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Developing an automatic collector of runoff for studies using rainfall simulators[1]

Desenvolvimento de um coletor automático de escoamento para estudos com simuladores de chuva

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HIGHLIGHTS:
Obtaining surface runoff and soil loss data by using rainfall simulators is laborious, time-consuming and resource-intensive.
A new collector equipped with pressure sensor and turbidimeter is proposed for automatic measurement of runoff and soil loss.
The low-cost collector proposed contributes significantly to future rainfall simulator studies.

ABSTRACT: Soil erosion studies using rainfall simulators are generally expensive and time consuming. Thus, the aim of this study was to develop a prototype of an automatic runoff collector, capable of real-time quantifying runoff volume and soil loss in field trials using a rainfall simulator. The used sensors were chosen based on the type A uncertainty computed from different volumes of water and concentrations of sediment. Through specific programming, the runoff volume, sediment concentrations and the time of occurrence of the collections corresponding to each 200 cm^3 of runoff were recorded on a micro-SD card. The robustness of the calibration and the programming developed were also evaluated in the Arduino Mega® 2560 microcontroller. The pressure (PSI.420) and turbidity (ST100) sensors were selected for developing the prototype, which was evaluated in the field with the InfiAsper rainfall simulator. Then, the data collected automatically by the sensors were compared to those obtained by manual measurement. The automatic runoff collector equipped with the PSI.420 and ST100 sensors has potential to obtain and store runoff data, and it was effective in evaluating the erosion process, generating mean errors of 12.25 and 13.16% for runoff volume and soil loss, respectively. The proposed prototype has a low cost of manufacture, in addition to optimizing the collection of erosion data in studies with rainfall simulators.

Key words: water erosion, runoff volume measurement, soil loss, microcontroller, Arduino

RESUMO: Estudos relacionados à erosão do solo usando simuladores de chuva são geralmente onerosos e demorados. Assim, o objetivo deste estudo foi desenvolver um protótipo de coletor automático de escoamento superficial, capaz de quantificar em tempo real o volume de escoamento superficial e a perda de solo em ensaios de campo utilizando um simulador de chuva. Os sensores utilizados foram escolhidos com base na incerteza tipo A calculada a partir de diferentes volumes de água e concentrações de sedimentos. Por meio de programação específica, o volume da enxurrada, as concentrações de sedimentos e o tempo de ocorrência das coletas correspondentes a cada 200 cm^3 de enxurrada foram registrados em um cartão micro-SD. A robustez da calibração e a programação desenvolvida também foram avaliadas no microcontrolador Arduino Mega® 2560. Os sensores de pressão (PSI.420) e de turbidez (ST100) foram selecionados para o desenvolvimento do protótipo, o qual foi avaliado em campo com o simulador de chuva InfiAsper. Em seguida, os dados coletados automaticamente pelos sensores foram comparados com os obtidos por medição manual. O coletor automático equipado com os sensores PSI.420 e ST100 tem potencial para obter e armazenar dados de escoamento, e foi eficiente na avaliação do processo erosivo, gerando erros médios de 12,25 e 13,16% para volume de escoamento e perda de solo, respectivamente. O protótipo proposto possui baixo custo de fabricação, além de otimizar a obtenção de dados de erosão em estudos com simuladores de chuva.

Palavras-chave: erosão hídrica, medição do volume de escoamento superficial, perda de solo, microcontrolador, Arduino

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Introduction

Technological advances and the ease of obtaining electronic devices have boosted research and the development of equipment in various areas of science (Kumar et al., 2021; Macedo et al., 2021; Zhan et al., 2021). The use of devices to evaluate hydrological and soil erosion processes has increased in the last years, for instance rainfall simulators, which began to be employed in 1930s and are currently widely used (Salem & Meselhy, 2020).

One of the greatest challenges regarding erosive processes assessment is obtaining data of surface runoff and soil loss from collections made in the field and later processing in the laboratory. As a result, human error and the laborious collection process have hampered studies in this area. Obtaining data is generally time-consuming and impractical due to the need to store the runoff volume in a large number of containers, in addition to the laboratory time required to quantify the loss of soil (Almeida et al., 2021).

Regarding rainfall simulators, obtaining surface runoff data depends on repetitive procedures that can be automated. Thus, the use of an automatic collector may improve the procedure and reduces the time required to obtain the data, reducing costs and the demand for labour. The runoff data generated from simulated rainfall represents the water volume and soil loss associated with soil management and cover that characterise the objectives of much of the research using rainfall simulators (Almeida et al., 2019).

Even though there is research in the area of developing collectors for runoff (Zhan et al., 2021), there is no specific model for field use that measures and stores the runoff volume and sediment loss in tests with simulated rainfall.

The aim of this study was to develop a prototype of an automatic runoff collector and analyser, capable of real-time quantifying runoff volume and soil loss in field trials using a rainfall simulator. To produce a reliable prototype for use in the field, sensors employing different operating principles were evaluated.

Material and Methods

The study was carried out in the Federal Rural University of Rio de Janeiro, municipality of Seropédica, RJ, Brazil (22° 45' 48" S, 43° 41' 50" W and average altitude of 33 m).

The prototype is based on a cylindrical container that stores and measures the runoff volume and makes it possible to estimate soil loss using a turbidity sensor. Two pressure transducers (models MPX5010Dp and PSI.420 A5 50MBAR 12N) and a capacitive sensor developed by this research group were evaluated for their ability to measure the runoff volume.

The prototype was constructed using PVC tubing, which is easily obtainable and of low-cost. It was designed to take consecutive water volume readings up to 200 cm^3, when the program triggers a reading of the turbidity sensor and records the runoff information on a micro-SD card. To control the entire process, an Arduino Mega® 2560 and the following components were used: SD module with 16 Gb memory card; two relay modules; two direct-action solenoids to control the input and output of the runoff; a sensor to read the runoff volume and one to measure the turbidity; an LCD display for viewing the data in real time; switches to turn the system on and off; and power supplies for the components (Figure 1).

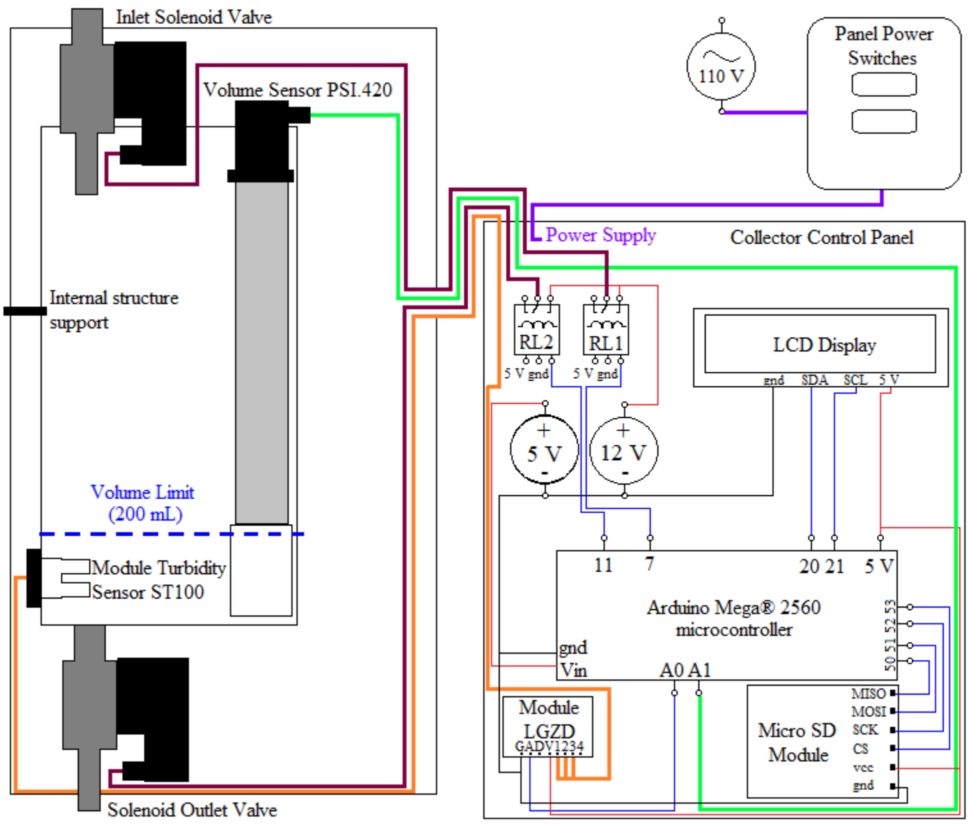


Figure 1. Internal schematic of the prototype showing the position of the sensors, structural schematic of the collector, and electrical configuration of the control panel

Comparing and evaluating the sensors used in the prototype were based on evaluating their performance relative to calibration (comparing the actual data to those calculated from models generated by regression) and Type A uncertainty as determined by Eq. 1.

$$u(xi) = \frac{s}{\sqrt{n}} \quad (1)$$

where:

u - Type A uncertainty;
n - number of repetitions; and,
s - standard deviation.

To obtain the Type A uncertainty and the sensor calibration curves, 30 tests were carried out using water containing no solid residues, in volumes ranging from 0 to 1200 cm^3 at increments of 50 cm^3, the largest volume corresponding to the maximum capacity of the collector, which was determined from data collected in the field using the InfiAsper rainfall simulator (Alves Sobrinho et al., 2008). Data with the capacitive sensor were obtained up to volumes of 900 cm^3 due to the size of the sensor in relation to the container used in the structure of the collector reservoir.

Readings with the capacitive sensor were taken using a specific routine developed from the capacitance readings generated by the sensor coming into contact with the water, while readings of the pressure transducers were taken using the analogue port of the Arduino (a port with an analogue-digital converter), where the pressure equalled the pressure of the air compressed by the column inside the 20 mm tube to which the transducers were connected. This procedure was adopted to avoid clogging and degrading of the sensor once in contact with the water and suspended particles.

The turbidity sensor (model ST100) was calibrated using two methods: the first consisted of producing runoff samples in the laboratory by sieving the soil collected in the experimental area through a 500 µm mesh and then diluting and homogenising in 200 cm^3 of water to obtain concentrations of 0, 0.7, 1.93, 3.16, 4.39 and 5.00 g m^{-2}. Fifteen replications were carried out for each dilution, with the sensor inserted into the sample to obtain the reading.

In the second method, 40 runoff samples, each of 200 cm^3, were collected directly in the field by the InfiAsper rainfall simulator (Alves Sobrinho et al., 2008; Macedo et al., 2021), applying rainfall intensities (RI) of 30, 45, 60 and 75 mm h^{-1} so as to best represent the working conditions of the sensor in the collector (Figure 2). Ten replications were carried out for each RI. The calibration was generated directly using regression of the turbidimeter data (0-5 V) relative to the loss of soil from each sample obtained by the gravimetric method.

The samples were taken to the laboratory, where the data was read in triplicate using the ST100 sensor, giving a total of 30 replications for each RI applied. The samples were then oven-dried and weighed to determine the soil loss in each sample. The average soil losses used in the calibration were 0.1454, 0.2021, 0.3084 and 0.3787 g m^{-2}, respectively, for RI of 30, 45, 60 and 75 mm h^{-1}. In both methods, the calibration curves were obtained via linear regression between the sensor reading (independent variable) and the concentration of suspended solids.

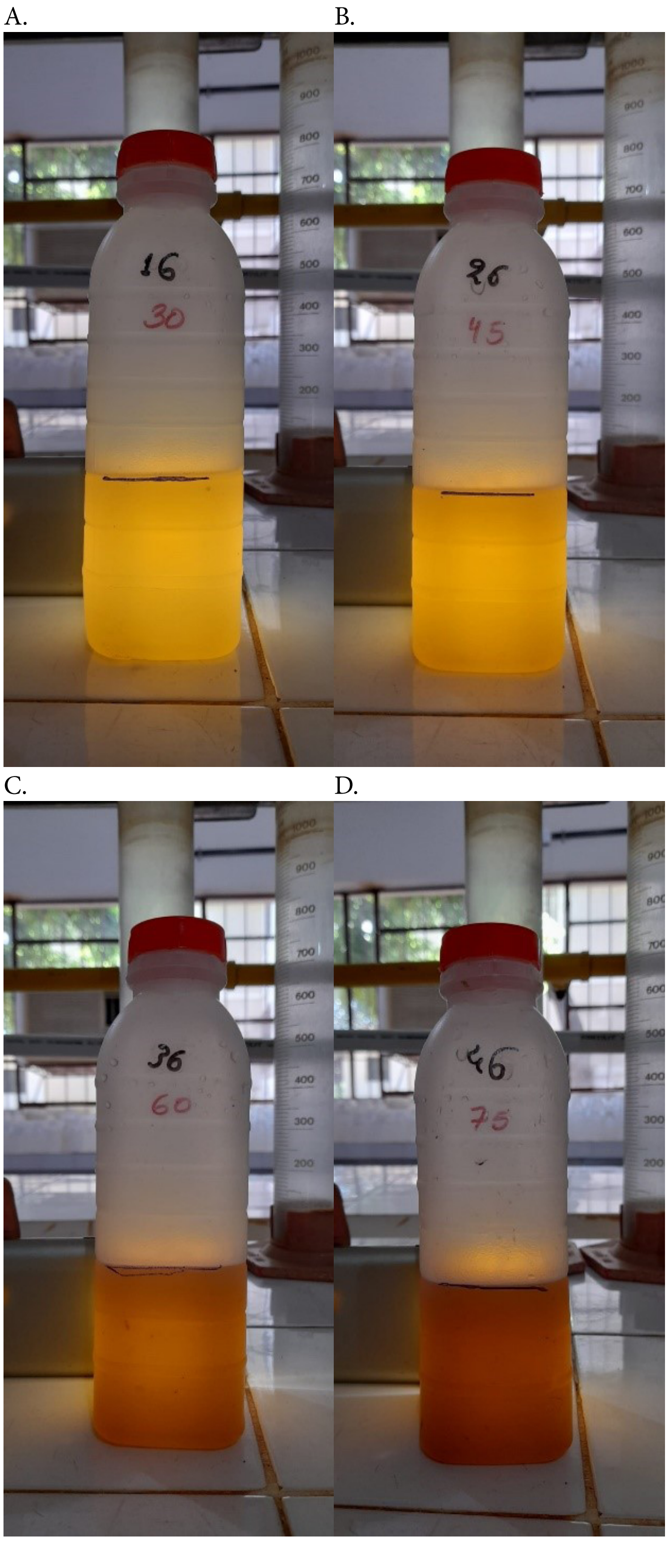


Figure 2. Runoff samples representing the rainfall intensities of 30 (A), 45 (B), 60 (C) and 75 mm h^{-1} (D) applied by the rainfall simulator in the field

The functionality of the turbidity sensor with the collector prototype was evaluated based on the same principles used for the volume sensors, by means of the calibration curve and Type A uncertainty. The choice of calibrating the turbidity sensor directly from runoff data generated in the field was due to the difficulty of reproducing artificial runoff having the same qualities as the samples produced by tests using the rainfall simulator.

The calibration curves generated using the sensors selected for producing the first collector prototype were then included when programming the microcontroller in the collector, which was subjected to a preliminary trial at field level in order to evaluate its effectiveness and robustness.

The collector can work with known volumes to collect a greater amount of data in the field, without setting the collection time, which would make the programming process more complex and the system more subject to reading errors for different volumes. The programming logic is shown in Figure 3.

The volume of 200 cm^3 was adopted as the criterion for both taking the readings and storing the data, as it is the same as the minimum height needed for the collected runoff to completely cover the turbidity sensor. Similar architecture for a runoff collector is presented by Zhan et al. (2021).

Field evaluation of the automatic collector using simulated rainfall from the InfiAsper simulator (Alves Sobrinho, 2008; Macedo et al., 2021) was by tests carried out in a Dystric Acrisol with a loamy sand texture (0.0-0.34 m) (WRB, 2022) located in an experimental area of the Federal Rural University of Rio de Janeiro, RJ, Brazil (Figure 4). The soil was prepared by ploughing once and harrowing twice, always following the contours of the land. The initial conditions of the terrain were standardised by manually levelling the plot to leave a slope of 9%.

Rainfall was simulated at a constant RI of 45 mm h^{-1} and with duration of 40 min, with automatic collections continuing until the surface runoff ended. Before the test, pre-wetting was carried out with the aim of standardising the initial moisture conditions of the experimental plot, using procedures commonly adopted in tests with rainfall simulators (Anache et al., 2014; Panachuki et al., 2015).

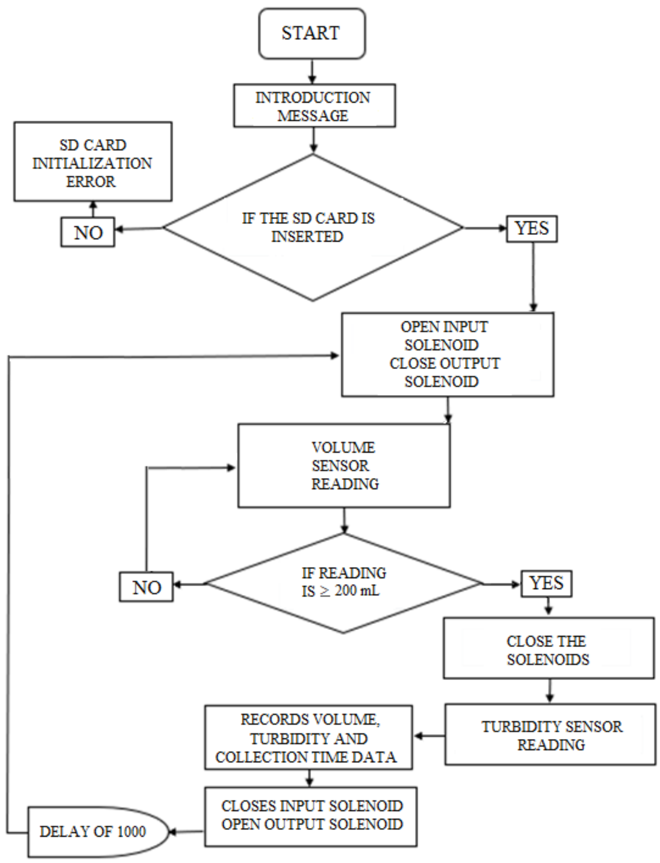


Figure 3. Flowchart of the programming used in the prototype of the runoff collector for readings made using a pre-defined volume of 200 cm^3

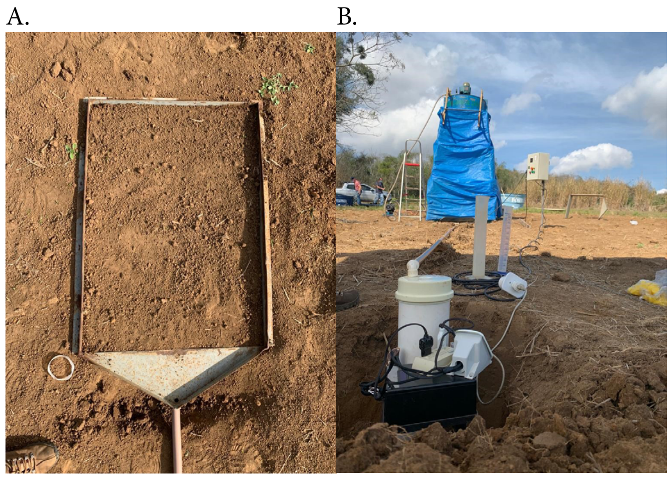


Figure 4. Structure of the collector plot (0.70 m^2) (A) and collector installed in the field next to the InfiAsper simulator (B)

The runoff and soil loss data collected automatically were compared with data obtained by laboratory analysis, and the error and standard deviation were calculated. The manual analysis carried out in the laboratory consisted in measuring the volume of collected runoff using a 500 cm^3 graduated cylinder, while soil loss was obtained by adding a precipitating agent (3% aluminium sulphate). The soil material in each sample was then dried in a forced circulation oven at 60 °C to constant weight. The dry material was weighed on an analytical balance with a resolution of four decimal places (gravimetric method). Soil loss in g m^{-2} was calculated by dividing the weight of the material by the working area of the experimental plot (0.70 m^2).

Finally, a cost-benefit analysis of the prototype was carried out to assess its limitations and advantages. The cost of the prototype was evaluated based on the price of the components used in its manufacture, and its performance in the field in computing the data and handling together with the rainfall simulator.

Results and Discussion

The uncertainties data obtained in the tests with the PSI.420 transducer and the other evaluated sensors are presented in Table 1. With the PSI.420, the results suggest an uncertainty of around 0.05% for the range of 0 to 50 mbar, as shown in the technical specifications of the sensor. The Type A uncertainty obtained as a function of the pressure sensor readings (average 0.427 cm^3) also demonstrates the repeatability of its response for similar values of applied volume. The mean values for Type A uncertainty were 5.803 and 4.902 cm^3 for the capacitive and pressure sensors (MPX5010Dp), respectively. The data show that PSI.420 is the best choice due to having low uncertainties for each of the volumes tested compared to the other sensors under evaluation.

Table 1. Results of the uncertainties obtained by the sensors under test for determining the data of volume in the runoff collector

Volume (cm^3)	Type A Uncertainty (cm^3)		
	Pressure Sensor PSI.420	Capacitive Sensor	Pressure Sensor MPX5010Dp
50	1.144	2.077	5.485
100	0.320	2.479	4.480
150	0.457	2.589	4.003
200	0.346	3.069	1.941
250	0.343	2.961	8.447
300	0.590	3.438	2.646
350	0.216	3.697	2.726
400	0.286	3.817	6.928
450	0.599	3.746	8.541
500	0.306	5.168	4.328
550	0.247	5.727	5.069
600	0.385	5.538	4.246
650	0.282	7.566	5.254
700	0.659	8.742	10.069
750	0.478	9.595	2.990
800	0.702	10.744	5.032
850	0.343	11.120	6.314
900	0.502	12.373	5.558
950	0.380	-	3.690
1000	0.363	-	3.705
1050	0.223	-	5.346
1100	0.300	-	5.181
1150	0.409	-	1.620
1200	0.379	-	4.038
Average	0.427	5.803	4.902

Obs.: - It means no data available

The overall calibration curve of the PSI.420 industrial transducer shows proper fit of the signal readings to the collected volumes (Figure 5A).

Due to the transducer response demonstrating high linearity and stability, as shown by the coefficient of determination (R^2 = 0.9999), the results presented in the calculated average were almost identical to the volumes added to the collector, showing the accuracy of the measurements and suitability of the calibration curve (Figure 5B), with a standard error of 2.806 cm^3. As such, the PSI.420 transducer showed characteristics that were suitable for developing the runoff collector. It was possible to notice that a water volume of less than 50 cm^3 may be overestimated due to the position of the transducer coupling tube, which was placed approximately 3 mm from the bottom of the collector, i.e. when the water depth is less than 3 mm, the transducer does not sense the water in the collector. However, for the purposes of collecting the runoff, this is not a limitation.

The standard error of the mean for the capacitive sensor and the MPX5010Dp sensor was 3.058 and 2.237 cm^3, respectively. The calibration curves produced linear models with coefficients of determination of 0.9999 for the MPX5010Dp (Eq. 2) and 0.9996 for the capacitive sensor (Eq. 3).

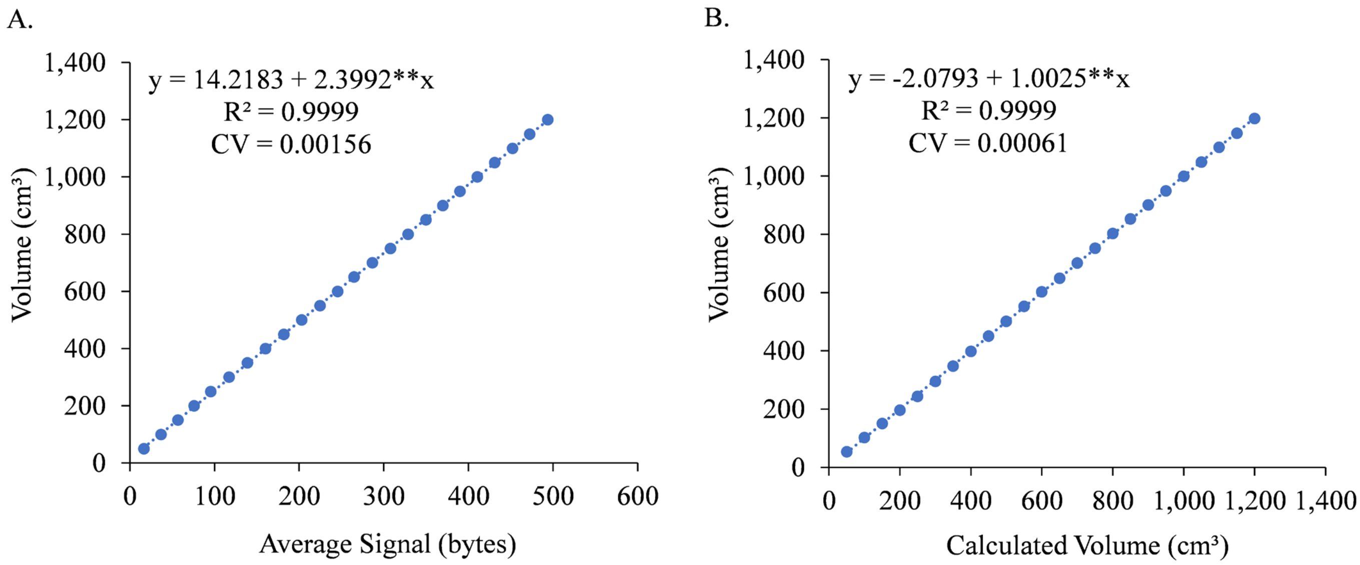
$$y = -229.9818 + 8.9487^{**}x \quad (2)$$

$$y = -843.4018 + 17.9725^{**}c \quad (3)$$

where:
** - significant at $p \leq 0.01$ by F test;
y - volume (cm^3);
x - average signal (bytes); and,
c - capacitance (pF).

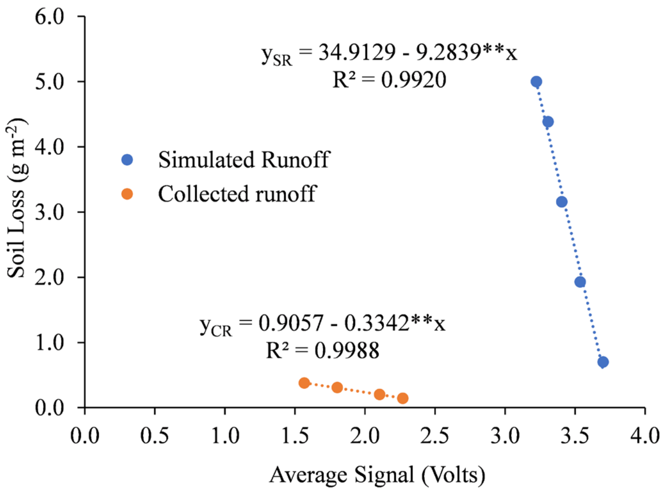
Although both sensors also showed good calibration curves and coefficients of determination, the PSI.420 industrial model proved to be more suitable for developing the collector and was selected for the prototype. The choice of using a pressure transducer was based on positive results from its use in scientific studies that include such components to measure the levels of water, gas and other substances (Schenato et al., 2019; Chan et al., 2020; Sá et al., 2021).

Calibration of the turbidity sensor using sieved soil samples and runoff samples obtained in the field (Figure 6) gave satisfactory results, with linear regression coefficients of determination greater than 99%. However, it can be seen that the calibration method changes the coefficients of the equations, with an angular coefficient 27 times greater when calibration is carried out using simulated runoff compared



** - Significant at $p \leq 0.01$ by F test

Figure 5. Calibration curve of the PSI.420 A5 50MBAR 12N industrial pressure transducer (A) and measured volume compared to the volume calculated by the calibration curve (B)



** - Significant at $p \leq 0.01$ by F test

Figure 6. Calibration curves for the turbidimeter generated from the mean values of the sieved samples and those prepared in the laboratory (y_{SR}), and obtained by collecting runoff in the field using the rainfall simulator (y_{CR})

to runoff samples collected in the field. It is important to point out that the values of the electrical signal are inversely proportional to the concentration of suspended solids. This is due to a smaller proportion of infrared emissions being captured as the solution becomes more turbid, with less light reaching the photodetector that converts the luminosity into an electrical signal (Merten et al., 2014).

The mean data generated from the calibration produced using simulated runoff in the laboratory are presented in Table 2. For the concentrations used with this calibration method that simulates runoff, the results for standard deviation, coefficient of variation and uncertainties were low, showing that the sensor is capable of accurate readings under the conditions to which it was subjected.

Table 3 presents the mean values for the turbidimeter signal and respective standard deviation, coefficient of variation (CV) and Type A uncertainty for the different soil concentrations in the runoff samples collected in the field. As in the previous calibration, the results for the statistical indicators from the runoff collected using the rainfall simulator show low mean values, suggesting that the sensor is able to generate good repeatability of response for small amounts of soil suspended in water; this suggests that it is possible to achieve a good calibration of the ST100 sensor using this method.

The fact that the method using field collections for calibration provide greater values for CV% and greater

Table 2. Statistical values of the turbidimeter signal from 15 replications calibrated using the simulated runoff method in the laboratory

Soil Loss ($g m^{-2}$)	Average Signal (V)	Standard Deviation ($g m^{-2}$)	CV (%)	Type A Uncertainty ($g m^{-2}$)
0.000	3.785	0.021	0.546	0.005
0.700	3.699	0.044	1.194	0.011
1.928	3.536	0.024	0.666	0.006
3.157	3.403	0.037	1.098	0.010
4.386	3.307	0.024	0.727	0.006
5.000	3.223	0.023	0.698	0.006
	Average	0.029	0.821	0.007

CV - Coefficient of variation

Table 3. Statistical values of the turbidimeter signal from 30 replications calibrated from field collections using the rainfall simulator

Soil Loss ($g m^{-2}$)	Average Signal (V)	Standard Deviation ($g m^{-2}$)	CV (%)	Type A Uncertainty ($g m^{-2}$)
0.145	2.270	0.202	8.908	0.037
0.202	2.105	0.029	1.394	0.005
0.308	1.803	0.051	2.832	0.009
0.379	1.567	0.074	4.711	0.013
	Average	0.089	4.461	0.016

CV - Coefficient of variation

uncertainties than the other evaluated methods may be related to the lack of homogenisation of the particles in the collected runoff solution compared to the solution produced in the laboratory after sieving. Even so, both methodologies showed promising results with the sensor under evaluation.

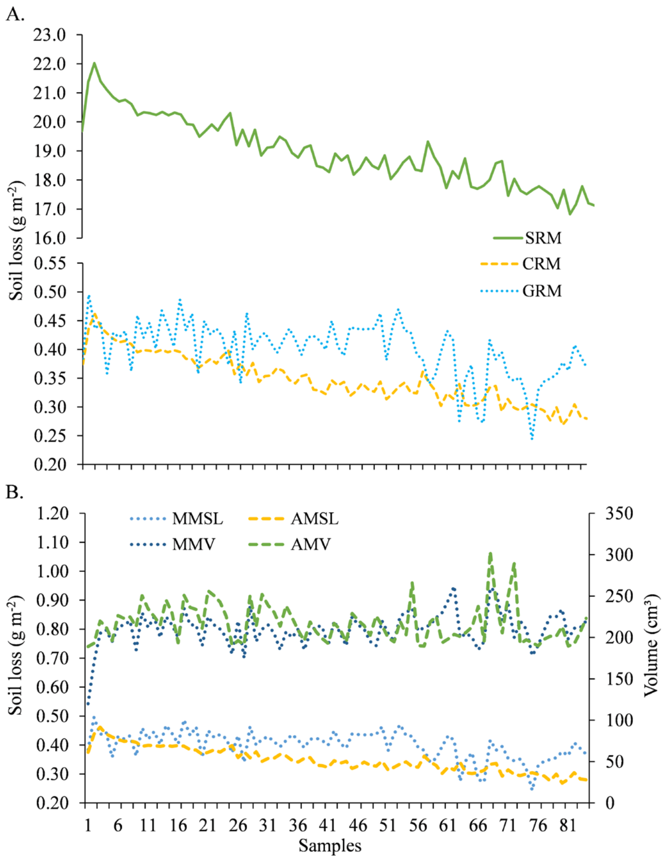
Studies show high correlation between turbidity and the values for suspended sediment concentration, generally used to measure the effects of erosion in river environments (Merten et al., 2014; Ferraz et al., 2018; Baucke et al., 2020). In the present study, the data for soil loss obtained in the laboratory showed a -95.91% correlation with the signal obtained from the turbidity sensor. Thus, the ST100 turbidity sensor may be considered a viable option for developing the automatic runoff collector. For other types of soil, the suggested calibration method should be used, considering that turbidimeters depend on the size, shape and colour of the particles (Landers & Sturm, 2013; Merten et al., 2014; Xu et al., 2020; Zhan et al., 2021).

In general, the field test of the prototype carried out in an experimental area showed that the device met initial expectations for storing information on collection time, volume and soil loss for the runoff produced by the InfiAsper simulator. The method of calibrating the volume applied to the PSI.420 proved to be adequate, just as the soil loss obtained by calibrating the ST100 with field data gave results closer to those obtained by the gravimetric method with measurements made in the laboratory (Figure 7A).

The mean error found when the soil loss was estimated from the calibration curve using simulated runoff was approximately 46 times greater than the one obtained with the soil loss measured by the gravimetric method and weighed in the laboratory. With the methodology using samples previously obtained in the field, the observed mean error was 13.16%. The overestimation generated by the method that simulates runoff suggests that the way of preparing the solution representing the runoff is very different from the conditions in the field. This may be linked to the way particles dispersed by the impact of the simulated raindrops are distributed over different particle sizes suspended in the runoff solution.

As these characteristics have a high degree of complexity if reproduced in the laboratory (Deletic, 2005), calibrating the turbidity sensor based on sieved samples may not be a viable option until it becomes possible to prepare samples that accurately match those reproduced by the simulator in the field. Therefore, it is recommended that the turbidity sensor be calibrated from runoff samples previously collected in the field.

The results obtained in a complete field test using the collector prototype together with the InfiAsper simulator are presented in Figure 7B. The mean standard deviations



SRM - Simulated runoff method; CRM - Collected runoff method; GRM - Gravimetric method; MMSL - Manually measured soil loss; AMSL - Automatically measured soil loss; MMV - Manually measured volume; AMV - Automatically measured volume

Figure 7. Soil loss data obtained with the laboratory method and automatically measured by the runoff collector calibrated using sieved material and field collections (A) and soil loss and runoff volume collected automatically and measured manually in the laboratory (B)

obtained automatically by the collector (23.18 g m^{-2}) and in the laboratory (20.65 g m^{-2}) were similar, showing that the prototype is functional and meets the objective of facilitating the collection of soil-loss data from simulated rainfall. The mean error observed in relation to the runoff volume was 12.25%, considered acceptable due to the difficulties of obtaining this type of data in the field. In general, the sensors selected for constructing the prototype showed good performance in measuring runoff volume and soil loss for the area of the tests and considering the calibration methods that were applied.

An analysis of the cost of the materials used in developing the prototype is shown in Table 4. The PSI.420 pressure sensor showed the best calibration and performance in computing the runoff volume; however, the acquisition cost is higher than those of the other sensors.

Based on the cost of the sensors selected to produce the collector together with the other components used, the total for the prototype was around US$ 692,35. A cheaper version, showing similar efficiency, can be produced by replacing components with lower-cost versions, especially the PSI.420 sensor with the MPX5010Dp, which would reduce the total cost by 58.2%. However, this would involve a reduction in the precision and accuracy of the data obtained with the device. When using the MPX5010Dp to develop a collector system for

Table 4. Costs of the main components used, and sensors tested in developing the runoff collector

Device	Model	Price (US$)
Pressure sensor	PSI.420 A5 50MBAR 12N	$ 431.64
Pressure sensor	MPX5010Dp	$ 28.42
Capacitive sensor	Non-commercial*	$ 3.50
Turbidity sensor	ST100	$ 57.46
Microcontroller	Arduino Mega® 2560	$ 28.89
Micro-SD module	REF: 4MD36	$ 1.93
Micro-SD card	ScanDisc Ultra 16 Gb	$ 9.74
Solenoid valve	12V NC Direct action**	$ 58.59
Relay module	JQC-3FF-S -Z**	$ 3.30
LCD Display	SKU: 500	$ 4.30
PVC structure	200 and 100 mm + Caps used*	$ 68.62
Sources	Dual voltage 12V 2A + 12V 3.5A	$ 14.44
Panel	100 x 150 x 214 mm Case	$ 13.44

* - Price specified using the cost of materials for producing the sensor; ** - Price for the two units that were used; Obs.: quotation of 03/16/2022

sprinklers in the laboratory, Queiroz et al. (2008) considered the sensor to be economically viable for the automatic measurement of water volumes.

The developed prototype acceptably carries out the function of obtaining runoff information from portable rainfall simulators and is a useful tool for more quickly obtaining data and reducing the possibility of human error. One of the main advantages of the collector is the possibility of generating a large amount of information from a single test, besides removing the need to store a large number of samples, a very common scenario in the study of large areas such as watersheds (Almeida et al., 2018; Santos et al., 2018; Assis et al., 2021).

Some caveats regarding the limitations of the prototype in the field should also be highlighted, such as the need to position the collectors at least 40 cm below the level of the collecting gutter of the rainfall simulator, and its being perfectly level to ensure proper operation. In addition, soil particles accumulating inside the structure can result in huge errors when determining soil loss, requiring the response of the device to be evaluated following calibration.

The equipment allowed data on soil loss and volume to be rapidly collected in the field. The time required to analyse and process the data by the laboratory method was approximately four days, whereas processing the data obtained automatically took only few hours. In addition, manual collection required the transport and storage of a large number of 500-cm^3 bottles, which represents both a monetary and logistical investment.

Based on all the information generated in developing this prototype, a new and more efficient device is proposed, with a structure that facilitates installation in the field, portability and communication with the user (Kumar et al., 2021; Zhan et al., 2021). In addition, the method of calibrating the turbidimeter to act in different types of soil has been improved (Xu et al., 2020) and the new functionalities added make it even easier to obtain the data generated by the rainfall simulator, and reduce costs and other observed limitations.

Conclusions

1. The automatic runoff collector equipped with the PSI.420 pressure transducer and the ST100 turbidity sensor has the potential to instantly obtain and store runoff data.

2. The runoff collector was effective in evaluating the erosion process, generating mean errors of 12.25 and 13.16% for runoff volume and soil loss, respectively.

3. The proposed prototype has a relatively low cost of manufacture and contributes in a relevant way to future applications in studies with rainfall simulators, speeding up and facilitating the obtaining of erosion data in the field.

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