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A Review on the Sedimentation Problem in River Basins

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ABSTRACT

River sedimentation is a global concern evidenced by a number of studies conducted. Now, that climate change is being experienced the rapid changes on the river landscape is manifestly observed. As unveiled, natural evolution of landscape and human activities are the two main factors affecting this phenomenon. Different methods of determination of the volume of sediments transported some are employed. Some studies used classic methods utilizing sophisticated apparatus while others artificial intelligence mode of sediment transport prediction.

Keywords: *river sedimentation, sedimentation, river basin*

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INTRODUCTION

Rivers are natural resources water flowing through to the sea or ocean. Some of the major rivers in the world are part of the history of human race. To name a few are Nile River, Yellow River, and Indus River. Rivers essentially helped improve the economy of a country. To some rivers are simply source of water for plants and animals and other domestic use, source of water for irrigation, a body of water for recreation and sports opportunity, navigation and transportation, for urban development, and for industry and energy development as well. But to others, river is part of their lives. It seems river has a connection in their lives especially when times they need tranquility.

Due rapid phase of human activities and development like urbanization and natural resources exploitation, there are water-related risk like flooding and water scarcity are being experience nowadays. Xu Jiong (1996) concluded that human activities have a great influence on the composition of suspended sediment, in that the quantity and quality of suspended sediment are greatly altered after the natural vegetation is destroyed by man. Furthermore, because of these activities, the landscape had been degraded by soil erosion which resulted to sedimentation of the river. It was found out by Petkovic et al. (1999) that the significance of soil erosion and related sediment problems is broadly recognized throughout the world. In addition, they also they said that erosion and sedimentation are part of the natural evolution of the landscape, but they constitute some of the most fundamental problems for the development of agriculture and forestry and for utilization of natural resources and they related these two processes to conditions in a river basin topography, geology, climate, hydrology, vegetation and sediment characteristics. Year 2000, when Di Stefano et al. analyzed that soil degradation in the form of water erosion has been recognized as a serious environmental problem in many parts of the world. Furthermore, according to them soil erosion on cultivated land causes damage because bare soils are often exposed for most of the year to the action of impacting rainfall and runoff. And they also said that soil erosion also causes other environmental problems such as reservoir sedimentation and non-point source pollution.

Elci et al. (2009), stated that sustainable management of soil and water resources is one of the critical environmental issues facing many countries, particularly developing countries and this include water supply, water quality, flood control, soil erosion, irrigation, tourism, reservoir management and fishing. Also, accordingly, of these issues, soil erosion causes the greatest environmental deterioration through both on-site (with the loss of fertile soil) and off-site (by deposition of eroded sediments) effects. Hence, this work is initiated.

This work intends to summarize the knowledge that is required for a water resources engineer or manager ought to know for him to prepare a sustainable management plan to save our rivers.

Discussion

Several studies were conducted in different places in the world on sedimentation in river basins. The studies cited below offer knowledge enrichment on the subject matter.

Sedimentation. General Concept and Processes

Sedimentation is a process of settling and depositing suspended matter in water by gravity as defined by Ozgur Kisi (2005). The assessment of the volume of sediment transported by a river is of vital interest in hydraulic engineering due to its importance in the design and management of water resources projects and the prediction of river sediment load constitutes an important issue in hydraulic and sanitary engineering (Kisi, 2005). Also, the evaluation of sediment yield in rivers, where total load consists predominantly of suspended load, plays an important role in the design of soil conservation and pollution control practices as well as in the design and management of dams, canals and other hydraulic structures (Caroni 1984).

As what Chen et al. (2016) discussed in their study, sediment transport in river can generally be classified into two major patterns, namely, the bed load and the suspended load, which depends on both the particle size and the flow conditions. Moreover, according to them, when the bed shear stress exceeds the critical value for incipient motion, the sediment begins to move by sliding or rolling over the bed and so if the bed shear stress further increases, the particles will jump up from the bed and start to saltate. Furthermore, they defined bed load transport which refers to movement of sediment particles by rolling, sliding and saltating.

Factors Affecting Sedimentation

Human Activities: Human activity has dual effects resulting in both increase and decrease of sediment (Gangyan et al. 2002). Analysis of the hydrological and geomorphological regimes of the River Morava over the last 130 years discloses a dynamic fluvial system that has been predominantly governed by direct, as well as indirect, human interventions since the first half of the 20th century (Brazdil et al. 2011).

Land Use and Urbanization: Lal (1985) stated that rapidly changing land use is one of the major factors responsible for accelerated soil erosion, and the effects of deforestation, grazing, fire, and of cultural practices. Hume et. al. (1986) concluded that catchment urbanization is expected to double suspended sediment input to Lucas Creek. Analysis of the effect of land use on water and sediment flux showed that agricultural use of land increases the surface runoff, soil loss and sediment yield more than those of the forest and grassland. This effect was also higher even when tilled and tile drains were not used (Maalim et al. (2013). However, with the considerable changes in the surface runoff and sediment load under the impact of land-use change, the effect of land-use change should be accounted for in water resource management in the Be River catchment (Dao Nguyen Khoi & Tadashi Suetsugi, 2014).

Erosion of agricultural cropland has been identified as a major source of sediments accumulating in water reservoir (Smith et al. 2013). Accordingly, poor vegetation and the low soil moisture explain the highest sediment fluxes observed in autumn (Megnounif et. el. 2007). But on the other hand, a study affirms the general character of an exponential decrease of sediment yield with increasing vegetation cover at a wide range of spatial scales, provided the distribution of cover can be considered to be essentially random (Molina et al.2008). However, analysis of correlations between SSY and runoff, vegetation cover and mean slope suggests that SSY is linearly correlated with runoff for catchments with less than 8% vegetation cover and mean slope greater than 40% (Pepin et al. 2010).

Environmental Factors: Rainfall is the principal factor affecting sediment load (Gangyan et al. 2002). Water erosion is a time-varying processes controlled both by rainfall and overland flow according to Hao et al. (2018). Wan Ruslan Ismail (2000) stated that hydrology and sediment transport on the Penang Hill, Malaysia is controlled by the hydro meteorological conditions and a series of rain events will set up wetting conditions favourable for erosion and mass movement, which provide sediment sources in the catchment and consequently, almost 60% of sediment was transported during storms. With an increase in rainfall, the vegetation-covered area decreases dramatically, causing high runoff events and soil loss rates (Alam et al. 2016).

The major factor causing variation in sediment yield from basins of the New Zealand Southern Alps is precipitation, or its surrogate, runoff (Hicks et al. 1990). Sharman et al (1982) said that sandy and eroded drainage basins situated in occasional and sporadic torrential rainfall zones generate heavy sediment inputs into the Nadis and thus limit their capacity for storage. However, coarse to medium grained, loose and less-compact formations lose more sediments with the increasing rainfall and basin slope than the fine-grained, hard and compact formations (Sharma et al. 1982).

Kangsheng Wu & Y. Jun Xu (2007) stated that soil erosion is a function of the eroding power of wind, raindrops, running water and moving earth mass, as well as the erodibility of the soil itself. According to Megnounifet. el. (2007), the high soil moisture and collapse of the stream banks are responsible for the large amounts of sediment produced at the end of the wet period.

Fox et. al. (1993) were able to identify the significant relationships between suspended sediment yields and several environmental factors influencing mechanical erosion, which among others, to wit, (a) mean suspended sediment concentrations and specific sediment yields increase with an increase in rock erodibility, from granites, through limestones and sandstones to marls. For each rock type, a relationship between specific sediment yield and runoff intensity can be established; (b) for all river basins, the mean suspended sediment concentration is inversely related to mean annual runoff, and tends to a limiting value of a few grams per litre; (c) specific suspended sediment yield decreases when the drainage basin area increases. for the major world river basins; and (d) finally, a multiple regression model has been established for all river basins of the Maghreb relating specific suspended sediment yield to several environmental factors. The factors identified by the regression, in order of influence, included the rock erodibility the mean annual runoff and the drainage basin area with the decrease in particle size were consistent patterns of increasing water content and decreasing sediment density (Schiefer, 2006).

Catastrophic phenomena also are contributors of soil erosion and sedimentation in river basin. In Amazon basin, seismic activity is the trigger for the disaggregation of sediments and, together with volcanic activity and variable precipitation, cause higher concentrations of sediments in this region and in the plain Napo basin showed the occurrence of erosion linked to tectonic activity and as well as in Santiago basin, the increased concentration of suspended sediments were observed which were contributed by driving factors such as lithology and seismic activity (Armijos et al. 2013). The large earthquake which affected northern Luzon, Philippines in 1990 has subsequently increased erosion and has prompted significant deposition within the river system (Atkinson, 1995). To a large extent, the sedimentation cannot be separated from tectonic controls (Browne, 1995).

Methods for Estimation and Prediction of Sediment Volume

According to Petkovic et al. (1999) sediment monitoring methodology is standard and consist of daily sampling of water and sediment with laboratory determination of sediment concentration. However, the length of period of observation depends on the scope of study and methods of analysis. The method to be employed to analyze the sediment data also depends on the type of sediment load which may either suspended sediment load or bed load. As studied by Fattorelli et al. (1988), the distinction suspended sediment load and bed load sediment is apparently, arbitrary and it is hardly possible to distinguish the two processes, they can in fact be viewed as two limiting aspects of the very same process. Furthermore, this distinction has a remarkable operational importance, since the measurement of different sensors, installations and rating techniques.

Bed Load: Hubbell (1964), bed load measurement can be determined by direct or indirect samples. Trap sampler is the most widely used but later study said (Fattorelli, 1988) said that available techniques for measurement of bed load transport have serious drawbacks and limitations, and in particular, it does not seem possible to measure bed load transport continuously using sediment traps. However, disturbed bed materials can be obtained by the following types of samplers: drag bucket; clam shell; piston or vertical core; and rotating bucket (ASCE, 1975). Bed load can also be measured by employing indirect method applying one or more bed load equation(s) however, particle size gradation and specific gravity at or near the bed surface are the most important characteristics (ASCE, 1975).

The flume experiment was conducted by Nelson et al (2018) to explore how unsteady and changing sediment supply influence the morpho dynamic evolution of gravel-bed rivers and result showed that unsteady flow had very little effect on equilibrium channel. In the same experiment, the concluded that increasing sediment suppy caused the bed and water surface slopes to increased considerably. Palucis et al. (2018) aslo conducted a series of flumes experiments but focused on the investigation on flow hydraulics, sediment transport rates and intensity, and bedform developed on steep bed slopes. Experiments were conducted using a range of water discharges and sediment transport rates in a 12 m long recirculating flume with bed slopes of 10%, 20%, and 30%, and a bed of nearly uniform natural gravel. On the other hand, Kreisler et al. (2016) used integrated monitoring system that combines the direct (mobile basket sampler, slot sampler) and indirect (geophone plates) measuring devices to investigate the bed load rate/discharge relationships on the actual location.

The classical formula Engelund formula was modified by Meng et al. (2016). The attempt to modify was grounded on the said equation drawback which is the oversimplification of parameters such as the, quantity of particle per unit bed area, mean velocity of moving particles in flow direction and the probability of sediment to be entrained into motion at any instant. After verification against well-recognized measured data, the modified formula has satisfactory predictions. However, Gao (2011) instead of modifying existing equation, he developed an equation for bed load transport capacities in gravel-bed rivers. That formula according to him, can be used to assess maximum possible bed load transport rate in the case of flood discharge.

Lopez et al (2013) evaluated the predictive power of 10 bed load transport formulae by comparing with the bed load rates obtained for a large regulated river (River Ebro), namely: Schoklitsch (1950), Meyer-Peter and Müller (1948), Wong and Parker (2006), Einstein–Brown, Brown (1950), Ackers and White (1973), Ackers (1993), Bagnold (1980), Yang (1984), Rottner (1959), Parker et al. (1982) and Bathurst (2007). The result showed that among the formulae, Meyer-Peter and Müller formula than in that of Bathurst (the only 2 of the 10 formulae that explicitly include the effects of river bed armoring in their development) had smaller discrepancy between predicted and observed bed load discharges.

Sediment Load: For suspended sediment quantification, sampling is necessary to describe accurately the water-sediment mixture. The technique of sampling depends on the stream size – for large river, a special type of pumping sampler (with 40 l bottle) has been developed and the sampling of suspended sediment in smaller river is based on a simple bottle (1- 5 l) sampler (Petkovic et al. 1999). Several studies were conducted on suspended sediment amount prediction using different types of samplers and employing appropriate method(s). Pepin et al. (2010) used depth integrating sampler (USD-74 or USD-59) while Filizola et al. (2004) used ADCP and some other devices. However, Thomas et al. (1988) said that suspended sediment rating "curves" are frequently used to define the water discharge/ suspended sediment relationship changes can either be accessed directly by comparing "before" or "after" rating curves, or the curves can be used to estimate long-term or storm sediment yields.

Various models were also employed to predict estimate of the sediment yield. Gangyan et al. (2002) stated that these models can be grouped as (a) empirical prediction models, (b) process-based prediction models, (c) dynamic simulation models, and (d) stochastic models. To name a few, Zhao et al. (2017), compared two different mathematical models: a fully coupled formulation of shallow water equations with erosions and deposition terms (a depth-averaged concentration flux model), and a shallow water equations with a fully coupled Exner equation (a bed load flux model); Chen et al. (2017) employed convection-dispersion model; Khoi et al. (2014) applied SWAT model; Gong et al. (2011) built a rainfall-run off model through simulation of flow pattern using one–dimensional river network hydrodynamic numerical model and taking the flow of tributaries and water level of boundary condition of the river using one-dimensional hydrodynamics and sediment transport numerical model; Lu et al. (2011) employed large eddy simulation model; Lu et al. (2010) used finite element method (FEM) to simulate sediment hydrodynamics was able to established two dimensional model; Gao, et al. (2010) analysed the precipitation, streamflow, and sediment discharge during 1950-2005 by the Mann-Kendall trend test and Pettitt change –point analysis; Elci et al. (2009), sedimentation patterns within the main lake were modeled by a 3-D hydrodynamics.

Recently, AbebeTadesse and Wenhong Dai, (2018) predicted the sedimentation comprehensively because they considered both the catchment level using Soil and Water Assessment Tool (SWAT) and in the river channel, applying HEC-RAS model. Yilmaz et al (2018), tried to test the applicability of ABC, TLBO, and MARS techniques for estimating SSL and compared SSL estimates (based on several machine learning models) with output obtained from traditionally used classical regression analyses (CRA) and sediment rating curves (SRC) and found that the MARS technique was more accurate than the other models in reflecting SSL change with flow through time and in estimating peak SSL values. Furthermore, they concluded that the Qt parameter (current day's flow data) was extremely effective in estimating SSL.

A comparative study of three different learning algorithms applied to adaptive network-based fuzzy inference system (ANFIS) for daily suspended sediment concentration was conducted by Kaveh et al. (2017). And the result indicated that the models trained with the Levenberg-Marquardt (LM) algorithm had greater ability for predicting the SSC in comparison with the other logarithms. Likewise, Kumar et al. (2015) also conducted a comparative study on the performances of six different soft computing techniques for suspended sediment prediction using hydro-meteorological variables. These techniques were artificial neural network (ANN), radial basis function neural networks (RBFNN), least square support vector regression (LS-SVR), multi-linear regression (MLR) and decision tree models such as Classification and Regression Tree (CART) and M5 model tree. The results showed that LS-SVR model outperformed ANN model and all the other models in this study and can be used as a tool for predicting the suspended sediment at single point of interest in river basin in North-Eastern India. Furthermore, M5 model tree is better in simulating suspended sediment than its near counterpart, the CART model and marginally inferior when compared to LS-SVR and ANN models. Moreover, when using RBFNN extra careful should be taken for the reason that RBFNN model consumes a lot of time to converge and depends solely on number of neurons and stopping criteria. However, MLR model can be a good alternative for sediment estimation on field where quick results are expected in least computational time.

In the study conducted by Kermani et al. (2016), Artificial neural network (ANN) with three different algorithms: gradient descent, conjugate gradient and Broyden–Fletcher–Goldfarb–Shanno (BFGS)] and support vector regression (SVR) models with four different kernels (linear, polynomial, sigmoid and Radial Basis Function [RBF]), evaluated and compared to multiple linear regression (MLR) and sediment rating curve (SRC) models were tested to forecast/estimate daily suspended sediment concentrations (SSC) and the result recommended to use BFGS training algorithm for ANN, and the RBF kernel function for SVR models as useful options for simulating hydrological phenomena.

Shamaei et al (2016) proposed a method to be able to predict the suspended sediment concentration accurately by stacking the genetic programming and neuro-fuzzy. The results clearly prove that the proposed method is able to predict the suspended sediment concentration accurately which was evidenced by the very low amount of Relative Error and RMSE and very high R^2. Furthermore, the results showed that said method can be extended and be used to predict other hydrological quantities such as rainfall, etc.

Artificial neutral networks (ANNs), symbolic regression (SR) based on genetic programming (GP) and adaptive network-based fuzzy inference system (ANFIS) were the three machine learning technique were utilized in an study conducted by Kitsikoudis et al. (2015) to assess sediment transport: In 2011, Rajaee attempted to investigate the hybrid Wavelet analysis and Artificial Neutral Network (WANN) for daily suspended sediment load prediction in Yadkin River At Yadkin College station in the USA and the result showed that said model could predict SSL one day ahead and it could also be used for SSL time series prediction because of using multi-scale time series of discharge and SSL data as the ANN input layer. Furthermore, this model could satisfactorily simulate hysteresis phenomenon, acceptably estimate cumulative SSL, and reasonably predict high SSL values.

Year 2008, Kisi et al. evaluated the potential of adaptive neuro-fuzzy technique (ANFIS) in estimating daily suspended sediment by comparing the results with those obtained by RBNN, FFNN, GRNN, MLR and SR models. Based on the comparison results, the ANFIS technique was found to perform better than the other models. Of all the ANN techniques, the RBNN generally performed better than the FFNN and GRNN. The GRNN method provided the worst suspended sediment load estimates of all the applications relative to the RBNN and FFNN models. The SRC technique was generally found to be better than the MLR. The third application indicated that the SRC may yield better suspended sediment load estimates than the GRNN model. The ANFIS model accuracy was also investigated by comparing the results with those of the other models. The comparisons revealed that the RBNN had the best accuracy in total suspended sediment load estimation. The ANFIS model ranked as the second best. The GRNN, SRC and MLR models were found to be insufficient in modelling total suspended sediment load. However, two applications indicated that the SRC may yield better total suspended sediment load estimates than the FFNN model. The difficulties in estimating suspended sediment load using only current discharge, resulting from the hysteresis effect, were also indicated in the study.

But as early as 2005, Kisi indicated the ability of neuro-fuzzy and the neural network models to model the stream flow-suspended sediment relationship. The NF and ANN models perform better than the regression and rating curve techniques in estimation of suspended sediment. The NF model is more flexible than the ANN model considered, with more options of incorporating the fuzzy nature of the real-world system. The SRC and MLR approaches give worse estimates of the peaks and sediment load then NF and ANN.

Kisi et al. (2008) proposed a genetic programming (GP) as a new approach for the explicit formulation of daily suspended sediment-discharge relationships and the result revealed that this model may provide a superior alternative to sediment rating curve and multi-linear regression technique. Very recent study by Kisi et al. (2019) developed a novel hybrid intelligence approach based on evolutionary fuzzy (EF) approach to predict river suspended sediment concentration. This model was demonstrated in Eel River, one of the most polluted river due to the streamside land sliding owing to the highly stochastic water river discharge. The model was constructed on the different locations of the stream. The developed model was validated using three different well-established integrated fuzzy model such as adaptive neuro fuzzy inference system coupled with subtractive clustering (ANFIS-SC), grid partition (ANFIS-GP), and fuzzy c-means (ANFIS-FCM) models. The developed model and the comparable predictive models were evaluated using four statistical metrices including root mean square error (RMSE), mean absolute error (MAE), Nash-Sutcliffe coefficient (NSE) and Willmott's index of agreement (WI). This model outperformed the other models.

Li, J. et al. (2017) a physically enhanced depth-averaged two-phase model was presented. The model equation was derived from the conservation laws under the framework of shallow water hydrodynamics, including the complete mass and momentum conservation equations for the fluid mixture, the size-specific mass and momentum conservation equations for the solid phase and sediments in the active layer of the bed surface. Bed aggradation due to sediment overloading was performed at the St. Anthony Fall Laboratory in a flume of 45m long and 0.305m wide with a uniform slope of 0.002. A constant clear water inflow of 0.049 m^3/s was released at the inlet boundary. Sediment mixture was fed into the flume manually at 1m downstream of the flume with a constant rate, leading to the formation of a depositional wedge. And the result revealed that the larger the grain size, the slower the sediment fraction transport, which occurs with prior findings from experimental observations and field data.

The Climate-Scale Modeling of Suspended Sediment Load ($CliSM_{SSL}$) model was developed in the study conducted by Diodato et al. (2018) to estimate annual sediment loads. The annual data on suspended sediment loads from 1987 to 2001 at experimentation station and the monthly precipitation data were utilized in the development of the said model. The model was evaluated its performance using mean absolute error and Dublin-Watson test. This was also compared with three other models including Fournier index-based model, effective precipitation-sediment model, and Douglas-based index. $CliSM_{SSL}$ out per formed said models. Also, in this study the importance of seasonality for prediction of catchment sediment yield was demonstrated.

Another study on predictive modeling was conducted by CShin et al. (2019) wherein the Soil and Water Assessment Tool (SWAT) and Environmental Fluid Dynamics Code (EFDC) were coupled. SWAT is a watershed loading model and EFDC is a receiving water-body model to simulate the sediment loading and spatiotemporal distribution of sedimentation in a downstream reservoir. In this study digital elevation map (DEM) was generated from a topographic map and used to delineate watershed boundaries. The result showed that model coupling facilitated an uncertainty analysis that employ a sampling-based calibration algorithm requiring many model runs with different parameter sets under a Generalized Likelihood Uncertainty Estimation approach. The developed coupling model permitted quantification of the uncertainty bounds of watershed flow and sediment loads and their propagation to the sedimentation modelling for a downstream reservoir.

Remote sensing techniques, offering data acquisition over a long time period and for a broad spectral range, are considered superior to the conventional methods for data acquisition (Jian et al. 2009). Pandey et al. (2016) stated that in order to get true picture of sediment deposition in the reservoir, an integrated survey by carrying out hydrographic survey below MDDL and multispectral analysis from MDDL to FRL would be more appropriate.

Another method is utilizing isotopes as tracer to determine the rate and trend of lake sedimentation. Rai et al. (2007) used ^{210}Pb and ^{137}Cs but Stefano (2000) used only ^{137}Cs as tracer.

Measures to Control Sedimentation

Astaburuaga et al. (2019) stated that sediment supply is a first-order control on bedload transport regime. Bedload rates were more affected by sediment supply regime, which significantly influenced bed surface texture and the availability of fully-mobile sediment over a run, than they were by the level of storage and bed slope. The key to reduce sediment supply is to implement best management practices in the catchment, and the latter highly encouraged practices such as minimum tillage, contour tillage, vegetation stripes, and grass seeding of abandoned lands and natural vegetation recovery on bare soil surfaces (Navas et al.,2009).Also, Zhang et al. (2017) conclude that ecological restoration have changed rainfall-stream, rainfall-susupended sediment concentration and rainfall sediment load dynamics which resulted to sediment reduction.

Conclusion

The main realization of this review is that problems associated with sedimentation in river basins are experienced globally and that there is a necessity for comprehensive ecological investigations. Future sedimentation studies should take into account the biases of the variety of the environment types within the river basin and corrective techniques should be included in the methodology. Kisi et al. (2019) recommended that future researches be conducted employing more hydrological or climatological or even morphological information to the predictive model. Furthermore, they suggested that water quality parameters that are associated with the percentage of the suspended sediment concentration can be involved in the modeling for inspection. Another research gap was found by Schoch et al. (2018) that sediment storage in low-order valleys often neglected in a large scale studies constitute a significant component of large scale sediment budget that needs to be better included in the future analysis.

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