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ASSESSMENT OF TURBIDITY AS A QUICK TOOL TO QUANTIFY THE SEDIMENT TRANSPORT

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ABSTRACT: Erosions on slopes or on riverbanks are consequences of the several mechanisms actions that can disrupt the system natural balance. Among the natural mechanisms, the action of rainfall events on different land uses is noteworthy, as depending on their intensity and duration, these events can generate high erosion rates and hence cause a large amount of sediment transported through fluvial channels. Knowing the dynamics of sediment transport in river basins is extremely important, because it helps decision-making regarding the need to seek new forms of soil management. In this work, solid discharge was calculated by determining the suspended solids concentration and by the correlation between the sediment concentration parameters and turbidity in the waters of Maringá Stream-PR, in order to evaluate sediment transport capacity. It was observed that the use of the correlation leads to significant errors in determining solid discharge; nevertheless, it can be an important tool given its practicality, lower cost and quick outcome.
Keywords: waterflow, sediment, discharge.

AVALIAÇÃO DA TURBIDEZ COMO FERRAMENTA RÁPIDA PARA QUANTIFICAR O TRANSPORTE DE SEDIMENTOS

RESUMO: *Erosões em vertentes ou em margens de rios são consequências da ação de vários mecanismos capazes de romper o equilíbrio do sistema natural. Entre os mecanismos naturais, a ação dos eventos pluviométricos sobre diferentes usos do solo merece destaque, pois dependendo de sua intensidade e duração, podem gerar altas taxas erosivas e, consequentemente, ocasionar o transporte de uma grande quantidade sedimentos pelos canais fluviais. Conhecer a dinâmica do transporte de sedimentos em bacias hidrográficas é de extrema importância, pois auxilia ogestor na tomada de decisão quanto à necessidade de buscar novas formas de manejo do solo. No presente trabalho foram realizadas a determinação da descarga sólida pela determinação da concentração de sedimentos e por meio da correlação entre os parâmetros concentração de sólidos e turbidez nas águas do ribeirão Maringá-PR a fim de avaliar a capacidade do transporte de sedimentos. Verificou-se que a utilização de correlação leva a erros significativos na determinação da descarga sólida, porém, pode ser uma ferramenta importante pela praticidade, menor custo e rapidez nas respostas.*
Palavras-chave: *vazão, sedimentos, descarga.*

1. INTRODUCTION

Promoting any sort of development for a given region implies awareness that human societies, whether rural or urban, impact the environment that they inhabit. These impacts are the result of poor soil use and occupation, in urban centers and farming areas (WEBER et al., 2003; MERTEN; MINELLA, 2006; MACHADO et al., 2006; ANDRADE et al., 2007). Knowledge of hydrosedimentological behavior of a watershed is essential for proper management of its water resources and to support the decision to develop anthropic activities. Monitoring the sediments flux at a given location makes it possible to diagnose potential impacts on its drainage area over time, possibly making it an important environmental indicator.

Sediment transport is a natural process in all fluvial channels. It takes place due to erosion processes that occur on slopes or riverbanks, and can feature variation due to intrinsic watershed characteristics (GARCIA; GONÇALVES, 2011; THOMAZ et al., 2011). In general, an increase in solid discharge is expected when flow intensifies; nevertheless, this behavior varies according to certain characteristics, such as water and slope variables (MEDEIROS et al., 2011).

QUEIROZ et al. (2010) state that soil management practices were significantly reduced by the sediment transport in a watershed. The soil management in farmlands by using practices such as no-till and terraces, as well as the presence of riparian vegetation on riverbanks, contribute to low sediment production in the channel.

The concentration of suspended sediments provides an important information about a waterway. A river with high sediment concentration is usually a muddy river. Sediments have great influence on water quality parameters; as they are carried into waterways, sediments bring along other pollution elements with them (XIAO-LONG et al., 2007; BOUZA-DEAÑO et al., 2008; SUTTON; FISHER, 2009; WEI et al., 2009). Rivers with high sediment concentration can cause problems for water collection and treatment systems. High concentrations of solids on surface waters can damage the water collection systems and make the treatment for public use more expensive (SOUZA; LIBÂNIO, 2009).

The difficulties in monitoring sediment transport involve certain aspects such as delays in determining the solids concentration and the samplings and laboratory analyses cost. Thus, studies that relate the amount of transported sediments to water turbidity could make the transport monitoring based on turbidity data less costly in terms of funding, time and labor. In this way, this article evaluated the turbidity parameter to determine the sediment transport in lotic environments.

2. MATERIAL AND METHODS

2.1. Sampling locations

The fluvial sediments transport evaluation was carried out by collecting water and flow measurement at points located in channels of the Maringá Stream watershed, located in Maringá, Paraná State, Brazil. The area of this watershed is 93 km^2 and its average slope is about 6% (BORSATO; MARTONI, 2004). Figure 1 shows the collection sites where was assessed the fluvial sediments transport (solid discharge).

Four collection points were set in this watershed stream: one at Mandacaru Creek (MS), one at Romeira Creek (RS) and two at Maringá Stream (MS1 and MS2).

2.2. Water flow and water samples collection

To evaluate the suspended load, the water samplings were carried out after rain events, whenever possible. The samples were sent to laboratory for a sediment concentration determination and turbidity. The samplings were conducted between July 2008 and August 2009.

The flow had to be calculated to determine the amount of transported solids. The flow rate was measured using the velocity and stream width and depth. The velocity was measured using the FlowTracker® device, following the procedure of measurements in equal width.

For water samplings, the device used for collections was the USDH-48 sampler. The collections were carried out as follows: the sampler was dipped in the water flow (vertical integration) at a constant velocity until reaching the riverbed, then instantly reversed and raised back to the water surface at a uniform rate, during a minimum sampling duration, calculated according to river velocity and depth.

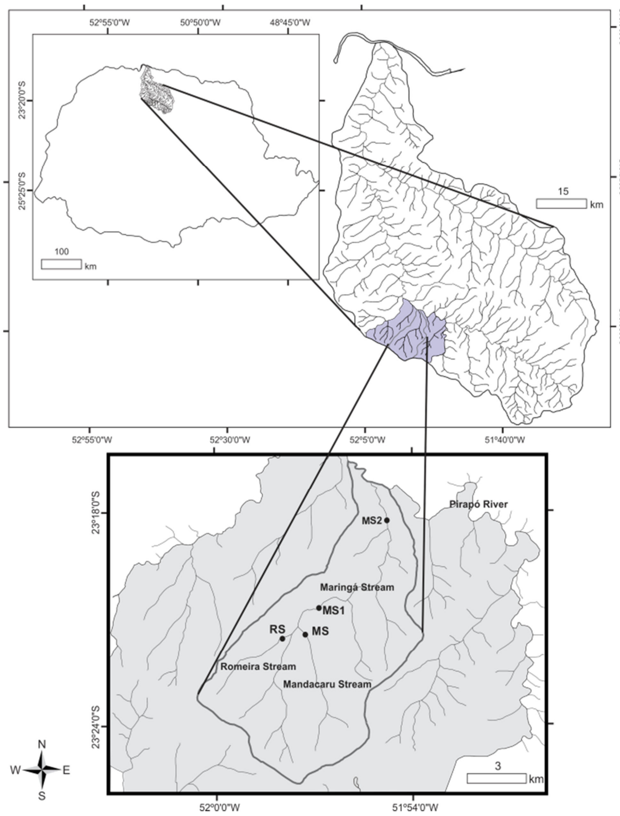

Figure 1. Maringá Stream watershed and sediment sampling points.

For the assessment, which was undertaken according to the integration method, the different samples from each vertical were collected, and homogenized in a single container at the end of the survey. Following homogenization, one part of the sample was placed in a refrigerated environment (container with ice), carefully avoiding freezing. The sample was taken to the Environmental Control, Conservation and Management Laboratory, belonging to the Chemical Engineering Department at the State University of Maringá. The solid sediment discharge was calculated through Equation 1, using data of flow and sediment concentration.

$$Q_{ss} = kQC_{ss} \qquad \text{(Equation 1)}$$

In which: Q_{SS} is the discharge or flow of suspended sediments ($kg.h^{-1}$); k is the unit transformation constant; Q is the liquid discharge or flow ($L.s^{-1}$); C_{SS} is the concentration of suspended sediment ($mg.L^{-1}$).

2.3. Determination of solids and turbidity in water

The sediment concentration (suspended solids) in the collected water samples was determined according to the methodology described by the American Public Health Association – Standard Methods for the Examination of Water and Wastewater, APHA (1995).

Suspended solids were determined by the filtration method. In this process, when samples arrived in the lab, they were filtrated by membranes with at least 0.45 µm pore diameter. Prior to being used, the membranes were oven-dried at temperatures between 100-110°C during 12 hours, then weighed. The concentration of suspended material for the respective sample volume that was actually filtered was determined by the difference between membrane mass before and after filtration (APHA, 1995).

Water turbidity values were determined in each sample collected using an APTO 1000II turbidimeter, which gave readings in Nephelometric Turbidity Units (NTUs).

The turbidity data obtained were plotted against sediment concentration and the relationship was analyzed. A linear model were used for represents the behavior between turbidity and sediment concentration. Using the models for each studied points, a "new sediment concentration" were determined from turbidity, and using Equation 1, the "new sediment transport" (Q_{ss}Corr) were also calculated. The "new sediment transports" were compared with sediment transports (Q_{ss}) calculated from direct determination of sediment concentration.

3. RESULTS AND DISCUSSION

Twelve samplings were carried out for Romeira Creek and Maringá Stream – segments represented by points 1 and 2 – and seven for Mandacaru Creek. The number of samplings was lower for Mandacaru Creek due to the fact that following a few rain events it became difficult to safely measure the flow and collect water. Because the river's headwaters are located in an urban area, water volume and the amount of waste that flowed down the river made measurements impossible.

The results found are presented below. A hypothesis test was applied for each of the monitored points. For this test it was found that there was a significant correlation between turbidity and suspended solids parameters at a 5% level of significance for all the points.

Figure 2 shows the relationship between turbidity and suspended solids in the samples of the studied segments from Romeira and Mandacarú Creeks.

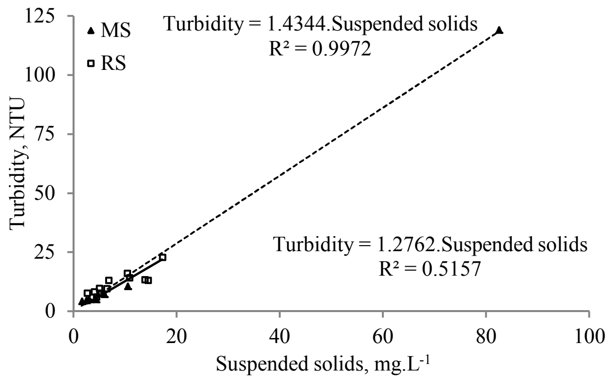

Figure 2. Relationship between turbidity and suspended solids for the different segments of Mandacaru and Romeira Creeks.

Figure 2 demonstrates that turbidity increases when there is an increase in the suspended solids concentration. The data obtained for Mandacaru Creek (MS) showed extremely high correlation, whereas the correlation for Romeira Creek (RS) showed an average value. In other words, practically all turbidity at Mandacaru Creek is explained by the sediment concentration (suspended solids) parameter, while at Romeira Creek less 52% of turbidity is explained by the suspended solids parameter.

It is believed that because a significant amount of organic matter, such as leaves and branches observed at the creek, these contributed to alter turbidity. So, not just the sediment concentration alters the turbidity in that creek. It is noteworthy that the drainage area of the Romeira Creek watershed does not suffer interference from urban areas, and that management of agricultural areas prevents the solids transport to the creek.

For the segments represented by points MS1 and MS2, the Figure 3 shows that there is also a trend of increasing the turbidity as the suspended solids concentration goes up. A strong correlation was detected between turbidity and suspended solids, especially for point MS2, in which a correlation of nearly 0.97 was found – that is, theoretically a large share of turbidity can be explained by suspended solids.

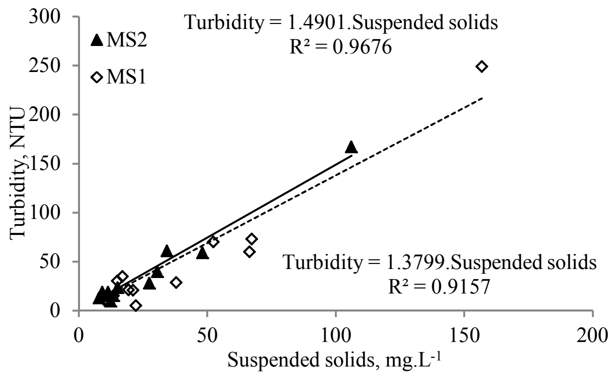

Figure 3. Relationship between turbidity and suspended solids for the segments at Maringá Stream.

On the other hand, a close look at the spatial distribution points shows that the data are scattered. Thus, we observe that even if the correlations shown for the segments represented by points MS, MS1 and MS2 are strong, so is the dispersion of the points. This behavior indicates that the determination of sediment transport using regression between data can lead to errors.

The turbidity values are changed according to the dissolved elements present in the water as, for example, iron (SILVA et al., 2009) and particle sizes (REGÜÉS; NADAL-ROMERO, 2013) so that there were differences between the turbidity values in relation to amounts of suspended solids. After that, there are sediment concentration changes at same flow rate according to the hysteresis behavior (MINELLA et al., 2011).

Thus, using the correlation equations presented in Figures 2 and 3 to calculate "new sediment concentrations" (Q_{ss}Corr), we can analyze the error that was caused in the calculation of a sediment transport if turbidity and sediment concentrations correlations were used to calculate a new sediment transports. The values are shown in Tables 1 at 4.

At high concentrations, it was detected that the relationship between turbidity and sediments created the smallest differences between the obtained and calculated solid discharges. This is important because the greatest problems or losses occur when high rates of sediment transport are observed.

Table 1. Values of solid discharge determined by the concentration of suspended solids and calculated by the correlation for Mandacaurú Creek.

C_{ss} mg.L^{-1}	TB NTU	Q_{ss} kg.h^{-1}	Q_{ss}Corr kg.h^{-1}	% D
1.6	4.22	0.9	1.6	-83.9
4.3	5	3.6	2.9	19.8
2.5	4.6	2.0	2.5	-28.3
3.0	4.92	1.7	1.9	-14.3
6.0	7.1	4.2	3.5	17.5
82.5	119	98.1	98.7	-0.6
10.5	10.5	6.9	4.8	30.3

C_{ss} – Sediment concentration; TB – Turbidity; Q_{ss} - Solid discharge; Q_{ss}Corr - Solid discharge obtained by correlation; D – Difference between Q_{ss} and Q_{ss}Corr.

Table 2. Values of solid discharge determined by the concentration of suspended solids and calculated by the correlation for Romeira Creek.

C_{ss} mg.L^{-1}	TB NTU	Q_{ss} kg.h^{-1}	Q_{ss}Corr kg.h^{-1}	% D
14.4	13.1	3.3	2.3	28.7
5.0	9.7	1.8	2.7	-52.0
2.6	7.7	0.8	1.8	-132.1
4.0	8.2	1.2	1.9	-60.6
13.8	13.4	6.4	4.9	23.9
17.2	22.8	8.8	9.1	-3.9
10.8	14.2	4.6	4.7	-3.0
5.3	7.72	2.0	2.3	-13.4
4.4	6.01	1.6	1.7	-7.0
6.8	13.1	2.7	4.1	-51.0
6.4	9.51	2.3	2.7	-16.4
10.4	16.1	3.6	4.3	-21.3

C_{ss} – Sediment concentration; TB – Turbidity; Q_{ss} - Solid discharge; Q_{ss}Corr - Solid discharge obtained by correlation; D – Difference between Q_{ss} and Q_{ss}Corr.

Table 3. Values of solid discharge determined by the concentration of suspended solids and calculated by the correlation for point 1 -Maringá Stream – MS1.

C_{ss} mg.L^{-1}	TB NTU	Q_{ss} kg.h^{-1}	Q_{ss}Corr kg.h^{-1}	% D
66.5	60.0	188.9	123.54	34.6
38.0	28.6	104.6	57.03	45.5
21.2	20.6	64.2	45.21	29.6
13.6	15.0	33.6	26.90	20.1
22.3	4.92	62.5	10.00	84.0
15.0	30.1	45.4	65.96	-45.4
156.9	249.0	815.9	938.62	-15.0
67.4	73.0	242.3	190.16	21.5
10.2	10.4	29.3	21.64	26.1
19.4	21.1	54.2	42.69	21.2
52.4	70.1	189.5	183.71	3.1
17.0	34.9	46.6	69.33	-48.8

C_{ss} – Sediment concentration; TB – Turbidity; Q_{ss} - Solid discharge; Q_{ss}Corr - Solid discharge obtained by correlation; D – Difference between Q_{ss} and Q_{ss}Corr.

Thus, whenever quick information is desired on discharge generated in a lotic environment, we observed that using the correlations between turbidity and sediment concentration that it can represent a solution. Despite the errors in determining the solid discharge calculated by the correlation, the order of the values magnitude was identified. In other words, a preliminary estimate can be easy, cheap and quickly to obtain the discharge.

Table 4. Values of solid discharge determined by the concentration of suspended solids and calculated by the correlation for point 2 -Maringá Stream – MS2

C_{ss} mg.L^{-1}	TB NTU	Q_{ss} kg.h^{-1}	Q_{ss}Corr Kg.h^{-1}	% D
66.5	60.0	188.9	123.54	34.6
38.0	28.6	104.6	57.03	45.5
21.2	20.6	64.2	45.21	29.6
13.6	15.0	33.6	26.90	20.1
22.3	4.92	62.5	10.00	84.0
15.0	30.1	45.4	65.96	-45.4
156.9	249.0	815.9	938.62	-15.0
67.4	73.0	242.3	190.16	21.5
10.2	10.4	29.3	21.64	26.1
19.4	21.1	54.2	42.69	21.2
52.4	70.1	189.5	183.71	3.1
17.0	34.9	46.6	69.33	-48.8

C_{ss} – Sediment concentration; TB – Turbidity; Q_{ss} - Solid discharge; Q_{ss}Corr - Solid discharge obtained by correlation; D – Difference between Q_{ss} and Q_{ss}Corr.

4. CONCLUSION

Evaluating sediment transport using the correlation between turbidity and sediment concentration led to significant errors. On the other hand, because it represents a quick and inexpensive reading, determining turbidity instead of sediment concentration can be an important tool whenever instant information needs to be evaluated. This is because the use of the turbidity parameter led to quantification of transport in the same order of magnitude as the determination of transport by quantifying solids. That is, it is not a precise piece of data, but it makes possible to identify the magnitude order.

Lastly, obtaining more data and calibrating the curve over time could reduce the errors observed here, resulting in better transport data with values closer to reality.

5. ACKNOWLEGMENTS

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