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REGRESSION MODEL AS A TOOL TO PREDICT CONCENTRATIONS OF TOTAL SUSPENDED SOLIDS IN RIVERS

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Abstract

The river polluted by different discharges today is a worldwide growing concern. Due to human interactions and hydrological extreme events, the amount of total suspended solids in rivers is continuously changing. For river quality, the estimation of Total Suspended Solids (TSS) is a must. The direct measurement of TSS requires frequent sampling, large suspension volume and is a very time consuming laboratory procedure. Therefore, the goal of the study was to develop a regression model that would enable the tracking of changes and predict TSS in rivers, through the measurement of turbidity. For this purpose, the grab samples were collected and then used for the preparation of subsamples in the laboratory. The results provided the necessary data for the establishment of a regression model. The relationship showed that there is a relation between turbidity and TSS, within the observed ranges, since the coefficient of determination is $R^2 = 0.8687$.

Keywords: *Total Suspended Solid, turbidity, regression model, sub samples, rivers, quality.*

Introduction

Today, as a result of the increased urbanisation and many new construction sites, rivers are becoming a receiving point for sediment discharges. Rivers are receiving untreated municipality wastewaters, industrial wastewater discharge, agricultural runoff and mining activities discharges as well as leachate from waste disposal sites. Also, the sediment amount in rivers is changing as a result of many natural hydrological events.

The presence of Suspended solids in rivers is a concern since very often solids can be associated by many other contaminants and nutrients, including phosphorus (Horowitz, 2008). To evaluate the total suspended solids in rivers is very long and expensive process. Typically it includes traditional grab sampling methods, which unfortunately couldn't evaluate daily, weekly and monthly concentrations and fluxes of suspended sediments concentrations (Christensen et al., 2002). The aim of this work is to establish a regression model that would enable the measurement of TSS in urban streams through the measurements of turbidity. Turbidity is the measurement of stream transparency, after the light is scattered and absorbed by

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the suspended sediment particles (Ziegler, 2002). Our regression model is based on the TSS analyses because it is a component of surface water quality and a significant indicator of physical, aesthetic degradation and other pollutants (particularly nutrients and metals) (Packman et al., 1999).
The universal correlation between turbidity and TSS doesn't exist, however there are some investigations showing that turbidity is in relation with suspended sediments. It is known that the eventual relationship between TSS and turbidity is affected by density, size and shape of particles and water colour (Nasrabadi et al., 2016). But, if a good correlation between TSS and turbidity is developed then turbidity may serve as a proxy for suspended solids and pollutant concentrations within a chosen basin (Nasrabadi et al., 2016).
Many researches have been conducted in this field. The relationship between suspended sediment and turbidity along the Elbe River was investigated by The German Federal Institute of Hydrology. This study took place from June 1996 until February 2001 and involved 1405 measurements of turbidity, suspended matter and flow rates. The study showed that large stream bed particles and water colour adversely affected the measurements and the measurement error was found to increase with increasing flow rate. A linear relationship between TSS and turbidity was found for naturally suspended sediments in rivers in South Germany as well (Rugner et al., 2013).
Another investigation was conducted in Kansas River and Little Arkansas River. About twenty samples were collected at eight stream-gauging stations between 1998 and 2001 in order to document the effectiveness of turbidity as a surrogate (Christensen et al., 2002). Results from this study, showed a coefficient of determination of 0.987 between the turbidity and suspended sediments. This was due to the favourable condition of turbidity measurement, noticing that the particle size for the test sites was 95 percent fines.
For this study's selected location, establishing a regression model required frequent sampling and measurement of turbidity and TSS. Due to financial issues, there was limited time and personnel available, so a different approach was used for this research (Kusari, 2012). Instead of frequent sampling to obtain the needed data, the laboratory subsamples were prepared with sampling from two locations, each with different turbidity and TSS concentration. The results gained from the laboratory analysis of subsamples provided the necessary data for the regression model, which was developed by conducting a linear regression analysis.

Site description

Sitnica River, as the main river flowing through Sitnica Catchment (Fig. 1) was selected for this research. Sitnica River is 167 km long and has average annual flow of 13.62 m^3/s. It is a meandering river mainly because of its small longitudinal slope of only 0.054%. The minimal water flow is 0.50 m^3/s and the maximal values of this river flow reaches up to 328,0 m^3/s (source: Hydrologic station in Nedakovc, Hydro Meteorological Institute of Kosovo).

Sitnica is amongst the most polluted rivers in Kosovo since it receives the untreated domestic and industrial waste waters.

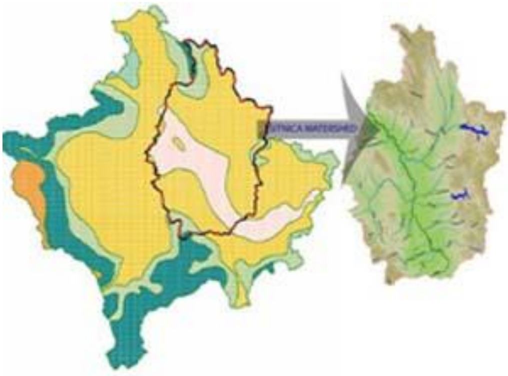

Figure 1
Map of Kosovo – Sitnica River Basin

At least 32 other different polluters are identified in the vicinity of Sitnica River, which contributes directly to its pollution (The State of Water in Kosovo - Report, 2010). Sitnica River is also endangered by various industrial activities such as ironmongery, the food and textile industry, the metallurgical and chemical industry as well as the energy industry. Therefore, the Sitnica River will be used for this research. The sampling location, as shown in the Figure 2, is Sitnica River near the Vragoli, with the coordinates 42.609138 latitude and 21.061295 longitude. The water samples from this location will be used for the development of a site specific regression model between turbidity and Total Suspended Solids.

Figure 2
Sampling location - Sitnica River

Materials and methods

The grab sampling was performed since it requires fewer personnel and financially it is more acceptable sampling method. Samples were collected manually with the use of a sampling rod, in clean 1000 ml polyethylene bottle, filled previously, shaken well and discarded away (Kusari, 2012).

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After that, two sets of grab samples were taken from the sampling locations. The second water sample served as a dilution for the first sample. For the determination of turbidity to TSS relationship, the sub sampling was done in a laboratory.
Sub sampling was carried out in order to prepare representative samples for the turbidity and TSS measurements. This method of sub sampling was based on the procedure described by Earhart (1984), which was initially designed to ensure compliance of the effluents from dike confined disposal facilities (CDFs) with the Total Suspended Solids violence standard set previously. The Earhart described the process of taking and mixing the samples of water and sediment to form suspensions, which were then tested for turbidity and TSS. The same suspensions were further diluted, remixed and also tested for the mentioned parameters. This procedure was repeated continuously, until 10 sub samples were gained and the laboratory results were used to plot a correlation curve (Thackston and Palermo, 2000).
Accordingly, the process of preparing subsamples for our study site, based on the Earhart described procedure, was as follows:
1. The original sample was well stirred to ensure consistency of the sample collected.
2. Then, from the first 1000 ml water sample, 100 ml of water were extracted and poured into previously prepared sub sampler of 120 ml volume.
3. From the second water sample (with the lower turbidity levels), 100 ml of water were extracted and added to the first water sample. Now, the first water sampler had 1000 ml in volume again, but at a different turbidity level.
4. After agitating the mixture, another 100 ml of water had to be extracted, and put to the second sub sampler of 120 ml volume.
By now, there were two sub samplers, 120 ml in volume, which were used for the determination of turbidity and TSS values.
5. Further, the process was repeated continuously, until 10 sub samples were filled and prepared for further laboratory analyses, one day after the river water collection.

Those subsamples were then sent to the Hydro Meteorological Institute of Kosovo (HIK) for the analyses of turbidity and TSS concentrations. The turbidity level was analysed by a portable nephelometer (Hach 2100N Turbiditimeter) and the turbidity units were reported in Nephelometric Turbidity Units (NTU), which represents a measurement of the light intensity being scattered, when light is transmitted through a water sample. This procedure was repeated for all water subsamples. On the other hand, the concentration of Total Suspended Solids (TSS) was analysed using the filtration method, by filtering a samples water volume through a membrane filter and weighing the dried residue.

Results and Discussions

To develop a regression model, initially data sets were plotted and analysed. The increase of TSS is associated with an increase of turbidity as well. Correlation between TSS concentration in y- axis and turbidity level in x-axis is developed by the use of a linear regression model. According to APHA, the turbidity is the optical property of water which causes the light to be scattered and absorbed rather than transmitted. The interaction between light and suspended particles in water subsample affects the value of turbidity. So, even though the turbidity does not measure directly the total suspended solids in water, it can be a useful tool for the estimation of the TSS concentration in our water subsample. After the plotted results, the summary output of the linear regression analyses for turbidity and TSS is given in the following table (Table 1).

Table 1
Summary output of the linear regression analyses.

Statistic regression	
Multiple R	0.932066903
R. Square	0.868748711
Adjusted R Square	0.8523423
Standard Error	1.491353451
Observations	10

	Coefficients	**Standard error**	**T Stat**	**P-value**
Intercept	3.680499888	1.724372446	2.134399617	0.065343801
X Variable1	0.857208815	0.117800284	7.276797547	8.57932E-05

The derived regression model for a study site, as noted from the summary outputs of the linear regression analyses, Table 1, is as follows:

$$TSS\ (mg/l) = 0.8572\ TTU\ (NTU) + 3.6805 \qquad [1]$$

Table 2.
Variable description

Variable	**Unit**	**Description**
TSS	(mg/l)	Total Suspended Solids
TTU	NTU	Turbidity

The equation [1] represents the relation between turbidity and TSS for our study site. The formula is gained after the laboratory analyses of our subsamples and results were used to plot a line between two parameters. The use of linear regression model, with Excel, using ANOVA analyses toolpack enabled the derivation of the above equation [1].

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Turbidity in our relationship, equation [1] as an explanatory variable, can be used to compute the response variable Total Suspended Sediments. As shown in the table 1, there is a strong correlation between turbidity and TSS for the selected location, (with a correlation coefficient of 0.868), since the predictive ability of the relationship can be assessed based on the coefficient of determination (R^2).
This equation is site specific and can only be applied for the investigated location. Other authors have developed similar equations, that will relate the turbidity and Total Suspended Solids, but with different coefficients of determination. For example, Yaseri et al. (2013), used turbidity to calculate the Total Suspended Solids in storm water, with the help of a log linear model. On the other hand, TSS concentration in sewers was estimated from turbidity measurements by means of linear regression, by Bertrand-Krajewski (2004). Another similar correlation equation, (with the coefficient of determination of $R^2 = 0, 80$) was determined for the data collected from 14 river –streams around Singapore, by the research of Daphne et al. (2011).
Equation [1] which represents our site specific correlation model is a useful real time indicator of total suspended solids, as noted by Thackson and Palermo (2000). Also, studies have indicated that the relationship between turbidity and total suspended solids shows good linearity (R^2 above 0, 80) regardless of weather conditions (Hannouche et al., 2011), but this needs to be further investigated for our site specific model. This model can also be used to detect sudden changes of water quality when pollution loads are introduced into a stream, especially heavy metals and metalloids in catchments as noted by Nasrabadi et al. (2016).

Conclusions

As the result, the developed regression model for analyzed river water indicates a fairly good linear correlation between TSS concentrations and turbidity levels. For the sampling site in this project, the Sitnica River reach, the turbidity is a significant factor when predicting the Total Suspended Solids value, since the correlation coefficient of $R^2= 0.8687$ is quite high. This correlation between turbidity and TSS is high even compared with the correlation coefficients from studies of Daphne et al., 2013. Daphne et al. conducted a research in Singapore Rivers, for the correlation between turbidity and TSS and developed a correlation coefficient $R^2= 0.800$, slightly lower than in our research. The higher correlation coefficient (of $R^2= 0.979$), was developed by a log linear model of Yaseri et al. (2013) while using the turbidity to determine Total Suspended Solids in storm water runoff from green roofs. Also, a study from Packman et al. (1999), focused on using turbidity to determine Total Suspended Solids in urbanizing streams in the Puget Lowlands, derived a correlation coefficient as high as of $R^2= 0.96$. As a conclusion, the results gained by this regression model, for our Sitnica River, the correlation coefficient $R^2 = 0,868$ were in quite good agreement with independent values for turbidity and TSS taken at the same location.
In cases when pollution loads are discharged into stream and there are sudden changes of river water quality, this regression model (equation [1]) can be used to

detect these situations. The river water quality monitoring will be time effective and financially wise with the use of this regression model. It will also help take the immediate actions for preventing further river deterioration.

However, more information is required to validate this regression model. Since the sampling was performed during dry wet conditions, the occurrence of heavy rain or snow melting in the spring may change the TSS concentration in river and turbidity value as well. More sample collections and laboratory analyses are required for the more accurate regression model. But, the firs results indicate that we can replace the measurements of TSS concentrations in this area by the easier and less costly turbidity measurements, by the use of this regression model.

It can also be used for measuring stream bank erosion, nutrient, contaminant transport and sediment loads. The benefits of water quality measurements using this regression model include the ability for quick action in response to negative water quality changes. This will result in a reduction of overall monitoring costs. Additionally, when surface water quality criteria are exceeded, then immediate action can be taken.

The outcome of this research, the regression model for Sitnica River, can help in documenting the effectiveness of stream restoration projects. In agriculture, it can help in monitoring suspended solids, in order to reduce non-point source pollution. The data gained from this regression model can be used to identify water bodies impaired by suspended solids, to prioritize areas for additional monitoring and research, and to detect trends of increasing or decreasing erosion in a watershed.

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