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Olotu Yahaya, Alimi L.O, Rodiya A.A., Omotayo F.S.

Design and Development of Electro-Mechanical Twins Tipping Buckets Runoff-Meter

Electro-mechanical tipping bucket runoff-meter was designed and developed to measure surface runoff water using locally-sourced components. The instrument consists of metallic-fabricated runoff plot area of 2 m^2, depth 0.25 m and metal gauge of 3mm. The tipping operation was initiated by arranging the sensitive electro-mechanical components such digital micro-switch (SW_1,SW_2, SW_3 and SW_4), pair of open/close circuit breakers (N_o,N_c), electronic speed gear and circular rotating disc to a pair of twins buckets of runoff volume 0.141 liter capacity per bucket which corresponds to 0.25 mm runoff depth. The whole arrangement was powered by a 12V by 75 AH battery and the tipping processes was being recorded by the electro-mechanical data logger. The instrument has a measuring accuracy of ±0.001 liter per tip. It was calibrated to measure minimum and maximum runoff volume from 0.14l to 200 liters, these values correspond to 0.25 mm and 800 mm runoff depths respectively. Therefore, precise results obtained using the instrument could be used to establish strong database for measuring and storing accurate surface runoff data which in turn could be applied for hydrological modeling for sustainable water resources management and design of hydraulic structures.

***Keywords**: runoff, water, Micro-switch, Tipping bucket, Data logger, accuracy*

1. Introduction

Soil erosion, downstream flooding and siltation pose a major challenge to watershed managers, particularly in the humid tropics with their high rates of deforestation and intense rainfall. Knowledge of the volume and rates of runoff generated in response to rainfall is very important, if not quintessential, to predicting soil losses. Although runoff may be generated in a number of ways

(Ward, 2004; Brammer and McDonnell, 2006), 'Hortonian' infiltration-excess overland flow may well be the dominant mechanism on bare, degraded soils (Kirkby, 1999; Hudson, 1995). These studies require the flow volumes and/or flow rates to be measured, where sediment- laden runoff normally occurs. The unique hydrologic characteristics from runoff plots, such as lower hydraulic head and lower discharge rate, causes difficulties for using the traditional technologies and methods developed for channels and/or streams and/or rivers. That run-off water and soil erosion have become problems of local and national importance that is widely recognized. To study qualitatively the amount of run-off and erosion from different typographical areas and types of soil under various climates as well as the quantities of soil lost under different methods of cropping, terracing, etc.

Rainfall intensity and raindrop energy impact on soil assist in the erodibility of the soil (Armsfstrong, 2005). The problem is further compounded because of the failure to accurately measure surface runoff and sediment loss using direct or conventional system of runoff measurement. Without accurate and precise data on runoff and sediment loss, land management decisions cannot be effectively reached (Okoli, 2000). Farmlands will still continue to be cultivated by farmers without knowing the extent of damage caused annually by surface runoff and erosion (Bhaduri *et al.*, 2001). Therefore, the research study is focused on the design and development of electro-mechanical tipping bucket runoff-meter which is expected to provide accurate and realistic data over the manual runoff-meter.

2.1. Materials and methods

The electro-mechanical tipping machine was designed to tip 0.14 litre of water per each operation and the rate of tipping depends on the rainfall-runoff intensity. Design calculations of some of the component parts of the equipment are shown below:

Dimension of steel bounded soil tray

= (900mm x 1200mm x 260mm)

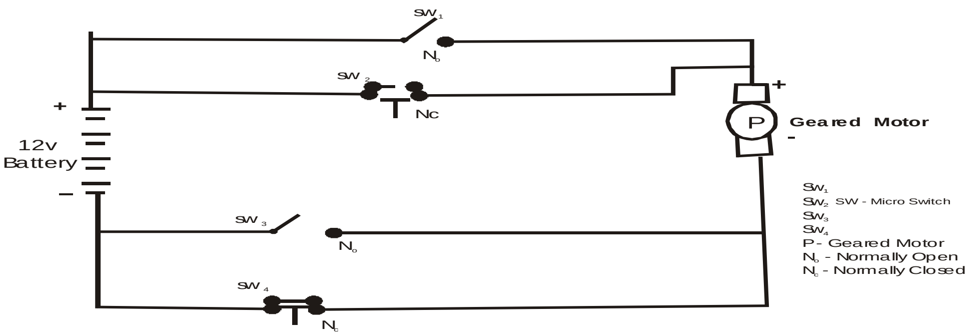
Soil tray:

(i) Measure a test area of 900mm by 1200mm
= $1.08m^2$
Measure a test of volume of soil tray.
= $0.28m^3$

(ii) **Tipping bucket**:
Area of tipping bucket.
= $0.007m^2$
Volume of the tipping bucket.
= $0.001m^3$

2.1.1. Description of an electro-mechanical tipping bucket runoff-meter

The developed instrument consists to soil tray, pair of tipping bucket, diverting funnel, water level sensors, sensitive micro-switch, geared electric motor, electronic timer, storage tank of 200 litres capacity which serves to store tipped runoff water for further laboratory assessment and analysis. Tipping bucket receives the runoff water from the soil tray and tips it to the storage tank through the cylindrical collector. Diverting funnel functions to guide the runoff water into the buckets repeatedly with little or no loss of runoff water. Connecting pipe conveys the runoff water from the soil tray to the collecting chamber and the runoff water flows from the collecting chamber to the diverting funnel and down to the buckets. Water level sensor was strategically positioned in each of the tipping buckets and it functions to sense the level of runoff water in the bucket. The sensitive micro-switch receives signal from the water sensor in response to the volume of runoff water in the tipping bucket and relay it to the control circuit of the instrument. Electronic timer and electromechanical counter are connected to the tipping buckets and they function to record the time to complete each tipping operation and total number of tipping operation respectively. The instrument is powered with 60AH, 12V battery.



Tipping bucket operational diagram
Fig iv

Figure 1. Tipping bucket operational circuit system diagram

2.1.2. Mechanism of operation

The instrument works on principle of tipping mechanism. Full view of mechanical steel fabricated component of the instrument is shown in fig1. Fig.3 shows the instrument when it has been assembled and position for operation. Rainfall is simulated on the prepared impervious materials in the soil tray and runoff water flows through the connecting pipe down to the collecting chamber and to the tipping bucket through the diverting funnel and finally to the storage tank. As runoff water flows into the bucket, which is positioned at 45^0 to the diverting funnel, the water level sensor positioned inside the bucket starts to be displaced. The displacement of the water level sensor increases with increase in the volume of runoff water inside the tipping bucket, gradual displacement is signaled to the sensitive micro-switch through the connected knob as reported in Olotu (2006). Once the tipping bucket has collected a certain volume of runoff water, the displacement of water level sensor stops and the signal is relayed to the connected micro-switch (SW_1, or SW_3) depending on the position of the tipping bucket. The signal is finally sent to the control circuit, which is sensed as preset in the variable resistor. If the instrument is connected to the main power source of 60AH, 12v battery, current flows through the power source to the circuit, the transistor will energize the relays to trigger on the geared electric motor that controls the tipping buckets. The electric motor rotation turns the motion converter and the motion is transferred to the mechanical arm of the buckets, with this process tipping is initiated and the runoff water is tipped into the cylindrical collector and finally to the storage tank. The process continues till the edge of the tipping bucket in operation touches a sensitive micro-switch positioned on the trapezoidal shaped panel (SW_2, or SW_4). The process is triggered off, water level sensor returns to its initial position inside the bucket. Immediately the first bucket tips, the second tipping bucket automatically positions itself in position of the tipped one. Tips are recorded with electro-mechanical countering device and time of each tip is recorded to the nearest second with the electronic timer, Fig. 2 shows the tipping bucket operational circuit diagram illustrating the tipping mechanism of the buckets.

Full view of the instrument during Experimentation

Figure 2. Full view of the assembled instrument during testing and experimentation.

3. Results and discussion

Rainfall depth of varying was simulated on impervious surface and generated surface runoff was measured using electro-mechanical tipping and conventional runoff-meters respectively. The result is shown in Table1. The tipping bucket of the instrument was appropriately developed and installed in other to bring together an unprecedented combination of high accuracy, versatility and true result. Calibration curves based on linear logarithms and power models are shown in Figure 4 and Figure 5 respectively. A summary of the calibration statistics is presented in Table 2. Results showed that strong relationship existed between the measurement reading of electro-mechanical tipping bucket and conventional observation of the system with R^2= 0.94 for power calibration model. The logarithms calibration curve showed R^2= 0.95 and 0.94 for the observation of simulated rainfall to generated surface runoff measurements using electro-mechanical and manual runoff-meters. All the models are highly significant at 0.05 level of significance with measurement accuracy and resolution of ±0.01/per tip.

Table .1 Measuring runoff depth using electro-mechanical tipping bucket and manual runoff-meter

N/S	SRD(mm)	RDemt(mm)	RDm(mm)
1	10.5	8.4	7.6
2	15.7	12.3	9.6
3	20.4	18.6	16.9
4	22.5	20.1	18.6
5	25.4	23.2	21.6
6	28.3	26.7	23.8
7	30.2	28.6	26.9
8	32.6	30.9	28.2
9	35.4	33.6	31.5
10	40.1	37.6	35.9

Sources: Calibration output

SRD= Simulated rainfall (mm);

RD_{emt} = Runoff depth using electro-mechanical instrument;

RD_m = Runoff depth using manual method.

Table 2. Outputs of statistical calibration analysis

N/S	Models	Overall statistical output			
		R2	Equations	SE	Sig. level
1	Logarithms	0.95	18.8ln(x)-32.01	0.144	0.05
2	Logarithms	0.94	18.7ln(x)-36.02	0.146	0.05
3	Power	0.94	$7.2988e^{0.05x}$	0.145	0.05

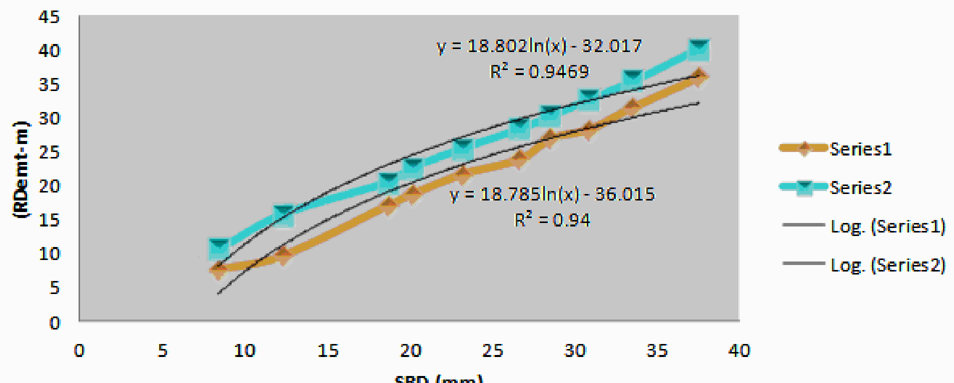


Fig.3 Calibration of Simulated rainfall and surface runoff depth

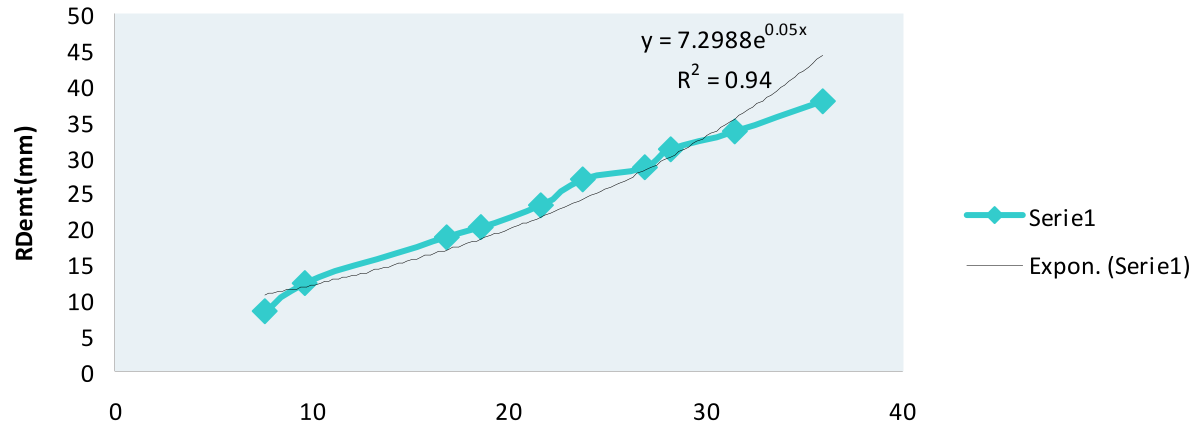


Fig.5: Calibration curve for RDemt-RDm

4. Conclusion

The design, development and evaluation of electro-mechanical tipping bucket runoff-meter have technically been explained. The electrical, electronic and mechanical components of the instrument were selected, welded and coupled together based on the intended function that the instrument was expected to perform. All the component parts were locally-sourced to meet the environmental conditions. The tipping rate depends on the intensity of runoff and each was designed to tip *0.14litre* of runoff water with an accuracy of *±0.001 litre*. The instrument was calibrated to tip or measure runoff water to the minimum and maximum values of *0.141* and *200 litres* respectively. Each tip was recorded by the electro-mechanical data logger to maximum counting and recording unit of *1,419*. Generally, precise results obtained during the calibration of the instrument establish strong accuracy and realistic system in measuring runoff and provides reliable data for hydrologist and water engineers to model hydrological system for water resource management and some other useful applications.

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Addresses:

- Olotu Yahaya, Department of Agricultural Engineering, Auchi Polytechnic, Auchi, Nigeria, realyahaya@yahoo.com
- Alimi L.O, Department of Industrial Chemistry, Federal University of Technology, Akure
- Rodiya. A.A., Department of Agricultural & Bio-Environmental Engineering, The Federal Polytechnic, Ado-Ekiti, Nigeria
- Omotayo F.S., Department of Agricultural & Bio-Environmental Engineering, The Federal Polytechnic, Ado-Ekiti, Nigeria

Corresponding Author: realyahaya@yahoo.com