Data for assessing of micro-hydro sites and developing micro-hydro power plants.

5. Conclusions

Results indicated validity of the low-cost remote rain and stream data acquisition system developed. Moreover, the validity of the orifice method of stream flow was verified. The ability of the DAS to measure the stage of the stream could also be used as a flood warning system, turning on alarms whenever a certain amount of rainfall or stage level is exceeded.

6. Recommendations

The remote rain and data acquisition can also be applied to the weir and staff gauge method of stream gauging.

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