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Erosion studies in lateritic soil and proposing solutions to mitigate-A Review

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Abstract. Soil erosion is become one of the global issue and is a serious environmental problem. Due to indiscriminate destruction of forests and woodlands soil erosion is accelerated which leads to terrain deformation. The surface runoff of water is very fast due to gradient and lateritic soil which accelerates soil erosion. This paper describes the hole erosion test for the erosion studies. By the erosion rate index which measures the rate of erosion and the critical shear stress, which represents the minimum shear stress when the erosion starts are the erosion characteristics found from hole erosion test. The properties of lateritic soil, microlevel studies of lateritic soil and proposing solutions to mitigate soil erosion are also discussed in this paper. The models for erosion prediction such as Revised Universal Soil Loss Equation, remote sensing and GIS are explained in this paper. Lateritic area is prone to erosion. Therefore, understanding its properties will help civil engineers by providing insight about solutions to erosion prone sites by implementing various engineering methods to control erosion.

Keywords: Hole erosion test, Revised Universal Soil Loss Equation, Remote sensing and GIS.

1 Introduction

The Indian Council for Agricultural Research (ICAR) has divided Indian soil into 8 major groups such as alluvial soil, black soil, red soil, laterite soil, desert soil, mountain soil, saline soil and alkaline soil and peaty soil. The term laterite has been used to describe a wide range of red soils. In India, laterites are extensively encountered in western coastal region including Maharashtra, Goa, Karnataka and Kerala. Laterite is defined as a soil layer rich in iron oxide and it is derived under rocks which weather in strongly oxidizing agents. Where the climate is humid, laterite is found in tropical and subtropical regions. In the steeper slopes with heavy rainfall in states such as Assam, Meghalaya, Manipur, Tripura, Mizoram and the Western Ghats the problem of soil erosion is common. Geometric changes of slope with subsequent major distress causes failure of slope due to erosion. The surface run off of water is very fast which in turn accelerate soil erosion and prevents percolation of water into sub soil due to gradient and lateritic soil. Due to indiscriminate destruction of forests and woodlands which leads to terrain deformation soil erosion is accelerated. Environmental quality through contaminants attached to the sediment is reduced due to soil erosion. Erosion effects may be considerably complicated by chemical wash and frost destruction on alluvial soils. By the intensity of removal from, or deposit on a land surface, the attenuation of soil cover, or the size, density and areal representation of erosion forms created by erosion over a certain period of time the intensity of erosion can be expressed. By measuring the amount (weight, volume, depth) of soil carried away or displaced, or of sediments created by erosion, the erosion intensity can be determined. The characteristics of its soil, its vegetative cover, its topography and its climate are the factors on which the erosion potential is determined. The characteristics determining the soil erodibility are the soil characteristics such as the soil texture, organic matter content, soil structure and soil permeability. The vegetative cover shields the soil surface from the impact of rain, holds the soil particles in place and reduces the velocity runoff. The amount and rate of runoff is influenced by size, shape and slope characteristics of watershed. The rate of runoff increases and the potential for erosion is magnified. as both slope length and gradient increases. Erosion risks are high where storms are frequent, intense, or of long duration.

2 Properties and classification of lateritic soil

Climate, geology and laterization influence the properties of lateritic soil. The leaching out of silica and alkali, and the accumulation of hydrated iron and aluminium oxides involves laterization. The laterites are highly jointed and fractured, which control their water bearing capacity besides inherent porosity. They are permeable, highly porous, slight acidic with low pH values and low in organic matter. 8 to 12 metres thick massive (hard) laterite exposed on the top of hills that are often plateaus consists a typical lateritic profile. It grades into a layer of gravelly laterite of varying thickness. Lithomarge cover the igneous and metamorphic rock which lie further below.

2.1 Problems associated with lateritic soil

Lateritic soils have low bearing capacity and are softer when wet and harder when dried. The main problem associated with lateritic soils are landslides, settlement and erosion. Due to the human interventions, rains and soft characteristics of lateritic soil landslides occur. Settlements are caused due to the soft lateritic soils. Figure 1 shows landslide in Goa which occurred on June 2022.

Fig.1. Landslide on national highway connecting IDC Verna to Loutolim,Goa.

2.2 Solutions for soft lateritic soil

One of the most problematic soil is the lateritic soils which is highly permeable, low pH and slightly acidic. Suitable ground improvement measures such as compaction, mechanical stabilization, wooden piles and vibro-replacement can be used.
The compaction is used for shallow depth and used in the improvement of highway foundation. In this method the densification of soil is done by expulsion of air from voids using dynamic loading. In mechanical stabilization some inert material (aggregate, gravel) is mixed with soil and compacted to required density. Timber piles can be useful for the structure to stand on soft clayey soil and useful in improving the bearing capacity of soil. Large-sized column of coarse backfill materials (stones) are installed in the soil by using special depth vibrators in vibro replacement. For different type of soils, from soft clays to lose sands, by forming reinforcing elements of low compressibility and high shear strength vibroreplacement with stone columns technique can also be used.

3 Erosion test

In order to determine the erodibility of soil different erosion tests such as hole erosion test, jet erosion test can be performed.

3.1 Jet Erosion test

To assess the erodibility of cohesive soil jet erosion test is used. A jet tube with nozzle is mounted inside an enclosed cylinder. Water produces a turbulent, circular jet, which impinges onto the soil from an initial height above the surface and water flows from a constant head level to the nozzle. The jet will erode soil particles at and near the point of impingement and a scour hole will form as long as the applied shear stress caused by the impinging jet is greater than the soil's critical shear stress.

3.2 Hole erosion test

For determining soil erosion characteristics; viz. critical shear stress, erosion rate coefficient, and erosion rate index the hole erosion test is widely performed. In the laboratory using an undisturbed tube sample or a soil specimen compacted into a Standard Proctor mold the hole erosion test is performed. Through the axis a 6.35-mm (¼ -in.) diameter hole is predrilled. Into a test apparatus the specimen is installed in which water flows through the hole under a constant hydraulic head that is increased incrementally until progressive erosion is produced. The test is continued at a constant hydraulic head for as long as flow can be maintained once erosion is observed. Basic erodibility parameters for the soil are defined by the relation between the shear stress and resulting erosion rate. Figure 2 shows the apparatus for hole erosion test.

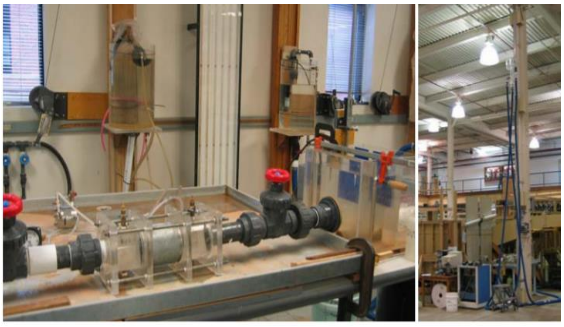

Fig. 2. Hole erosion test apparatus (Wahl et al., 2008).

The enlargement of the diameter of the pre-drilled hole is the primary mode of erosion. But slaking of the upstream and downstream surfaces of the specimen is possible that changes the length of the erosion hole at the same time that enlargement of the hole is occurring. The hydraulic gradient is determined from the difference between the piezometric heads measured at the inflow and outflow chambers in hole erosion test. The table 1 shows the erosion rate index and progression of internal erosion

Table 1. Erosion rate index and progression of internal erosion [Wan and Fell 2002, 2004]

Group number	Erosion rate index (I_h)	Progression of internal erosion
1	Less than 2	Extremely rapid
2	2-3	Very rapid
3	3-4	Moderately rapid
4	4-5	Moderately slow
5	5-6	Very slow
6	Greater than 6	Extremely slow

4 Erosion control measures

The degradation of land at a very large scale resulted in the problem of erosion. Degraded steep hill slopes landslips, landslides characterizes the problem of erosion. Many methods can be adopted that prevents erosion.

4.1 Turf Reinforcement Mats

Various non-degradable UV stabilised synthetics fibres and filaments processed into permanent, high-strength, three dimensional matrices consist of turf reinforcement mats. Erosion protection, enhance vegetation establishment and provide long term functionality by permanently reinforcing vegetation during and after maturation the Turf Reinforcement Mats are designed. For slopes up to 0.5H:1V, shear stresses up to 576 pa and velocities up to 6.1m/s depending on the type and structure of the TRM and its tensile strength TRMS can be used. High Performance TRMs (HPTRMS) contain higher tensile strengths (more than 44 kN/m) and performance. They can be used for steeper slopes and higher shear stresses and velocities. TRMS have proven ability to substantially increase the erosion resistance of vegetation, enabling its use in high velocity/shear stress areas and are an alternative to to hard armour techniques. Figure 3 shows the TRM fibre.

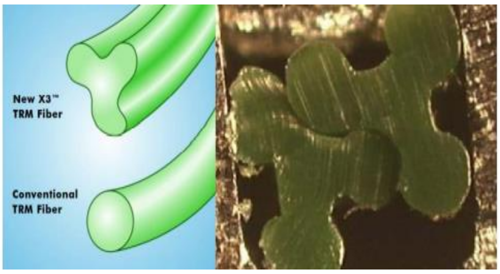

Fig 3. TRM Fibre (Shahkolahi, 2015).

4.2 Geojute to control erosion

Geojute is biodegradable erosion control net and lightweight used for the prevention of soil erosion. Geojute protects the soil from future erosion, it offers a high degree of soil retention before biodegrading completely to add to the organic content of the soil after sufficient time has passed for natural vegetation to establish. By simply unrolling down the slope, without any need for unfolding, also avoiding potential snagging and tangling the geojute rolls are easy to install. Without the need for mechanical lifting aids geojute rolls can be lifted and maneuvered. Figure 4 shows a geojute.

Fig. 4. Geojute (https://www.green-tech.co.uk).

5 Micro-level studies on lateritic soil

The information on structures, phases, preferred crystal orientations (texture), and other structural parameters, such as average grain size, crystallinity, strain, and crystal defects is provided by X-ray diffraction technique method. Magnified images of the size, shape, composition, crystallography, and other physical and chemical properties are given by Scanning Electron Microscopy.

5.1 X-Ray diffraction method

The analysis of minerals and mineral phase's identification and quantification can be conducted by XRD analysis. Powder diffraction has a high-tech, rapid, cheap and non-destructive technique for qualitative and quantitative analysis of crystalline compounds. A diffraction pattern called a diffractogram is produced when X-rays interact with a crystalline substance or powder. Phase composition of a sample, types and nature of crystalline phases (minerals) present, crystal structure, amount of amorphous (OM) content, micro strain, size and orientation of crystallites is information obtained from this patterns. An X-ray tube, a sample holder, and an X-ray detector is provided in an X-ray diffractometers. In a cathode ray tube by heating a filament to produce electrons, accelerating the electrons toward a target by applying a voltage, and bombarding the target material with electrons X-rays are generated. X-ray spectra are produced when electrons have sufficient energy to dislodge inner shell electrons of the target material. The sample rotates in the path of the collimated X-ray beam at an angle u while the X-ray detector is mounted on an arm to collect the diffracted X-rays and rotates at an angle of 2u. Figure 5 shows a schematic diagram of a diffractometer system.

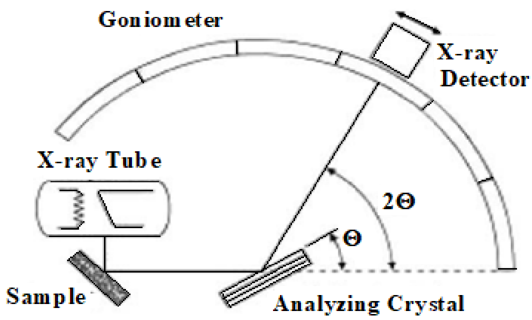

Fig. 5. Schematic diagram of a diffractometer system. (Andrei et al., 2015).

5.2 Scanning Electron Microscopy

The magnified images of the size, shape, composition, crystallography, and other physical and chemical properties are given by SEM analysis. The material is analyzed by an electron beam generated in a vacuum environment and thinned with electromagnetic lenses in the same situation to create a high-resolution image. With SEM information on topography, morphology, shape, size, composition, and crystallographic structures of materials such as ground, rock, ceramic, glass, metal, polymer, and local crystal structure is obtained. Figure 6 shows scanning electron microscope.

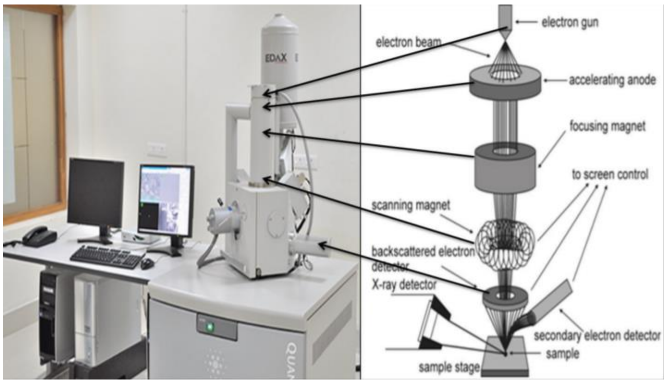

Fig. 6. Scanning Electron Microscope (Kannan, 2018).

6 Methods for erosion prediction

In order to identify physiographic units to serve as a common (physiographic) base map for assessments of different kinds of soils, degradation, and conservation. to overlay data layers for different map units, to make area calculations, to link spatial data with non-spatial but more detailed attribute data and to present data in map and other graphic format remote sensing technique can be used. The Revised Universal Soil Loss Equation (RUSLE) is used models to study water soil erosion.

6.1 Revised Universal Soil Loss Equation

Many computer models have been developed and used to effectively estimate soil erosion and to establish soil erosion management plans. The Revised Universal Soil Loss Equation (RUSLE) is most widely used models to study water soil erosion. Long-term average annual soil loss from field slopes under a specific land use and management system can be predicted. Figure 7 shows the RULSE flowchart.

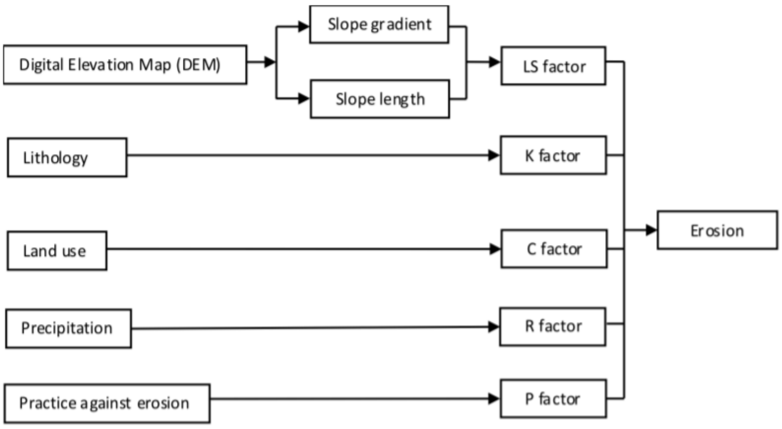

Fig. 7. Revised Universal Soil Loss Equation flowchart (Efthimiou et al., 2014).

The RUSLE is written as

$$A = L_S.R.K.C.P \quad (1)$$

where A = soil loss, L_S = steepness factor, R = Rainfall – runoff erosivity factor, C = cover and management factor, K = soil erodibility factor and P = conservation practices factor.
Table 2 shows the K factors for different soil erodibility class.

Table 2. K factors for different soil erodibility class (Samanta et al.,2016).

Soil erodibility	K factor
Very low	0.07
Low	0.17
Moderate	0.27
High	0.37

6.2 Remote sensing technique to predict soil erosion

For predicting soil erosion, rremote sensing data is an important source of information for mapping and monitoring. Information about the set of erosion factors - the topography, soils, vegetation, land use can be found from the satellite images. From digital elevation models created by satellite image processing terrain characteristics can be obtained. The slope and shape of the slope profile, horizontal and vertical dismemberment of the earth's surface can be calculated. To detect features related to soil erosion various remote sensing based methods have been developed. To estimate soil erosion process, investigate soil exposure intensity, measure soil reflectance, evaluate soil erosion status and assess soil properties and bare soil fractions ssatellite-based spectral indices, for example, Normalized Difference Vegetation Index (NDVI), Normalized Difference Soil Index (NDSI), Tasselled Cap Transformation (TCT), along with Linear Spectral Unmixing Analysis (LSMA) have been frequently employed. In soil erosion monitoring, synthetic Aperture Radar (SAR) data can provide an auxiliary source and the fusion of microwave and optical data.

7 Conclusions

Due to indiscriminate destruction of forests and woodlands soil erosion is accelerated which leads to terrain deformation. The surface run off of water is fast due to gradient and lateritic soil which accelerates soil erosion and prevents percolation of water into the subsoil. Understanding lateritic soil properties, which are prone to erosion will help civil engineers by providing insight about solutions to erosion prone sites by implementing various engineering methods to control erosion. Turf reinforcement mats, geocellular confinement system and geojute are some measures used to control the erosion. By conducting the hole erosion test the erodibility characterization of soils prone to erosion can be conducted. For mapping, monitoring and predicting soil erosion rremote sensing data is an important source of information. X ray diffraction and scanning electron microscopy can be performed and information on structures, phases, crystal orientation can be obtained.

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