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Development and Performance Evaluation of Rainfall-Runoff and Soil Sediment-Measuring Instrument

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Abstract During the rainy season, people experience floods, soil erosion in the uplands, and soil pollution in the lowlands caused by sediment from runoff flowing into the coastal area. Runoff happens when the rate of rainfall is higher than the rate of soil infiltration or when the soil is already saturated, and when the depth and rate of rainfall exceed infiltration, surface runoff occurs. The depth of rainfall was already monitored by the national weather monitoring agency. However, the depth (volume) of runoff in each area is still unmonitored, and even the volume (weight) of soil sediments carried by this surface runoff has not been evaluated and measured. The study objectives were to develop a rainfall-runoff and sediment-measuring instrument, evaluate the depth of runoff every rainfall-runoff event, and assess the volume of soil sediment caused by the rainfall-runoff event. This study was conducted at the Bataan Peninsula State University – Abucay Campus, Bangkal, Abucay, Bataan, Philippines (North 14°44'28.4" East 120°27'6.7") from October 2023 to October 2024. The type of soil in the study area was Antipolo clay (vertisols). The developed instrument was fabricated and calibrated. The instrument has a sediment and runoff trough 10x10x50 centimeters in dimensions. The runoff measuring device was attached to it upon overflowing of the trough. Since the repairs were corrected, it was evaluated. Instruments were laid out in 30, 25, and 18 percent land slope with a length of 15 meters and 100 percent vegetation. Environmental parameters like rainfall, temperature, humidity, and wind were considered in the study. The runoff depth of every rainfall event observed and monitored was significantly higher in the steeper slope area using the instrument. Concurrently, soil sediments eroded using the instrument were higher than using the revised universal soil loss equation in the steeper areas at 25 and 30 percent slope. The developed instrument was portable and could easily be carried and used by researchers, environmental planners, and policymakers in gathering rainfall-runoff depth and volume of soil sediments eroded.

Keywords Runoff, Soil Erosion, Soil Sediments, Rainfall Event, Steep Slope

1. Introduction

During a rainfall event, there are times when the rainfall depth is not enough for runoff. On the other hand, when the depth and rate of rainfall exceed infiltration, runoff (surface runoff) occurs. Runoff happens when the rate of rainfall is higher than the rate of soil infiltration or when the soil is already saturated [1]. In the watershed, runoff and soil transport may vary according to intensity, temporal and spatial distribution of precipitation events, humidity conditions, soil, and land use [2]. The significant increase in precipitation instability caused by global climate change has increased the probability of flash flood risk and attracted widespread attention [3]. During the rainy season, people experience floods, soil erosion in the upland [4], and soil pollution in the lowland caused by sediment carried by runoff going to the coastal area [5][6]. These were the annual problems that were tackled by the researchers, planners, developers, and policy makers on how they were going to be minimized. Insufficient information makes them unable to mitigate and adapt to climate change, the occurrence of unpredictable rainfall events (rainfall depth, intensity, and duration) [7]. According to Defersha et al. [8], soil erosion is a two-phase process consisting of the detachment of individual particles and their transport by erosive agents such as flowing water. The rate at which erosion occurs depends upon the individual as well as the interactive effects of different parameters responsible for soil erosion. Many studies have been conducted about runoff water, but most of them were concentrated on water quality [9] and water sampling devices. Consequently, the construction of large water reservoirs and water storage, such as dams and the like, was not affordable to small-scale farm developers or farmers. However, if there is an instrument that will measure the depth of surface runoff and soil sediment carried by this runoff, there will be a basis for a local development plan and a national plan [10]. Surface runoff can be estimated using the rational method; however, it is applied only to areas less than 200 acres (80.93 ha) [11][12]. The curve number (CN) method could also be used based on antecedent soil moisture and physical watershed characteristics. The soil conservation service (SCS) method can also be used in estimating surface runoff from rainfall that is based on a developed hydrograph [13]. The tipping bucket was also considered a reliable instrument in measuring rainfall runoff [14]. In the Philippines, the depth of rainfall was already monitored by the DOST-PAGASA, but the depth (volume) of runoff at a given area has not been recorded, and even the volume (weight) of soil sediments carried by this surface runoff has not been evaluated and measured [15]. To establish the data regarding depth of runoff and soil sediment carried by this surface runoff, there must be an instrument or device and a method to be used that will be used by the researchers, planners, developers, and policy makers to mitigate and adapt to climate change [16]. The establishment of a monitoring system in the watershed (rolling and upland production area) has a significant impact in terms of production and income because of the impact of rainfall-runoff volume and even the soil erosion with soil nutrient transport [17]. Soil nutrient loss results in additional farm inputs for the farmers if this is not mitigated [18]. The model developed would be disseminated to crop/animal producers, researchers, environmentalists, planning officers, and policy makers for them to have the basis for a development plan in a specific area for improvement, specifically in the rolling area. The aims of the study are to develop a rainfall-runoff and sediment-measuring instrument, evaluate the depth of runoff every rainfall-runoff event, and assess the volume of soil sediment caused by the rainfall-runoff event. The study was carried out in Bataan Peninsula State University, Abucay Campus, Bataan, Philippines, from 2023 to 2024.

2. Methodology

This section presents the materials used, the crop used in the study, the site identified, the preparation of the experimental area, data gathered and monitored, the experimental design, and data analysis.

2.1. Soil Type and Infiltration Rate

Selected micro-watershed for experiment at coordinates North 14º 44' Latitude and East 120º 27' Longitude. The observed textural class of soil within the watershed area was clay, following the USDA Percent Particle Size Distribution (Table 1) with a bulk density of 1.13 grams per cubic centimeter (g/cm^3). The total infiltration before runoff occurs was 52.2 millimeters (mm) [19]. However, a steeper slope has a lower infiltration rate [20].

Table 1. Soil physical analysis

PARTICULARS	AMOUNT
Particle Size Distribution	
Sand (%)	41.27
Silt (%)	32.79
Clay (%)	25.94
Textural Class	Clay
Acidity (pH)	5.6
Moisture (%)	15.8
Organic Matter (%)	1.84

2.2. Materials

The materials used specifically for the fabrication and development of rainfall-runoff and soil sediment measuring instruments were plain stainlesssteel sheet, stainless pipe, hinges, calibrated stainless steel stakes, and a water meter. A plain stainless steel sheet was used for the fabrication of instruments, such as the trough and platform, which served as an entrance for surface runoff before passing the trough. A stainless pipe was used as a passage for water from the trough to the water meter going out. Hinge was used as a platform and trough for different slopes. A calibrated stake was used for measuring the surface runoff and sediment yield in the trough. A water meter was used to measure the surface runoff overflow of the trough.

2.3. Fabrication

The instrument was fabricated from plain stainless steel. This was done by an expert in welding and fabrication.

2.4. Calibration and Development

After it was fabricated, the instrument was calibrated through trials in a laboratory setup to identify differences. The leaks in the trough were sealed with glue to avoid inconsistency of data. The device was repaired and recalibrated after corrections to the design.

2.5. Evaluation

The developed and fabricated instrument was evaluated on-site at different steepnesses of land configuration and fully covered with vegetation [21].

2.6. Data Gathered and Collected

Data gathered and collected were the volume of sediment yield silted in the trough (Soil Sediment Measuring Instrument) and the volume of rainfall-runoff in the water meter attached to the instrument.

2.7. Population and Study Location

The developed instrument was evaluated in the specific watershed in the Bataan Peninsula State University (BPSU) Abucay Campus at three different land slopes. Vegetation density was measured and considered, including the activity in the area.

2.8. Experimental Design and Layout

The data compiled from the study were analyzed using a Completely Randomized Design, statistical analysis for mean differences, and the F-Test for the significance of the gathered data.

Layout: Treatment 1, T1 – 18% land slope
Treatment 2, T2 – 25% land slope
Treatment 3, T3 – 30% land slope

3. Result and Discussion

3.1. Rainfall-Runoff and Soil Sediment Measuring Instrument

The instrument (Fig. 1) was fabricated with stainless steel as the material to minimize deterioration and rusting due to exposure. The trough measures 10 centimeters (cm) in width, 50 cm in length, and 10 cm in depth. To avoid rainfall from directly falling into the trough, it has a cover connected by hinges. An inlet platform with a pen serves as the waterway during runoff through the trough. It is also connected to the trough by hinges. At a depth of 7.5 cm, a runoff measuring device was connected to measure overflowing water from a trough. The outlet pipe measures 1.47 cm, passing through a flow measuring device.

3.2. Depth of Rainfall

The total rainfall depth from October 01, 2023 to October 12, 2023, was 3,238.9 mm with variable monthly rainfall depth (Fig. 2). The rainfall depth was monitored by the Department of Science and Technology - Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA).

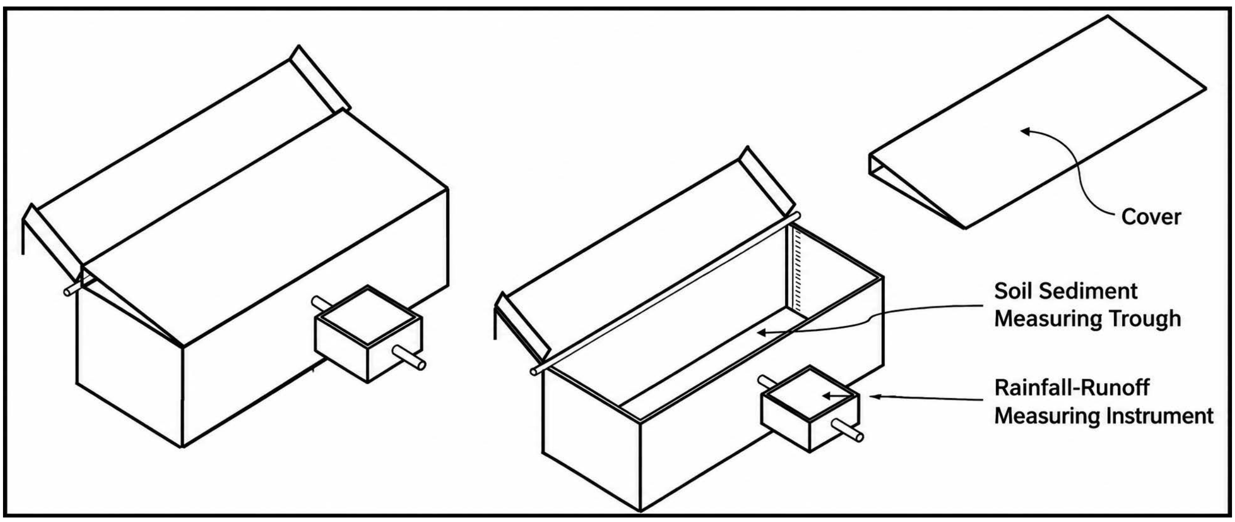

Figure 1. Rainfall-Runoff and Sediment Measuring Instrument

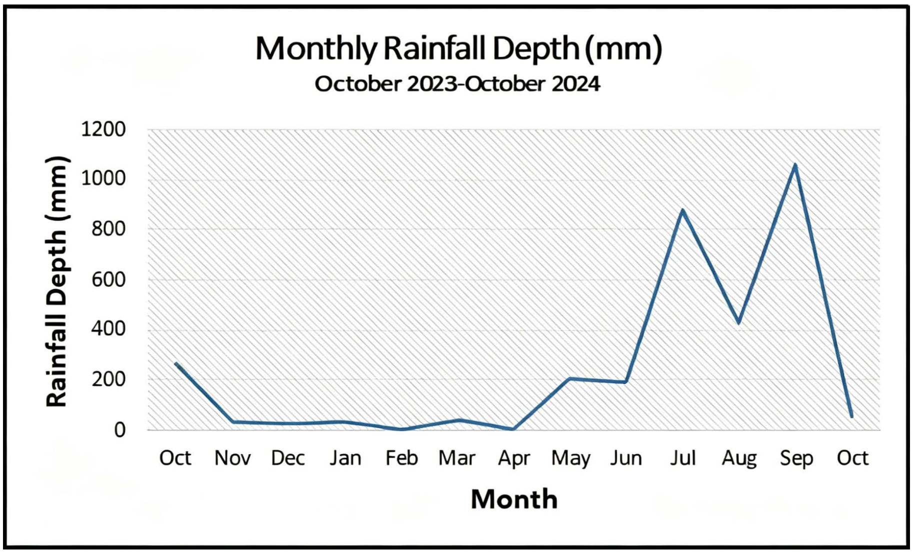

Figure 2. Monthly rainfall depth (mm)

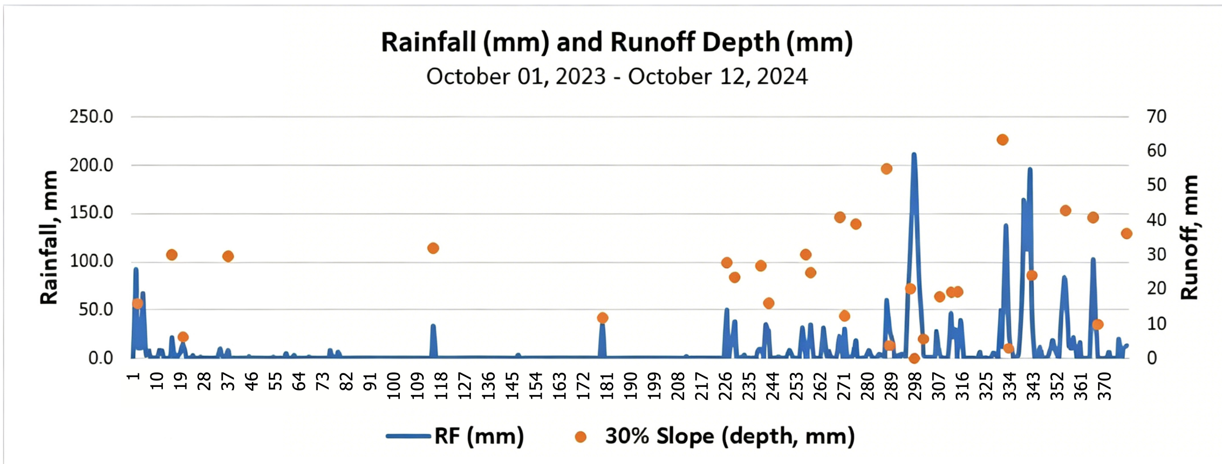

Figure 3. Runoff depth on a 30% slope

3.3. Depth of Runoff

The runoff depth (mm) gathered from the instrument laid out on a 30% slope (Fig. 3) was the highest compared to 25% and 18% slopes during the study period from October 01, 2023 to October 12, 2024, with 63.3 mm in August 2024. Runoff depth in 30% slope was significantly different from 25% and 18% slopes. The runoff will increase as the slope increases [22][23]. Different slopes under study were significantly different. There were rainfall events and intensity below the infiltration rate, resulting in no surface runoff, contrary to the rainfall and runoff simulator [24]. Consequently, rainfall with low intensity but long duration may result in surface runoff.

The runoff depth (mm) gathered from the instrument laid out on a 25% slope (Fig. 4) during the study period from October 01, 2023 to October 12, 2024, with 61.3 mm in August 2024, which is less than a 30% slope lower than the steeper land configuration. There were rainfall events and intensities below the infiltration rate, resulting in no surface runoff. Consequently, rainfall with low intensity but long duration may also result in surface runoff [25].

The runoff depth (mm) gathered from the instrument laid out on an 18% slope (Fig. 5) during the study period from October 01, 2023 to October 12, 2024, with 62.3 mm in August 2024 lower than steeper land configurations (25% and 30%). Runoff depth in 18% slope was significantly different from 30% and 25% slopes of the same study area condition and status. There were rainfall events and intensities below the infiltration rate, resulting in no surface runoff [26].

3.4. Summation of Runoff Depth

During the study period of October 2023 to October 2024, the greatest depth of runoff (Fig. 6) was the slope of 30% (729.4 mm) among the two slopes under observation (25% slope with 643.9 mm and 18% with 440.3 mm) [23]. Slopes under study were significantly different in terms of surface runoff and sediment yield carried by this surface flow [27]. Still, there were rainfall events that did not exceed the infiltration rate.

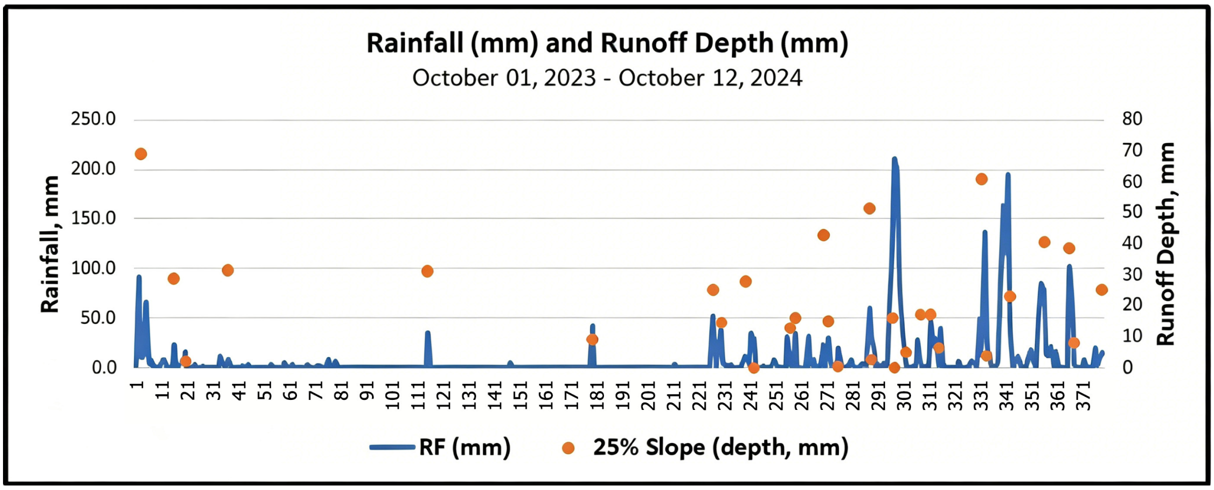

Figure 4. Runoff depth on a 25% slope

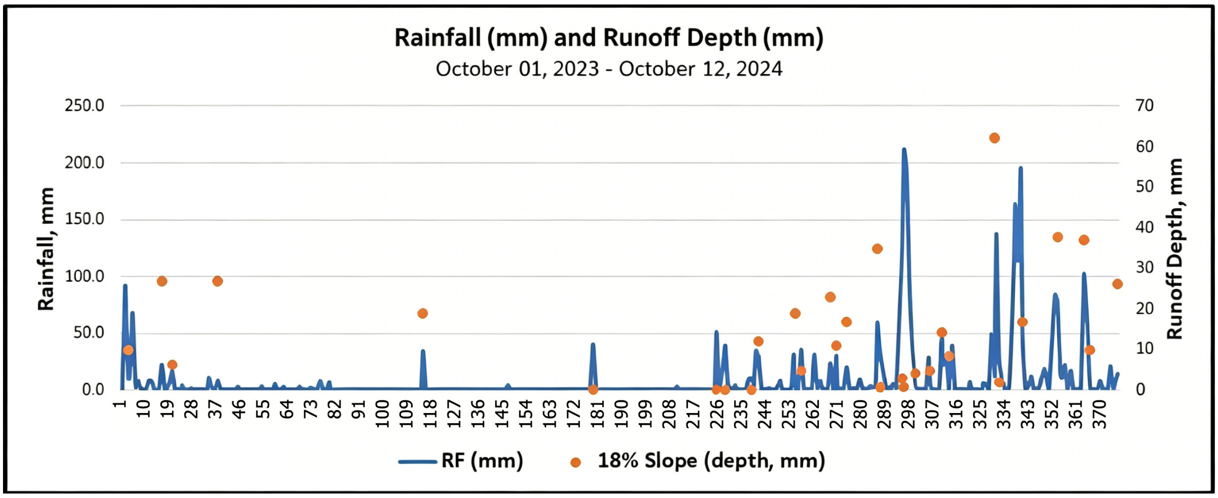

Figure 5. Runoff depth in 18% slope

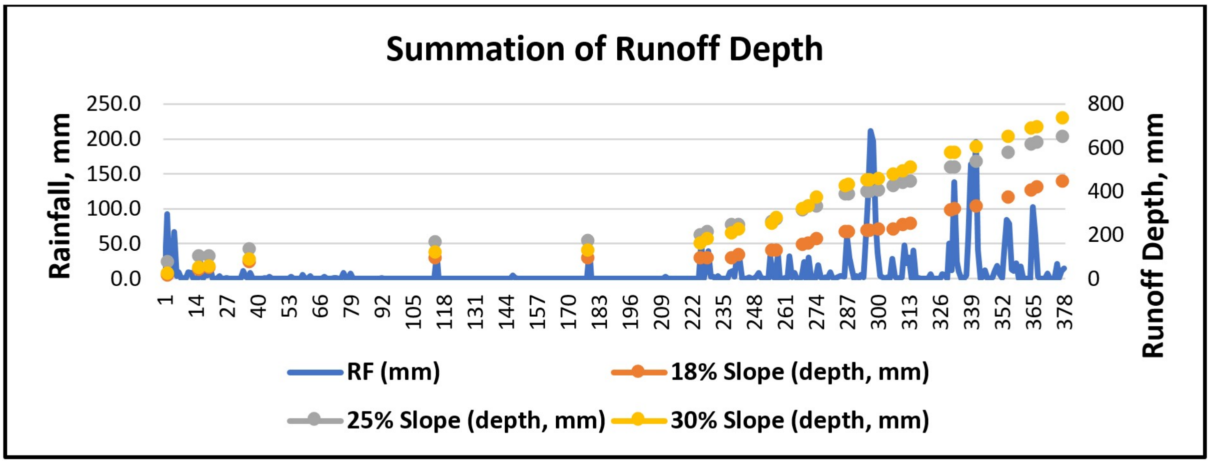

Figure 6. Summation of runoff depth

3.5. Soil Eroded

The rainfall depth during the study period (October 01, 2023 to October 12, 2024) was 3,238.9 mm higher than the normal rainfall depth of the area. The clay loam density was 1.13 g/cm^3. Within that rainfall depth, only 300 cubic centimeters (0.40 m^3/ha/year higher than revised universal soil loss equation (RUSLE) = 0.045 cubic meters per hectare per year (m^3/ha/y) of soil eroded was observed in 30% steep land, 0.267 m^3/ha/y greater than RUSLE (0.037 m^3/ha/y) of soil eroded in 25% steep land, while in 18% steep land has no soil eroded (less than RUSLE = 0.026 m^3/ha/y). The RUSLE (A = RKLSCP) uses the following factors, such as rainfall intensity, duration, and depth of specific location (R=193 for Philippines); the soil properties and characteristics (K=0.052); slope length of watershed waterway (L=0.774 for 18%; 0.764 for 25%; and 0.76 for 30%); slope steepness (S=2.47 for 18%; 3.57 for 25%, and; 4.32 for 30%); vegetation characteristics of area under consideration (C=0.003); and conservation practices made in crop production (P= 0.40). More vegetative land cover [28] is merely smaller than that of cultivated slope land [29]. The soil eroded gathered with the use of developed instruments was comparable to and greater than the use of the RUSLE at steeper land, which was estimated to be with so many parameters [30].

4. Conclusions

The rainfall depth was monitored by the local agency, however, the runoff depth had no data in a specific watershed or basin. A rainfall-runoff and soil sediment transport that may cause destruction to property and even life. A simple and portable instrument was designed and developed to measure the actual rainfall-runoff and sediment yield in a rainfall-runoff event. The instrument was fabricated with stainless steel as the material to minimize deterioration and rusting due to exposure. It has a cover connected by hinges, and an inlet platform with a pen serves as the waterway during runoff. A runoff measuring device was connected to measure overflowing water from a trough. It was easy to use and could be carried anywhere within the watershed for actual runoff monitoring due to its lightweight and portable size. For a watershed that is composed of micro-watersheds, the instrument was used instead of using an empirical formula and other methods that have many parameters. It was laid in three different land slopes with the same vegetative characteristics. The 30% land slope had the greatest surface runoff of the same basin's characteristics, such as vegetation and other configurations, compared with 25% and 18% due to steepness, which affects the runoff velocity at the rainfall depth. Consequently, sediment yield from different slopes of land was significant; the steeper (30% land slope) had greater soil sediment detached and carried by runoff within the study period covering two local seasons (rainy and dry). The rainfall-runoff measuring device should be upgraded to a digital instrument to have precise data, which may include the time when runoff occurred (real-time). Other environmental parameters should be included in the observation that will affect the measurement of runoff water in the trough during a long-time interval of a rainfall-runoff event.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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