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Original Article

Erosion Distribution and its Mitigation in Muvattupzha River Basin

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Abstract - *Tons of soil are removed every year from various river basins by water, posing a danger to an agricultural country like India. The spatial distribution of quantitated soil erosion must be accessed to propose effective soil conservation practices. Revised Universal Soil Loss Equation (RUSLE) is a model used to predict soil erosion. Muvattupuzha River, flowing through the Western Ghats and draining into Vembanad Lake, has undergone many changes over the years. The sediment load deposited by this river on the side of Vembanad Lake has resulted in various changes in the Vembanad Lake. In this work, an attempt was made to determine the soil erosion in the Muvattupuha River basin. It was observed that more than 90% of the plantation area of the Muvttupuzha River basin is undergoing erosion. Various methods that can mitigate erosion are also included. The addition of materials generating calcium, like a combination of clamshell powder and metakaolin, can increase the shear strength of soil, improving resistance to erosion.*

Keywords - *Basin, Clamshell powder, Erosion, Metakaolin, Mitigation, Shear strength.*

1. Introduction

Land is a precious resource, being the basis of production in agricultural activities. Original topsoil structures and ecological systems in many parts of the world have been damaged by anthropogenic factors [40] like construction and agriculture, resulting in their weak performance in terms of water stability, shear strength and erosion resistance. This often causes serious nutrient losses, making the exposed soil unfit for agriculture, damaging vegetation growth, and affecting slope stability and other engineering structures [24].

According to studies conducted in India since the 1950s, soil erosion causes a loss of 5.37 to 8.4 Mt of plant nutrients annually [5, 10, 32]. Soil conservation practices have to be undertaken to control the depletion of quality and quantity of available soil resources. To infer effective management strategies to control soil erosion and to locate critical areas for its implementation, a region-specific quantitative assessment of erosion is needed [3, 23, 30].

The Vembanad Lake is the longest and largest brackish water lake in India. It supports more than 150 fish species and 20,000 bird populations during winter and provides livelihood for 1.6 million people [18]. The sediments from the seven rivers draining into this estuary significantly affect its properties. Muvattupuzha River, flowing through central Kerala, originates in the Western Ghats and drains to the Arabian Sea in the northern part of Vembanad Lake. Drastic changes in landuse pattern, commissioning of the Idukki hydroelectric project [1], and severe mining activities on its banks created large changes in the flow characteristics, altering the river's morphological characteristics and sediment dynamics considerably. With an average sediment discharge of 167408 MT and an erosion rate of 0.042 mm/year [2], the sediments from the Muvattupuzha River affect the Vembanad Lake [8]. The shape and depth of the Vembanad estuary have also been controlled by the sediments deposited by the Muvattupuzha River. A wedge-shaped island, Perumbalam Island, originated on the estuary from the fluvial deposits of this river [11]. Changes in Vembanad Lake drastically affect the rich biodiversity relying on it and alter the socio-economic balance of people depending on it [38]. The morphology of the river is altered by the sediment transported, affecting the life of human beings and animals living on the banks of the river. River meandering is also accelerated by the sediment loss, creating uncertainty in the lives of people near the river.

Studies on the impact of sediment transported by Muvattupuzha River on Vembanad Lake and soil erosion of Muvattupuzha River are reported [11], but no studies have been reported on strategies to mitigate erosion in the basin. Hence, the present study was carried out with the objective of assessing the annual soil erosion of the Muvattupuzha river basin using RUSLE and GIS techniques and suggesting a suitable remedy for its mitigation.

2. Location and Description of the Study Area

Muvattupuzha river basin extends between latitude 9°45' to 10 0 05'N and longitude 76°22' to 76°50'N with an area of 1554 km$^{2, a}$s shown in figure 1. The average annual rainfall of the basin varies from a minimum of 2779 mm to a maximum of 4526 mm, and the mean monthly wind velocity varies from 6.7 to 10.9 km/hr, with a normal daily mean temperature from 25.9 °C to 28.7 °C and humid atmosphere.

Physiographically, the Muvattupuzha basin consists of coastal plains, the midlands and the highlands. The Muvattupuzha river drains through highly varied geological formations of Precambrian crystallines, tertiary sedimentary rocks and laterites. Three types of soils occur in the study area: lateritic soil, hydromorphic soil, and riverine alluvium.

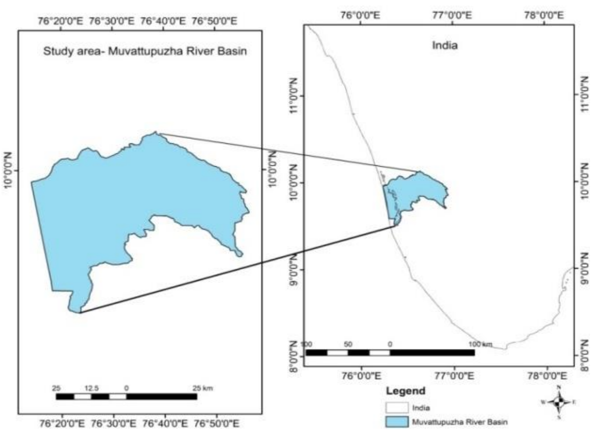

Fig. 1 Study area

3. Erosion Distribution Assessment

Various empirical, conceptual, and physical-based soil erosion models with varying degrees of complexity [15, 16] are available. Among these are the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), and Modified Universal Soil Loss Equation (MUSLE), which are the popular empirical models used globally for soil erosion prediction and control. RUSLE, developed by the U. S. Department of Agriculture, is commonly used to obtain the spatial distribution of erosion in river basins and to obtain specific soil conservation and land use planning practices [36]. It uses a set of mathematical equations to describe ecological processes related to conservation practices and erosion in a given landscape [12, 20, 33].

RUSLE is a flexible model [7] requiring less data that can be conveniently used together with satellite images and a Geographical Information System (GIS). RUSLE, being implemented in the GIS environment, is the most frequently used empirical soil erosion model worldwide [19, 34, 37]. The integration of GIS and RUSLE helps determine the potential for soil erosion and the distribution of spatial data by reducing costs and providing more accuracy, especially over a wide area [29]. It is tiresome to use statistical methods for the determination of spatial distribution of erosion. Cell-to-cell variation of erosion can be obtained using the RUSLE model integrated with GIS to spatially predict the erosion distribution pattern [17]. Different erosion models with different characteristics and application scopes are available [11]. The RUSLE model, due to its lesser data requirement, flexibility, reasonable accuracy, and applicational convenience integration with GIS, is dominant applied worldwide to soil loss prediction [19, 22].

The RUSLE model uses five input parameters to predict the average annual erosion expected on the catchment [43]. The inputs are rainfall erosivity, slope length, soil erodibility, cover and conservation factors. Soil erosion within each pixel is computed based on these input factors, which vary in space and time. The RUSLE model predicts average annual soil loss (t/ha.y) as

$$A = R \times LS \times K \times C \times P \qquad (1)$$

Where dimensional factors are R, the rainfall erosivity factor (MJ.mm/ha.y) and K, the soil erodibility factor (t/ha.MJ.mm). The dimensionless factors include slope length factor LS, cover management factor C and conservation support factor P. These factors are obtained using empirical and statistical methods and are interpolated and superimposed in the GIS environment to obtain the erosion distribution. RUSLE model, along with GIS, has been used to analyze the erosion distribution of various Indian River basins, including Nethravathi [9], Ganga [13], Barakar [41], Daltonganj [6], Dikrong [14] and Pampa [43].

3.1. Rainfall Erosivity Factor

Rainfall erosivity is defined as the power of rain to cause erosion. It measures the erosive force of a specific rainfall and is correlated to precipitation data. The equation of rainfall erosivity suggested by Wischmeier and Smith in 178 and modified by Arnold in 1980 is as follows:

$$R = \sum_{1}^{12} 1.736 \times 10^{\left(1.5 \log_{10} \frac{P_i}{P} - 0.08188\right)} \qquad (2)$$

Where Pi is the monthly rainfall in mm and P is the annual rainfall in mm.

3.2. Slope Length Factor

It is the product of slope length (L) and slope steepness (S) and is defined as the ratio of soil loss from a site at a specific condition to that at a site with 9% slope steepness and 22.6m slope length [45]. The slope factor was determined, as suggested by Moore and Burch in 1986, as

$$LS = \left[\frac{QaM}{22.13}\right]^{y} \times (0.065) + (0.045 \times S_g) + (0.0065 \times S_g^2) \quad (2)$$

Where Qa is the flow accumulation grid, S_g is the grid slope in percentage, M is a grid or pixel size, and y is a dimensionless factor with a value in the range of 0.2 to 0.5 [45].

3.3. Soil Erodibility Factor

This factor depends on the permeability and particle size distribution of soil and the organic content of the soil. It refers to the inherent susceptibility of the soil to erosion owing to the mineralogical, chemical, physical and morphological attributes of the soil. The higher the factor, the higher will be the possibility of soil erosion. The soil erodibility factor is obtained using the following equation.

$$K = \left\{0.2 + 0.3\, exp\left[-0.0256 m_s \left(1 - \frac{m_{silt}}{100}\right)\right]\right\} \times \left[\frac{m_{silt}}{m_c + m_{silt}}\right]^{0.3} \times \left\{1 - \frac{0.25\, org\, C}{[org\, C + exp(3.72 - 2.95\, org\, C)]}\right\} \times \left\{1 - \frac{0.7\left(1 - \frac{m_s}{100}\right)}{\left\{\left(1 - \frac{m_s}{100}\right) + exp\left[-5.51 + 22.9\left(1 - \frac{m_s}{100}\right)\right]\right\}}\right\} \quad (3)$$

3.4. Cover Management Factor

This factor depends on land use and is the ratio of soil loss from cropped land in a particular condition and continuous tilled fallow, both having the same soil and slope [35]. This factor considers the effect of vegetation on soil erosion and varies from 0 to 1.

3.5. Conservation Practice Factor

This factor is defined as the soil loss ratio from areas with and without conservation practices. Its value varies from 0 to 1. For areas with no conservation practices, the highest value is assigned. Lower values correspond to areas with conservation practices like plantation and built-up areas; a lower value is allotted.

4. Data used and Erosion Distribution Map Generation

Muvattupuzha river basin was delineated from a Survey of India (SoI) toposheet of 1:50,000 scale using ArcGIS 10.3 software to prepare a base map. The study area was then extracted from satellite images obtained from an Indian Remote Sensing satellite, linear image self-scanning sensor 3 using this base map. Carto digital elevation model obtained by cartographic satellite. The various parameters estimation and data used are described below.

The monthly rainfall of different locations from 1981 to 2021 was obtained from NASA MERRA. From this monthly rainfall data, the annual average rainfall for forty years is obtained and using the above equation, the rainfall erosivity index is calculated at different stations.

The special distribution of rainfall erosivity index is obtained using Inverse Distance Weighted (IDW) interpolation. The rainfall erosivity value for the basin is in the range of 826 to 1559 MJ.mm/ha.hr.y., the highest obtained at Kannamppadi town near Idukki wildlife sanctuary.

The slope factor was obtained using Catostract DEM obtained from BHUVAN. The variation of the slope length factor is shown in Figure 3. The higher the value, the greater its potential to erode. The slope decreases from 7% at the north of the basin to 0% at the south of the basin. The slope length factor varies from 0 to 3.713.

Using supervised classification of LANDSAT 8 image obtained from USGS, the landuse of the basin was determined. The basin was divided into forest, water body, plantation, agriculture, built-up area and barren land.

The cover management factor is obtained from the landuse map by allotting 1 to an area with no cover (most prone to erosion) and 0 to an area with cover (least prone to erosion). Using this landuse map and slope of basin obtained from DEM, the conservation practice factor is obtained.

Figures 2 and 3 depict the distribution of the rainfall erosivity factor, soil erodibility factor and slope length factor. The pattern of change in the cover management factor and conservation practice factor of the Muvattupuha River basin, respectively, is depicted in Figures 4 to 6.

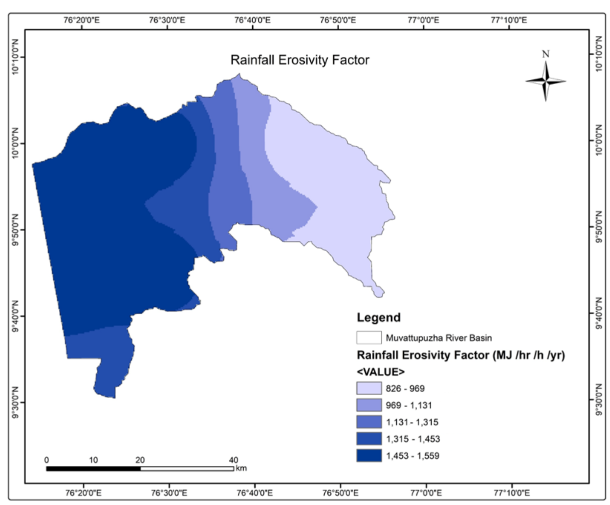

Fig. 2 Rainfall erosivity factor

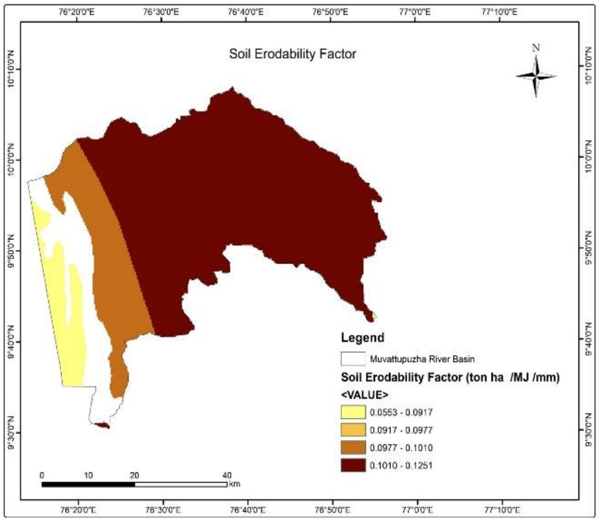

Fig. 3 Soil erodibility factor

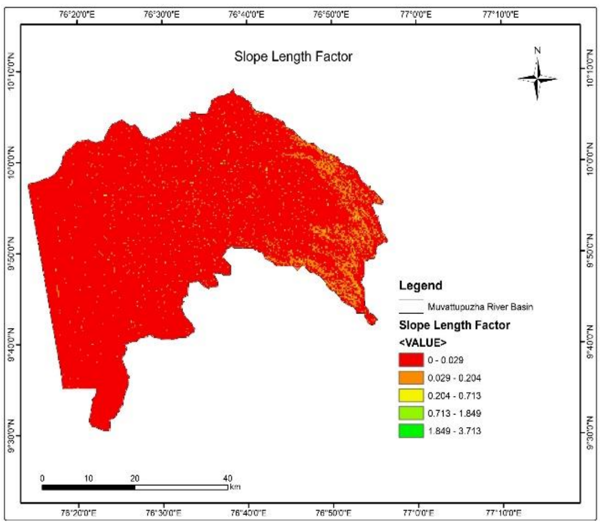

Fig. 4 Slope length factor

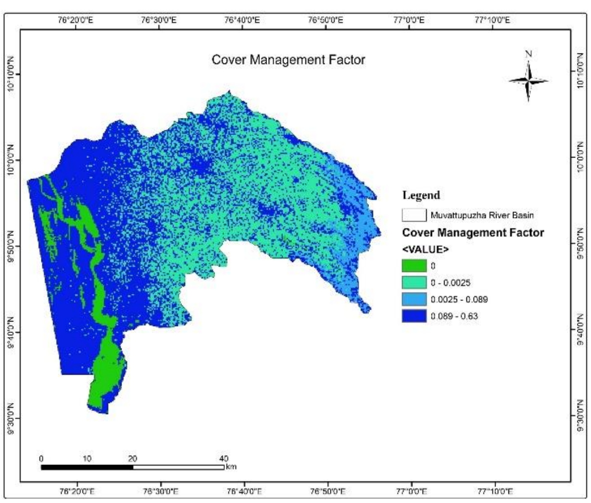

Fig. 5 Cover management factor

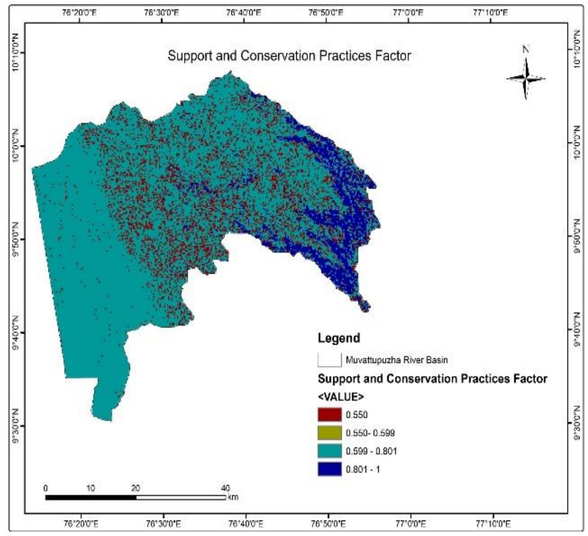

Fig. 6 Conservation practice factor

4.1. Soil Erosion Map

The soil loss of the river basin is the product of the above-mentioned factors (R, K, P, C and LC). Hence to obtain the soil erosion map, the above obtained five maps were superimposed in GIS. For better analysis, the soil erosion of the basin is categorized into six ranges, as shown in Figure 7.

On analysis, it was found that more than 90 percent area of the Muvattupuzha River basin is eroded. The areas with no erosion included areas with hard rock. 99% of the area used for plantation is eroded. Of the total area, there is extremely severe erosion in 0.21 percentage of the area. Hence, erosion control measures are required to be practised in this river basin.

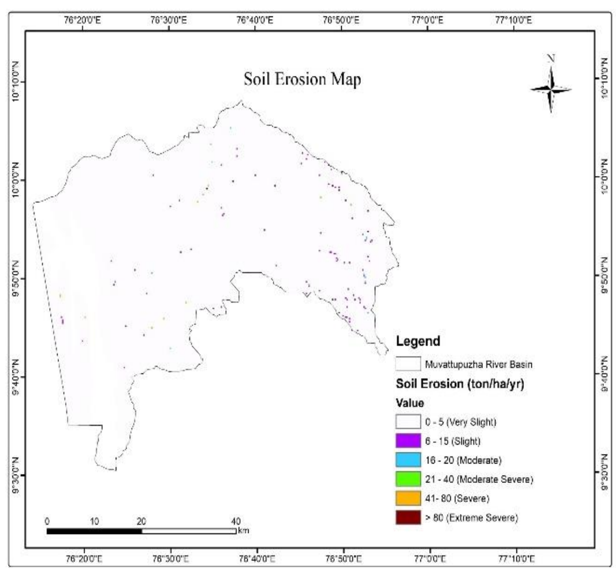

Fig. 7 Soil erosion map of Muvattupuzha River basin

Table 1. Area of Muvattupuzha River basin with their corresponding severity of erosion

Severity of Erosion	Area (km2)
Very Slight	2347.597
Slight	4.825
Moderate	0.513
Moderate Severe	0.459
Severe	0.257
Extreme Severe	0.209

5. Erosion Control Methods

Effective control measures need to be implemented in the river basin. Different measures for controlling erosion include control of tillage applications [4, 25, 42], intercropping [39, 47], using crop cover [26, 28], addition of organic matter [32], and cultivation of grass [27, 46-48]. Department of Soil Survey and Soil Conservation, Kerala Government suggests various methods like the construction of bunds, vegetative hedges, trenches, moisture conservation pits, check dams, coir geotextiles and percolation pits. Soil stabilization using various additives can improve the soil structure and enhance erosion resistance. Many inorganic additives like cement, lime, fly ash, bottom ash, and slag have been successfully applied for soil stabilization, which significantly enhanced soil properties, including strength, water stability, and stiffness. The main type of soil in the Muvattupuzha River basin is laterite soil. In the coastal areas near the Vembanad lake, the soil contains more montmorillonite. Laterite stabilization with various additives like lime and cement are already reported to be successful [21, 40, 44]. The addition of calcium to laterite soil has proved to improve the shear strength and, hence, resistance to erosion of soil [36]. Utilization of calcium-rich industrial wastes is also reported to be successful [35].

5.1. Materials Used

A clamshell is a waste material generated after the processing of edible clam meat. Many marine organisms exist similar to clams, like oysters, periwinkle, and mollusks; all of these are shell organisms. The main constituent element in these shell organisms is calcium carbonate (CaCO3). The chemical composition of these shell powders is similar to limestone powder, which is often composed of skeleton fragments of marine organisms. Kaolin is a natural clay that contains [$Al_2Si_2O_5(OH)_4$], which is the kaolin mineral. On thermal decomposition of this clay, an anhydrous aluminosilicate is obtained and formed. This compound is called metakaolin. It consists of minerals that are necessary for hydraulic reactions. Adding metakaolin into the mix should result in an enhanced strength of lime pastes and increased durability. As kaolin contains no carbonates, no CO_2 is released during heating, leading to reduced embodied CO_2 in the final materials when replacing cement or lime. Due to the pozzolanic properties of metakaolin, there might be a good reaction between metakaolin and calcium-based clamshell powder. Hence, in this work, the effect of adding clamshell powder and metakaolin to improve soil erosion resistance is studied.

The combined effects of the addition of both metakaolin and clamshell powder on the engineering properties of laterite soil are studied and reported. Based on the literature review, it is found that not more than 25% of laterite soil can be mixed with fine particles because it will lose its binding on excessive addition. Hence, soil was mixed with various percentages of metakaolin and clamshell powder, as shown in Table 2.

Table 2. Various mix proportions for the study

Nomenclature	Metakaolin (Percentage by weight of soil)	Clam Shell powder (Percentage by weight of soil)
B0	0	0
B1	5	5
B2	5	10
B3	10	5
B4	5	15
B5	10	10
B6	15	5

5.2. Effect on Atterberg`s Limits

The Atterberg limits are the water content at which the state of soil is changed in terms of behaviour and consistency, which form an important factor in erosion resistance. The Atterberg1s Limits of various mix proportions are graphically represented in Figure 8.

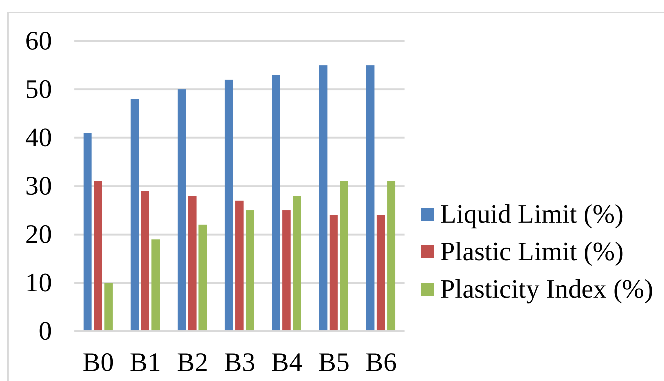

Fig. 8 Variation of Atterberg`s limits with different percentages of Clam shell powder and Metakaolin

The gelatinous material formed due to the pozzolanic reaction of silica and alumina in metakaolin and laterite soil with the calcium component can hold a large amount of water, leading to an increase in the liquid limit. The plastic limit may be decreased due to the increased amount of clay content contributed by metakaolin, which requires less water for the mix to reach the plastic limit.

5.3. Effect on Shear Strength

The unconfined compressive strength is defined as the compressive strength of an unconfined cylindrical soil specimen subjected to a compression test. The unconfined compressive strength of laterite soil and soil mixed with various percentages of metakaolin and clamshell powder was found and is reported in Figure 9.

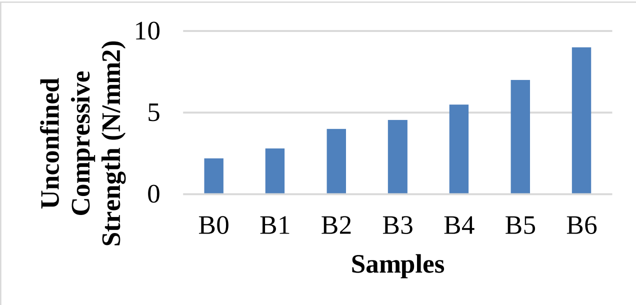

Fig. 9 Variation of Unconfined Compressive Strength with different percentages of Clam shell powder and Metakaolin

Strength of stabilized soil improved due to the formation of cementing materials like calcium alumino silicate. Silic and alumina present in soil and metakaolin react with calcium content in clamshell powder to form these natural cementing materials.

Increase in unconfined compressive strength with the increased amount of additives due to the interlock and interaction mechanism between the soil particles by the compaction effort provided during the making of the specimen.

6. Conclusion

The soil erosion of the Muvattupuzha River basin is obtained using the RUSLE model. More than 90 % of the river basin is undergoing erosion. Effective control measures need to be implemented in the river basin. The addition of materials generating calcium, like a combination of clamshell powder and metakaolin, can increase the shear strength of soil, improving resistance to erosion.

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