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# Assessment of soil erosion in tropical ecosystem of Goa, India using Universal Soil Loss Equation, geostatistics and GIS

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## ABSTRACT

Soil erosion in tropical ecosystem of Goa, India was assessed using Universal Soil Loss Equation (USLE), geostatistics and Geographic Information System (GIS). In the study, field data collected for 500 locations at 2.5 km grid interval on various pedological and land use parameters were used to compute USLE factors (R, K, LS, C and P) and develop thematic rasters using Gaussian kriging model in GIS for assessment of soil loss in the state. The results showed that about 53.0% of total geographical area (TGA) in the state is subject to severe (20-40 t $ha^{-1}yr^{-1}$), very severe (40-80 t $ha^{-1}yr^{-1}$) and extremely severe (>80 t $ha^{-1}yr^{-1}$) soil erosion. Based on the severity of soil erosion in the state, Bardez, Bicholim, Pernem and Ponda tehsils have been categorized under high priority zone with very severe (40-80 t $ha^{-1}yr^{-1}$) and extremely severe (>80 t $ha^{-1}yr^{-1}$) soil loss. The study demonstrates that use of USLE, geostatistics and GIS becomes a powerful approach in spatial assessment of soil erosion and identify the erosion prone areas.

## 1. INTRODUCTION

Soil erosion by water involves the processes of detachment and transportation by impact of raindrop and flowing water (Wischmeier and Smith, 1978; Julien, 1998). The extent of erosion, specific degradation, and sediment yield of an area are related to a complex interaction between topography, geology, climate, soil, vegetation, land use, and man-made developments (Shen and Julien, 1993). Water erosion result either in loss of top-soil or in terrain deformation or both is the most widespread form of degradation and occurs widely in all agro-climatic zones of India. Mandal and Sharda (2011) reported that soil erosion caused by water is a major factor contributing to land degradation in India and many other countries, as it exceeds the natural soil formation rates. Dhruvanarayana and Rambabu (1983) have estimated that about 16.4 t $ha^{-1}yr^{-1}$ of top soil is detached annually in India out of which 29% is lost permanently into the sea, 10% gets deposited in the reservoirs reducing their storage capacity by 1 to 2% every year and the remaining 61% gets displaced from one place to another. Researchers involved in soil erosion studies for a long time, developed many models for soil erosion loss estimation (Wischmeier and Smith, 1965, 1978; Nearing *et al.,* 1989; Shen *et al.,* 2003). The Universal Soil Loss Equation (USLE), is the empirical method widely used to predict long-term rates of soil erosion from field or farm size units subject to different management practices (Chaudary and Sharma, 1998; Fistikoglu and Harmancioglu, 2002; Reddy *et al.,* 2004; Dabral *et al.,* 2008 and Reddy *et al.,* 2013). The amount of soil erosion is mainly affected by vegetation cover, topographic features, climatic variables, and soil characteristics (Singh and Khera, 2008). Soil erodibility is mainly affected by aggregate stability, texture, depth, organic matter, and stoniness (CORINE, 1992).

The utility of GIS capabilities increased in spatial assessment of soil erosion when they coupled with empirical and predictive models (Kinnell, 2001; Reddy *et al.,* 2004, 2013a). Further, geostatistical techniques in GIS quantify the spatial autocorrelation among measured points and account for the spatial configuration of the sample points around the prediction location (Isaaks and Srivastava, 1989). Wilson and Lorang (2000) reviewed the applications of GIS in estimating soil erosion and concluded that GIS provides tremendous potential for improving soil erosion estimation. GIS enable to integrate erosion prediction models not only to estimate soil loss but also provide the spatial distribution of the erosion (Okalp, 2005). USLE methods with GIS integration provide significantly better results than using traditional methods (Wang *et al.,* 2003). Assessment of soil erosion and generation of accurate erosion risk maps in GIS further helps to locate the areas with high erosion risks and to develop appropriate soil conservation strategies (Mitasova *et al.,* 1996 and Vrieling *et al.,* 2002). Sharda and Dogra (2013) analysed annual productivity losses of all rainfed cereal crops together at state level due to water erosion in India and reported that the state of Goa experiences highest loss of 10.9 q ha$^{-1}$ among all the states in India. The study was, therefore, aimed to assess the soil loss due to water erosion in tropical ecosystem of Goa, India using Universal Soil Loss Equation (USLE) and geostatistical techniques in GIS.

## 2. MATERIALS AND METHODS

### Study Area

Goa state is bounded by Arabian Sea in the west, Maharashtra in north, Karnataka state in the south-east and is situated between 14$^o$ 53' 47" to 15$^o$ 47' 59" N latitudes and 73$^o$ 40' 54" to 74$^o$ 20' 11" E longitudes, covering an area of 0.37 mha (Fig.1). The climate is warm and humid tropical with an average annual temperature of 26.4°C. South-west monsoon provides a mean annual rainfall of 3265 mm from June to October. Geologically, Goa is predominantly covered by rocks of the Goa group belonging to the Dharwar Super Group of the Archaean/Proterozoic age, except a narrow strip at the north-eastern corner that is occupied by Deccan Trap of the Upper Cretaceous to Lower Eocene age (GSI, 1981). Vegetation consists of dense forests of dry to moist deciduous types. The major land utilization types of Goa are forest area, net sown area, total cropped area and area not available for cultivation covers 125, 132, 164 and 37 thousand ha of TGA of the state, respectively (Indiastat, 2011-12).

### Computation of Universal Soil Loss Equation (USLE) Factors

Universal Soil Loss Equation (USLE) predicts long-term average annual soil loss from a specified field area under specified cover and management conditions (Wischmeier and Smith, 1978). The USLE expresses the rate of soil erosion as soil loss and can be written as:

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

Where, A= mean annual soil loss (t ha$^{-1}$yr$^{-1}$), R= Rainfall erosivity factor (MJ mm ha$^{-1}$yr$^{-1}$), K= Soil erodibility (t ha Mj$^{-1}$mm$^{-1}$), LS= Topography factor, C= Cover and management factor and P= Conservation practice factor. During the soil resource inventory of Goa (Harindranath *et al.,* 1999), field data was collected at 2.5 km grid interval for 500 geo-referenced locations in the state on pedological and land use parameters. Based on the geo-referenced location (latitude and longitude) of grid points, point data coverage has been generated in ArcGIS (ESRI, 2010) and appended the attribute data on rainfall (annual mm), soil and land use parameters. Based on database generated on rainfall, silt+very fine sand (%), sand (%), organic matter (%), soil structure, permeability (cm hr$^{-1}$), slope (%), slope length (m) and land use parameters at grid level, the values of USLE factors were computed as per the standard procedure (Wischmeier & Smith, 1978).

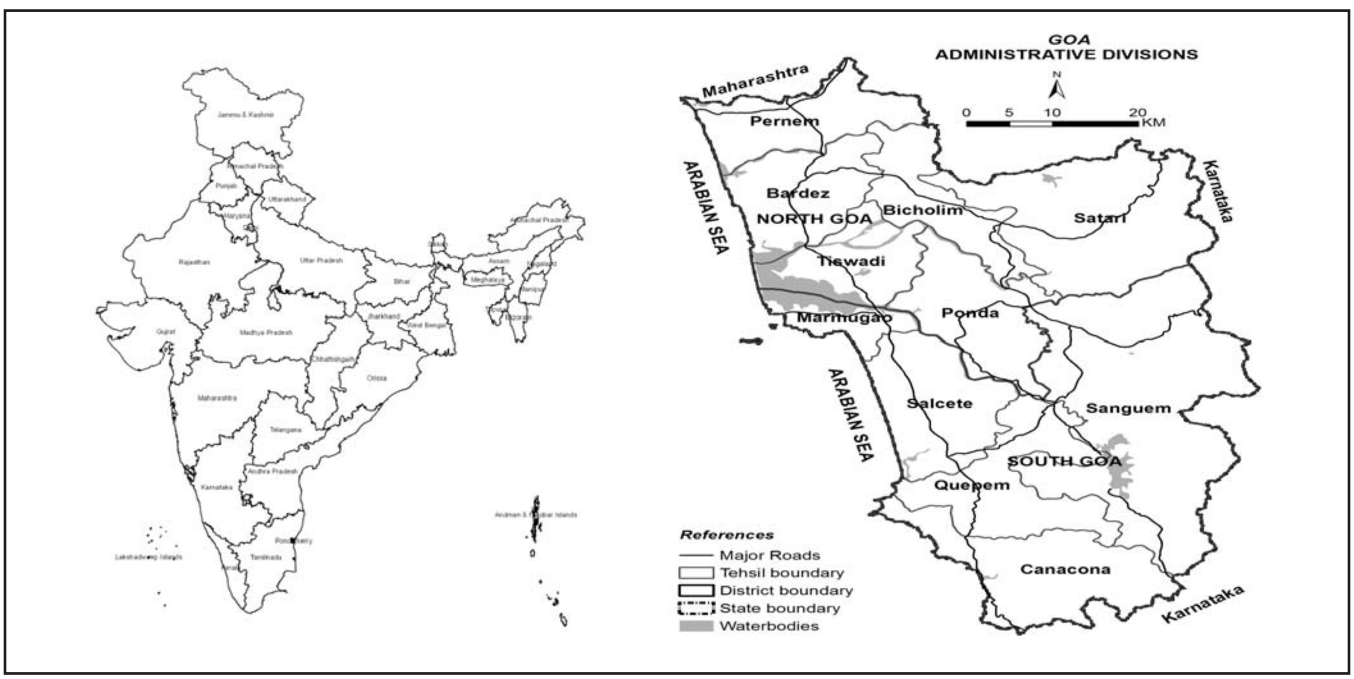


**Fig. 1. Location map of the study area**

Rainfall erosivity, defined as the potential ability of rain to cause erosion and given as the product ($EI_{30}$) of the total energy of rainstorm (E) (Foster *et al.,*1981), which gives erosive potential of rainfall and erosion index values of USLE for given meteorological station. Computation of R, which is essentially seasonal total erosion index ($EI_{30}$) were computed from recording type raingauge charts as described in Singh *et al.* (1981). In the present study the following equation was employed to compute R values at grid level.

$$(EI \text{ or } R) = 79 + 0.363x \quad ...(2)$$

Where, x is the annual rainfall in mm.

R factor values for 500 grid points were computed and iso-erodant map of Goa has been prepared. Similar methodology was adopted by Kurothe *et al.* (2001) and Ramamurthy *et al.* (2014) in computation of R values for adjoining Maharashtra and Karnataka states, respectively.

The most important soil parameters that influence soil erodibility include soil texture, stability of soil structure, soil permeability and infiltration, organic matter and soil mineralogy (Singh *et al*., 1981). In reality, the direct measurement of K from experimental run-off plot is expensive and time consuming. The nomograph developed by Wischmeier *et al.* (1971) was employed to estimate K values in the study area using the following equation:

$$100\,K = 2.1\,M^{1.14}\,(10^{-4})\,(12-a) + 3.25\,(b-2) + 2.5\,(c-3) \quad ...(3)$$

Where, M= Percent silt x (100 percent clay), a= percent of organic matter, b= the soil structure code used in soil classification, c= the profile permeability code in which M= [silt (%) + very fine sand (%) x{100-clay (%)}], a = organic matter (%), b = structure code and c = profile permeability code.

The LS factor is used in the USLE to consider the effect of topography on erosion (Renard *et al*., 1997). The greater accumulation of runoff on longer slopes increases its detachment and transport capacities (Singh *et al*., 1981). The slope length factor, L is the ratio to field soil loss to the corresponding loss from 22.13 m slope length, its value may be expressed as:

$$L = (\lambda/22.13)^m \quad ...(4)$$

Where, $\lambda$ = field slope length (m) and m= a factor ranging from 0.2 to 0.9 (Singh *et al*., 1981).

Through several modifications (Singh *et al*., 1981) the S factor of USLE has assumed the following form.

$$S = 65.41\,\text{Sin}^2 A + 4.56\,\text{Sin}\,A + 0.065 \quad ...(5)$$

Where, S = slope gradient factor (%) and A = angle of the slope (degree). Combining equations (4) and (5) we get,

$$LS = (\lambda/22.13)^m\,(65.41\,\text{Sin}^2 A + 4.56\,\text{Sin}\,A + 0.065) \quad ...(6)$$

The above equation has been used to compute LS factor for 500 grid points in the study area.

The C-factor measures the effects of all inter-related cover and management variables (Renard *et al.,* 1997). Several authors have worked on soils with various types of vegetative covers to find out C factor (Singh *et al*., 1981). According to Benkobi *et al*. (1994) and Biesemans *et al*. (2000), the vegetation cover factor together with slope steepness and length factors are most sensitive to soil loss. The C factor for each grid point in the study area was computed on the basis of main crop grown/land use collected during the field survey at each grid point of the study area (Table 1).

Practices of soil conservation have an influence on a reduction of erosion processes; therefore, soil loss values vary according to practices adopted (Ruhoff *et al.,* 2006). P factor values for the grid points of the study area were assigned depending upon the major conservation practice adopted under a particular grid point area (Singh *et al*., 1981; Kurothe, 1991).

**Spatial Assessment of Soil Erosion Using Geostatistics and GIS**

The computed values of R, K, LS, C, and P at 500 grid points were spatially interpolated using Gaussian kriging model in GIS and generated rasters for R, K, LS, C and P factors at 30 m spatial resolution, which is compatible at 1:50,000 scale. The generated rasters of USLE factors have been integrated in GIS and assessed the soil loss of Goa in a spatial domain (Fig. 2). In spatial distribution of raster, every grid cell has a unique parameter value and the model

**Table: 1**
**C-factor values used in assessing soil erosion**

| S. No. | Cover and Management (C) | C-factor value |
|---|---|---|
| 1. | Forest and grass lands | 0.01 |
| 2. | Degraded forest/wastelands | 0.14 |
| 3. | Croplands | 0.20-0.43 |
| 4. | Degraded (waste) lands | 0.50 |
| 5. | Fallow lands | 1.00 |

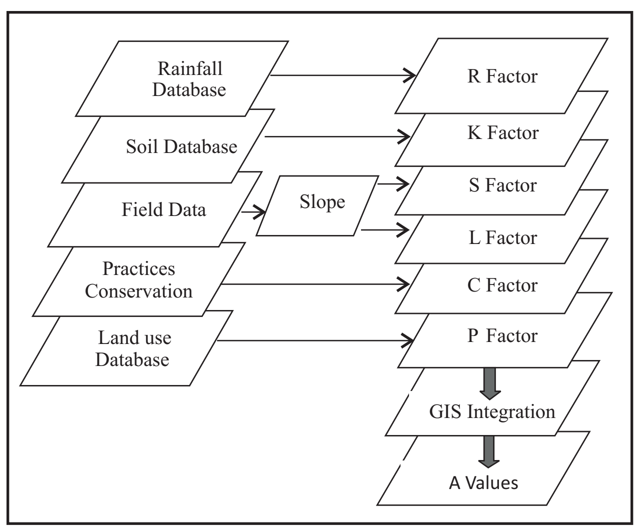


**Fig. 2. Flow chart of methodology followed in the study**

was executed through multiplication of input rasters mathematically. The soil erosion map thus generated through the model in GIS indicates the spatial distribution of soil loss in terms of t $ha^{-1}yr^{-1}$. Average soil loss was calculated as the product of each pixel value multiplied by pixel area. Finally, the 'administration boundaries' map of the study area was overlaid on the final erosion map in order to assess the soil loss at tehsil level.

## 3. RESULTS AND DISCUSSION

The spatial distribution of rainfall erosivity (R factor) reported from 868 to 1202 MJ mm $ha^{-1}yr^{-1}$ in the state. The spatial distribution R in the state shows that the lowest range of R values (<900 MJ mm $ha^{-1}yr^{-1}$) covered in isolated places of Sanguem and Satari tehsils in eastern part of the state with an area of 5.9% of TGA. However, major part of the state (36.9%) particularly area under Tiswadi, Marmugao, Ponda, Salcete, Sanguem and Satari tehsils in central part of the state is covered with R values of 900-950 MJ mm $ha^{-1}yr^{-1}$. R values of 950-1000 and 1000-1050 MJ mm $ha^{-1}yr^{-1}$ covered on either side of the Central region particularly in Bicholim, Quepem and Sanguem tehsils with an area of 33.2%. The higher R values of 1050-1100, 1100-1150 and >1150 MJ mm $ha^{-1}yr^{-1}$ are found in Pernem and Canacona tehsils in northern, south and southeastern parts of the study area with an area of 19.8% (Fig.3a). It was observed that as the topography changes in the study area from steep slope area to plain areas, the erosivity tends to decreases.

The soil erodibility (K factor) reported to vary from 0.10 to 0.25 t ha $MJ^{-1}mm^{-1}$ in the state. The low K values from 0.10 to 0.13 t ha $MJ^{-1}mm^{-1}$ were observed mostly in Canacona and Satari tehsils, which covers western and northern part of the study area (14.3%), where soils are mostly sandy, sandy loam, loamy sand, sandy clay loam texture. The major part of the state (41.6%) is covered by the K values from 0.13 to 0.16 t ha $MJ^{-1}mm^{-1}$, where soils are mainly silty clay to gravely silty clay texture. Ponda, Sanguem and Satari tehsils in central part of the state mainly covered by silty clay to gravely silty clay, gravelly sandy clay to gravelly clay and gravelly clay to clay soils are associated with higher K values of 0.21 to 0.24 and >0.24 t ha $MJ^{-1}mm^{-1}$ covering an area of 8.3% (Fig. 3b).

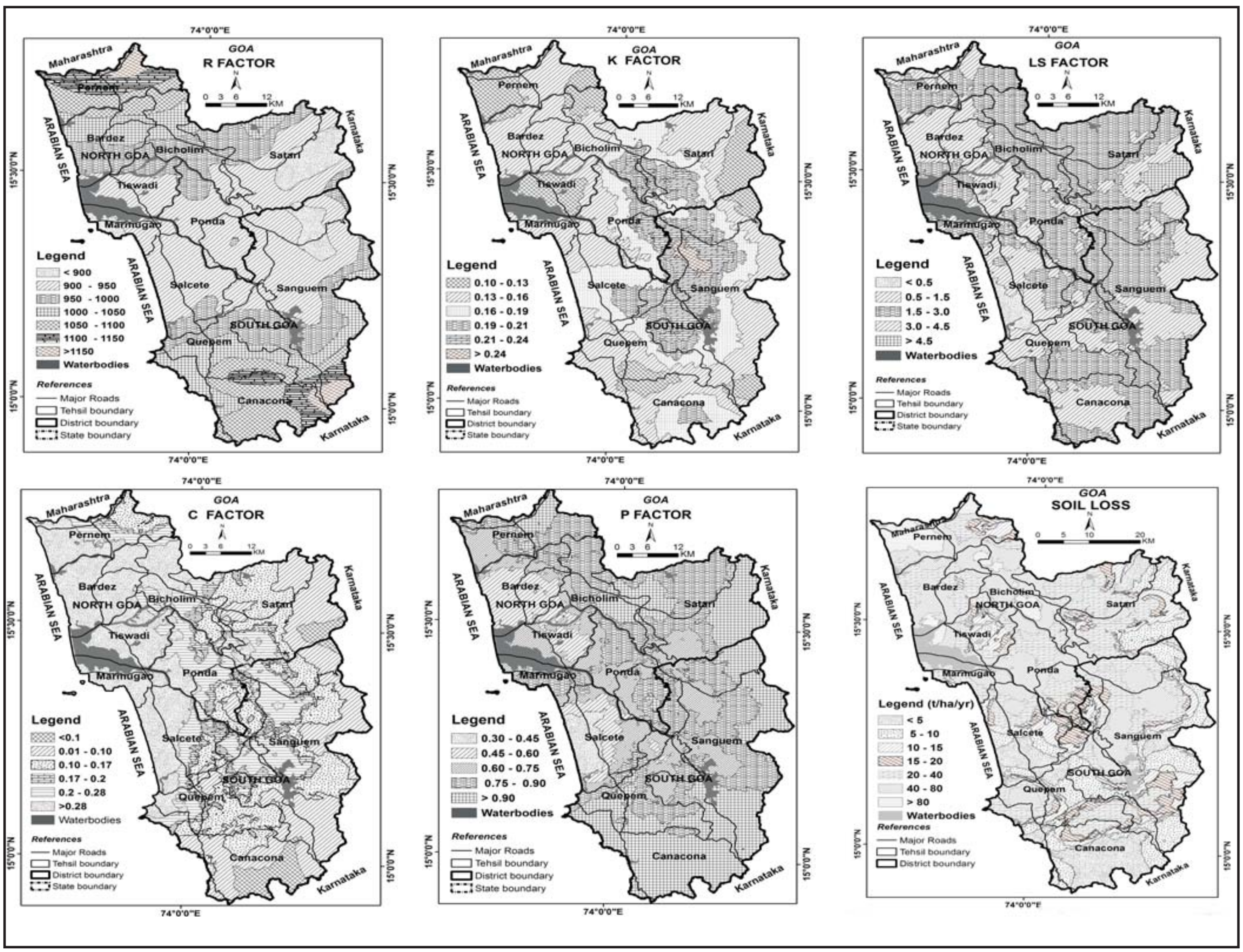


**Fig. 3a. to 3f. Computed R, K, LS, C, P Factors and soil erosion map of Goa state**

The topography factor (LS factor) ranges from 0.13 to 4.9 in the state. The lower LS factor values of <0.5 and 0.5-1.5 have been mostly noticed in very gentle to gentle (0-1%) and gentle slopes (1-3%) of Tiswadi, Salcete and Quepem tehsils in the western region of state covering 29.4% of TGA. Major part of the area (54.4%) is covered by the LS factor values from 1.50 to 3.0 in Bicholim Ponda, Pernem Sanguem and Satari tehsils of central, north and southern parts of the state, where moderate (8-15%) and moderately steep slopes (15-30%) exists. The highest LS factor of 3.0 to 4.5 and >4.5 have been observed in parts of Sanguem and Satari tehsils (11.9%) in eastern parts of the state with moderate steep slopes (15-30%) and steep slopes (30-50%) (Fig. 3c).

The C factor in Goa encompasses land use, which includes forest, agricultural lands, plantations, pastures and wastelands. The C values of the state ranges from 0.009 to 0.39. C factor of <0.01 was noticed in isolated places of Canacona and Satari tehsils in southern and eastern parts of the state covering an area of 3.9%. The values 0.01-0.20 is located in Bicholim, Ponda, Satari, Sanguem, Quepem and Canacona tehsils mostly in central part of the state stretching from north to south with an area of 49.8%. However, the highest values of 0.2-0.28 and >0.28 were found mostly in Pernem, Bardez, Bicholim, Tiswadi Marmugao and Salcete tehsils of northern and west coastal regions covering 42.1% (Fig. 3d). Analysis shows that the C values for forest are close to 0 and for the bare rocks tending to 1. The predicted C values of the arable classes depend on crop type and management practices.

The values of P ranges from 0.30-1.00, the lowest (0.30-0.45) were observed in coastal region of Salcete tehsil and highest (0.75-0.90 and >0.90) was noticed in Quepem, Canacona, Sanguem and Satari tehsils in southern and eastern parts, which covers more than 60% of TGA (Fig.3e). Adoption of suitable conservation measures like contour bunding, terrace farming and contour cultivation helps to reduce the top soil loss due to water erosion.

**Spatial Assessment of Soil Erosion**

The soil erosion was assessed spatially by integrating the rasters of R, K, LS, C and P factors in GIS. Seven soil erosion classes namely very slight (<5 t $ha^{-1}yr^{-1}$), slight (5-10 t $ha^{-1}yr^{-1}$), moderate (10-15 t $ha^{-1}yr^{-1}$), moderately severe (15-20 t $ha^{-1}yr^{-1}$), severe (20-40 t $ha^{-1}yr^{-1}$), very severe (40-80 t $ha^{-1}yr^{-1}$) and extremely severe (>80 t $ha^{-1}yr^{-1}$) were identified in the state (Table 2 and Fig. 3f). Many authors have followed similar classification system in defining the soil loss classes in India (Challa *et al.,* 2001, Sahoo, *et al.,* 2005; Reddy *et al.,* 2013). Analysis shows that very slight (<5 t $ha^{-1}yr^{-1}$) and slight (5-10 t $ha^{-1}yr^{-1}$) classes covered mainly in Canacona and Salcete tehsils of southern and eastern parts of the state with an area of about 9.6 and 15.5%, respectively. However, area under moderate (10-15 t $ha^{-1}yr^{-1}$) and moderately severe (15-20 t $ha^{-1}yr^{-1}$) soil loss was noticed in Senguem, Satari, Canacona, and Quepem tehsils in central and northern parts of the state covering an area of 8.8 and 8.9%, respectively. Severe (20-40 t $ha^{-1}yr^{-1}$) and very severe (40-80 t $ha^{-1}yr^{-1}$) soil loss was observed in Quepem, Ponda, Marmugao, Bardez, Bicholim, Tiswadi and Pernem tehsils mainly in northern and central parts of the state with an area of 26.9 and 22.0%, respectively. Extremely severe (>80 t $ha^{-1}yr^{-1}$) soil loss was noticed in Bardez, Bicholim and Pernem tehsils in central and northern parts of the state with an area of 4.1%. Analysis shows that Pernem, Bardez, Bicholim Sanguem, Ponda, Marmugao, Quepem and Satari tehsils affected with severe, very severe and extremely severe soil loss at places. Despite moderate to moderately steep slopes in the southern and eastern part of the state, the severity of soil loss increases from south to north in the study area and maximum soil loss was found in the northern part of state with 40-80 t $ha^{-1}yr^{-1}$ and > 80 t $ha^{-1}yr^{-1}$. The less severity of soil loss in the southern and eastern parts of the state might be attributed to adequate canopy cover, however, severe, very severe and extremely soil loss in central and northern parts of the state could be due to sparse vegetation cover and inadequate soil and water conservation structures.

Soil erosion in Goa is due to both natural causes like water erosion and anthropogenic activities like deforestation and mining activities, which accelerated the process of soil erosion. Beach erosion is a common phenomena in coastal regions of Goa, where beach sand gets eroded either due to human factors or tidal waves. There is a need to develop site-specific conservation strategies to preserve soils production potential, sustain productivity, conserve *in-situ* rainwater, minimize soil erosion, moderate flood downstream, harvest and recycle inevitable runoff and ensure environmental security (Handbook of Agriculture, 2009).

**Priority Areas and Suggested Soil and Water Conservation Measures**

Based on the severity of soil erosion, Bardez, Bicholim, Pernem and Ponda tehsils have been categorized under high priority zone, where appropriate soil and water conservation measures need to be adopted on priority. The

**Table: 2**
**Status of soil loss in Goa**

| S.No. | Soil loss (t $ha^{-1}yr^{-1}$) | Area (ha) | Area (%) |
|---|---|---|---|
| 1 | Very slight (<5) | 35375.2 | 9.6 |
| 2 | Slight (5-10) | 57496.8 | 15.5 |
| 3 | Moderate (10-15) | 32731.3 | 8.8 |
| 4 | Moderately severe (15-20) | 32897.3 | 8.9 |
| 5 | Severe (20-40) | 99541.6 | 26.9 |
| 6 | Very severe (40-80) | 81273.0 | 22.0 |
| 7 | Extremely severe (>80) | 15319.3 | 4.1 |
| 8 | Others (Water bodies etc.) | 15565.7 | 4.2 |
| | Total | 370200.0 | 100.0 |

tehsils like Marmugao, Quepem Tiswadi, Sanguem and Satari were categorized under medium priority, whereas, Canacona and Salcete tehsils were grouped under low priority zone. Agronomic measures on cultivated lands like contour farming, intercropping, strip cropping, tillage practices and mulching are recommended on mildly sloping areas (<3%) with the objective of maximizing conservation of *in-situ* rainfall for sustained and higher production. The perennial non-leguminous fodder species like Ajan grass (*Cenchrus setigerus*) and Karad grass (*Themeda quadrivalis*) could be adopted in non-cultivable areas not only to protect top soil loss and but also to feed the livestock. Mechanical measures like contour bunding, graded bunding and bench terracing could be the better options, where slope is more than 3% in arable lands. Mechanical measures like slope stabilization and drainage line treatment measures could be adopted in non arable lands. For control of beach erosion, various hard (seawalls, bulkheads, revetments, groins, jetties) and soft measures (dune rehabilitation, dune vegetation, green belts, Biorock, geotubes, geotextile sand containers) could be adopted depending upon the local conditions to minimize the severity of beach erosion.

## 4. CONCLUSIONS

The spatial assessment of soil erosion in Goa state reveals that about 53.0% area is subject to severe (20-40 t $ha^{-1}yr^{-1}$), very severe (40-80 t $ha^{-1}yr^{-1}$) and extremely severe (>80 t $ha^{-1}yr^{-1}$) soil erosion. Spatial assessment of soil erosion using USLE, geostatistics and GIS enable to identify the most susceptible areas as erosion hazard zones in order to adopt suitable soil and water conservation measures in the study area. The study demonstrates that use of USLE model and geostatistics in GIS becomes powerful tool in assessment of soil erosion and identify the erosion prone areas. Many researchers (Dabral *et al.,* 2008; Erdogan *et al.,* 2007; Kim *et al.,* 2005; Ozcan *et al.,* 2008 and Sheikh *et al.,* 2011) also concluded that USLE model in GIS environment can be used effectively to identify the areas prone to high level erosion risks. The results obtained from the study could be effectively used by the planners, watershed managers and policy makers to develop site-specific agronomic and mechanical soil and water conservation strategies, particularly in high erosion risk areas to minimize the soil loss and preserve soils for sustained productivity.

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