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Sediment transport modeling in circular smooth and rough rainwater transport pipes using factorial analysis, intelligence and empirical methods

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ABSTRACT: Sedimentation is one of the serious problems in water and urban wastewater transport pipes, which disturbs the transport of water flow. In this study, the capability of the intelligence Gaussian Process Regression (GPR) approach was investigated in predicting sediment transport in circular rainwater transport pipes with smooth and rough beds. In this regard, at first, the hydraulic and sediment parameters which had the most correlation with sediment transport were determined using factorial analysis. Then, different models were developed using these parameters and were investigated via three experimental data series. Also, the accuracy of the obtained results was compared with the traditional techniques. The results showed the high efficiency of the intelligent GPR model in the prediction of sediment transport in rainwater transport pipes compared to the empirical methods based on non-linear regression techniques. For the two-mentioned hydraulic conditions of pipes, the model with input parameters λs, Fm, Dgr, d50/y, which are relative sediment size, non-dimensional sediment size, Froude number of sediments, and total roughness coefficient, respectively, was obtained as a superior model. The factorial and omitted sensitivity analysis showed that d50/y was the most effective parameter in the estimation of sediment transport in both smooth and rough pipes.

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1- Introduction

Sediment transport and accurate prediction of its rate are some of the important issues for hydraulic engineers and researchers. Due to the complex nature of bedload transport and the lack of measured data and validated models, it is difficult to simulate bedload discharge in sewer pipes carrying stormwater. A large number of classical sediment transport models have been developed, which describe the complex phenomenon of the bed sediment transport process in pipes and channels. May [1] studied the limit of the deposition state using 77 and 158 mm diameter smooth pipes flowing full and part-full. Vongvisessomjai et al. [2] studied the sediment transport for non-cohesive sediment in uniform flow at the non-deposition state. A semi-theoretical sediment transport equation at the non-deposition state was developed by Ota and Perrusquıa [3]. In recent years, the Meta model approaches such as Artificial Neural Networks (ANNs), Neuro-Fuzzy models (NF), Genetic Programming (GP), Support Vector Machine (SVM), and Gaussian Process Regression (GPR) have been applied in investigating the hydraulic and hydrologic complex phenomena. Due to the complexity of the sediment transport and the effect of various parameters on its prediction, in this study, the capability of GPR as a kernel-based was assessed for sediment transport modeling in sewer pipes with smooth and rough beds. The models were prepared based on hydraulic characteristics and properties of the solid load. Then, the accuracy of the best GPR model was compared with the accuracy of several existing empirical equations. Also, the factorial and omitted sensitivity analyses were performed to determine the most effective parameters in the sediment transport prediction process.

2- Methodology

In the current study, sediment transport in smooth and rough bed sewer pipes was investigated using the GPR method. The GPR models are based on the assumption that adjacent observations should convey information about each other. Gaussian processes are a way of specifying a prior directly over function space. This is a natural generalization of the Gaussian distribution, whose mean and covariance are a vector and matrix, respectively. The Gaussian distribution is over vectors, whereas the Gaussian process is over functions. Thus, due to prior knowledge about the data and functional dependencies, no validation process is required for generalization, and GP regression models are able to understand the predictive distribution corresponding to the test input. A GP is defined as a collection of random variables, any finite number of which has a joint multivariate Gaussian distribution. For investigating the main effects of

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Table 1. Statistical parameters result for Test series

Model	Performance criteria					
	Testing set		Testing set		Testing set	
	R	RMSE	R	RMSE	R	RMSE
	Smooth		Rough		Mixed data	
λs, Fm	0.507	0.199	0.445	0.199	0.507	0.199
Dgr, Fm	0.729	0.148	0.659	0.157	0.729	0.148
λs, Fm, Dgr	0.873	0.083	0.871	0.092	0.873	0.083
λs, Fm, y/d_{50}	0.881	0.080	0.879	0.082	0.881	0.081
λs Fm, Dgr,d_{50}/D	0.883	0.079	0.880	0.081	0.883	0.080
λs, Fm, Dgr, y/d_{50}	0.940	0.067	0.922	0.066		
λs , Fm, Dgr, d_{50}/y	0.962	0.052	0.980	0.057		

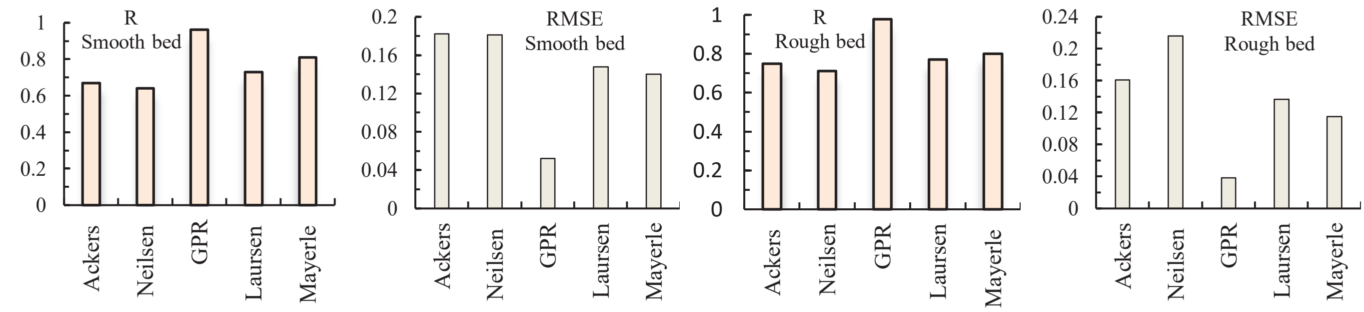

Fig. 1. Comparison of prediction from proposed equations and the best GPR model.

parameters quantitatively, the factorial analysis (FA) was also performed. FA is originated from experimental design to explore both the main and interaction effects of several factors on a response variable [4]. It is particularly useful when there is a curvilinear relationship between design factors and the response variable. In fact, FA attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. It is often used in data reduction to identify a small number of factors that explain most of the variance that is observed in a much larger number of manifest variables. FA can also be used to generate hypotheses regarding causal mechanisms or to screen variables for subsequent analysis.

3- Results and Discussion

In order to evaluate and review the performance of the developed models and determine the accuracy of the selected models, three performance criteria named Correlation Coefficient (R), and Root Mean Square Errors (RMSE) were used according to Table 1. At first, affected parameters were determined via factorial analyses then, using these parameters, several models were developed and tested. According to the results, superior performance for smooth and rough beds was obtained for the model with inputs λs, Fm, Dgr, and d50/y. According to Table 1, it seems that for modeling bedload transport in sewer pipes using relative flow depth and overall friction factor as input parameters improved the efficiency of the models. In order to obtain a model which could be applied for both smooth and rough pipes, data sets of smooth and rough beds were used together. The best models were selected to analyze the new data sets. The obtained results are listed at the end of Table 1. Based on this table, using the mixed dataset decreased the models' accuracy. However, it should be considered that the models based on mixed data sets are able to cover a wider range of data. In this case, the sediment transport process can be studied without regard to the pipe bed condition (i.e., smooth or rough bed).

The experimental data in pipe channels were used to evaluate the applicability of several existing equations for sediment transport. Based on Figure 1, the results showed that the used formulas didn't yield reasonable results, while the results obtained by the best GPR models were close to the measured data.

According to Figure 2, sensitivity analysis was performed to determine the most significant parameters in the modeling process. It was observed that d50/y is the most effective parameter in sediment transport modeling.

4- Conclusions

The comparison of the developed models' accuracy revealed that GPR models had better performance compared with the semi-empirical models in predicting the sediment transport in sewer pipes with different bed conditions. Also, based on the sensitivity analysis, d50/y was found to be the most effective parameter in the modeling process.

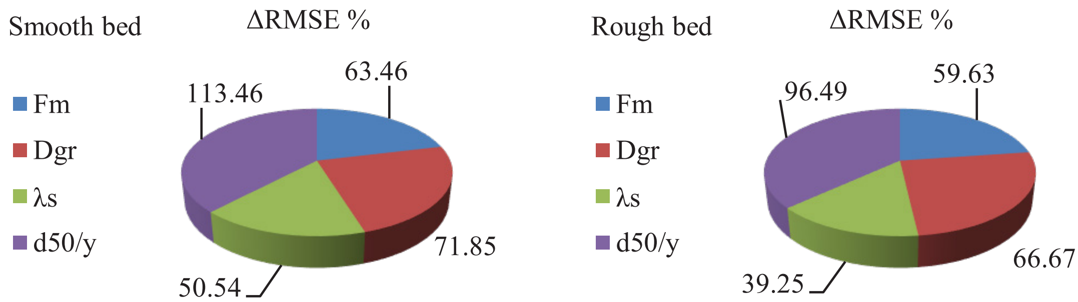

Fig. 2. Relative significance of each of input parameters of the best model

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