Vol. 46, No. 2, pp 171-180, 2018
Indian Journal of Soil Conservation
Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Mapping of soil erosion for soil and water conservation measures in Kolleru lake catchment area

A. Mani[1], Ch. Kranthi Kumar[2] and D. Sai Gangadhara Rao[3]

[1]*College of Agricultural Engineering, ANGRAU, Bapatla, Guntur-522101, Andhra Pradesh;* [2]*Research Technician-II, IRRI, India Office, Andhra Pradesh;* [3]*College of Agriculture, Rajahmundry, Andhra Pradesh.*

[1]*E-mail: manidigumarthi@rediffmail.com*

ARTICLE INFO

Article history:
Received : August, 2016
Revised : June, 2018
Accepted : July, 2018

ABSTRACT

Mapping of soil erosion assumes significance for land use planning and watershed management. Erosion can be predicted by integrating meteorological, topographical, field survey and satellite data in GIS environment. The spatial and temporal variation of soil erosion map has been generated for the Kolleru lake catchment. The areas under different classes of soil erosion risk have been worked out. The Kolleru lake catchment area is 6252 km^2. The elevation of the catchment varies from 0 to 532 m. The catchment has been divided into subbasins based on the outlet points of drains and rivers (Budameru, Ramileru Tammileru and Gunderu) flowing into the Kolleru Lake. Majority of soils are sandy clay loam (45%) in texture. There are 12 types of land uses in the catchment with major area under agriculture. Soil erosion has been estimated for a period of 23 years (1990 to 2012). The quantitative potential soil loss through erosion in the catchment was estimated by universal soil loss equation with the relevant information on factors like erosivity (R), soil erodibility (K), topographic factor (LS), cover and land management factor (C) and conservation practice factor (P). The values of R, K, LS, C and P factors were used for generating maps of each factor. About 16% area is under the slight erosion (5 t ha^{-1}yr^{-1}). Moderate erosion (5-10 t ha^{-1}yr^{-1}) occurs in about 37% area. High and very high erosion occurs in 13% and 14% area, respectively. Severe erosion (>20 t ha^{-1}yr^{-1}) occurs in 20% area of the catchment. Based on severity of soil erosion, suitable sites for check dams and percolation tanks on 2nd/3rd order streams were identified using thematic maps of the catchment area.

Key words:
GIS,
Kolleru lake,
Soil erosion,
Universal soil loss equation

1. INTRODUCTION

Land and water resources are finite and important for agricultural production. The natural resources are rapidly shrinking and degrading due to demographic and socio-economic pressures, monsoon disturbances, increasing frequencies of floods and droughts. India loses about 16.4 t of soil ha^{-1} yr^{-1}, of which 29% is lost permanently into the sea, 10% gets deposited in the reservoirs reducing their capacity by 1–2% every year and the remaining 61% gets displaced from one place to another (Mandal and Sharda, 2011). Recent data indicated that 64 out of 142 Million hectare (M ha) of net sown area are affected with one or other kind of degradation (NBSS&LUP, 2015). In Andhra Pradesh, it is observed that Cuddapah, Visakhapatnam, Chittoor, Anantapur, and Vizianagaram districts are suffering from severe soil erosion. Soil erosion is a worldwide environmental problem that degrades soil productivity and water quality, pollution of water-courses by agricultural chemicals, causes sedimentation in water bodies and increases the probability of floods. About 30–50% of the world's arable lands are substantially degraded due to soil erosion.

It is the most significant contributor of ground water pollution on a global scale with most of the contaminants originating within an agricultural setting. Erosion control requires the information on the spatial distribution of the areas susceptible to degradation and a quantitative and qualitative evaluation of severity of erosion hazard. The combined use of remote sensing, GIS and erosion models have proven to be an effective approach for estimating the severity and spatial distribution of erosion. Soil erosion estimates are needed in soil conservation planning and design of hydrological structures (Dhruva Narayana and Ram Babu, 1983). Modeling can only provide a quantitative and consistent approach to estimate soil erosion under a wide range of conditions.

Models available in the literature for soil erosion estimation can be grouped into two categories: (1) Physically-based models and (2) Empirical models. Most of these models need information related to soil type, land use, landform, climate and topography to estimate soil loss. Physically based models are intended to represent the essential mechanisms controlling erosion process by solving the corresponding mathematical equations. These models are organized into different sub-models related to hydrology, hydraulics, meteorology and soil mechanics. The physically-based models include Water Erosion Prediction Project (Nearing *et al*., 1989), Areal Non point Source Watershed Environment Simulation model (Beasley, *et al*., 1980) and Kinematic runoff and erosion model (Woolhiser *et al*., 1990) etc. The major drawback of adopting these models is the requirement of huge data set.

Simple empirical models such as the universal soil loss equation (USLE) (Wischmeier and Smith, 1978), the modified universal soil loss equation (MUSLE) (Williams, 1975), or the revised universal soil loss equation (RUSLE) (Renard *et al*.,1991) are frequently used for the estimation of surface erosion and sediment yield from catchment areas because of simple structure, availability of data and ease of application. Vemu and Pinnamaneni (2011) estimated sediment yield at the outlet of Indravathi catchment using MUSLT model. An attempt has been made by Parveen and Kumar (2012) to estimate the annual soil loss in Upper South Koel basin, Jharkhand using USLE in GIS framework for implementation of soil conservation measures. Sakthivel *et al*. (2011) assessed soil erosion in the Kalrayan hills and identified Karnelli, Uppur, Pattivalavu, Arampundi, Vellar, Tekkampattu and Karumanturai are highly prone for soil erosion and implemented conservation measures. Many researchers have integrated GIS technique with USLE model to estimate soil erosion in watersheds (Reddy *et al.,* 2016; Singh *et al*., 1981; Sheikh *et al*., 2011; Saygin *et al*., 2014). Hence, USLE model integrated with remote sensing and GIS has been applied to determine spatial distribution of soil loss in Kolleru lake catchment in order to reduce siltation in the kolleru lake.

2. MATERIALS AND METHODS

Study Area

Kolleru Lake is the largest fresh water lake located between Krishna and Godavari delta and covers an area of 308 km^2. The lake is fed directly by water from the catchment area of Ramileru, Budameru, Tammileru, Gunderu and other streams. The catchment of the lake extends upto 6252 km^2. The catchment is located between latitude $16^0$20'32" and $17^0$25'11"N and longitude $80^0$30'12" and $81^0$40'07"E which comprises parts of Khammam, Krishna and West Godavari districts of Andhra Pradesh (Fig. 1.). The minimum elevation in the catchment is 0 m and the maximum elevation is 532 m. The mean elevation of catchment is 64.9 m.

Climate

Climate of the study area is tropical humid type with oppressive summer season and good seasonal rainfall. The summer season extends from March to May followed by southwest monsoon season, which lasts till September. October and November constitute the post monsoon season. December to February months experience cold weather conditions. The

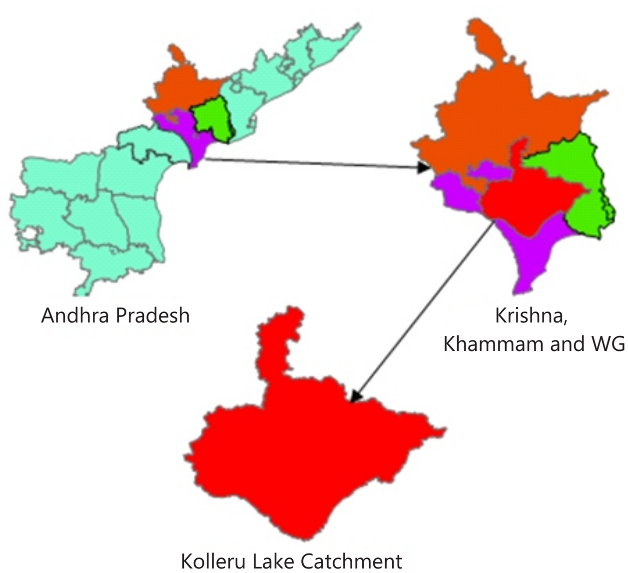

Fig. 1. Location map of Kolleru lake catchment

average annual rainfall of 23 years from 1990 to 2012 was 986 mm. The highest amount of rainfall was recorded as 1631.1 mm in the year 2010.

Digital Elevation Model (DEM)

The DEM was prepared by downloading ASTER DEM of catchment area with a resolution of 30 x 30 m. Two tiles were down loaded and mosaicing and rectification was done. The projection UTM, the spheroid type (WGS, 1984) and Datum of WGS 84 and 44 N zone has been applied to DEM. The stream network layer was prepared in GIS environment utilizing watershed delineation interface in ARC SWAT. The catchment boundary has been delineated (Fig. 2).

Land Use / Land Cover Map

The LU/LC prepared for the study area by EPTRI was utilised (Fig. 3). There are 12 types of land uses in the catchment. Major portion of the study area was covered with agricultural crops *viz.*, paddy, maize, tobacco and cotton. Orchards and oil palm plantations also exist in considerable area. Around 9.42% area is under aqua ponds.

Soil Texture Map

The soil map (1:250,000) developed by NBSS& LUP has been taken as reference map and clipped to the catchment area. The soil textural classes were identified. In addition to that the soil map prepared by SWAT group for India was also considered to ascertain the types of soils. The generated soil map is shown in Fig. 4. The properties of soils were finalized from the analysis of soil samples collected in the catchment area. The Kolleru lake catchment consists of mainly four types of soils. Majority of soils are sandy clay loam (45%) in texture followed by clay (24%), loam (12%) and clay loam (11%), respectively.

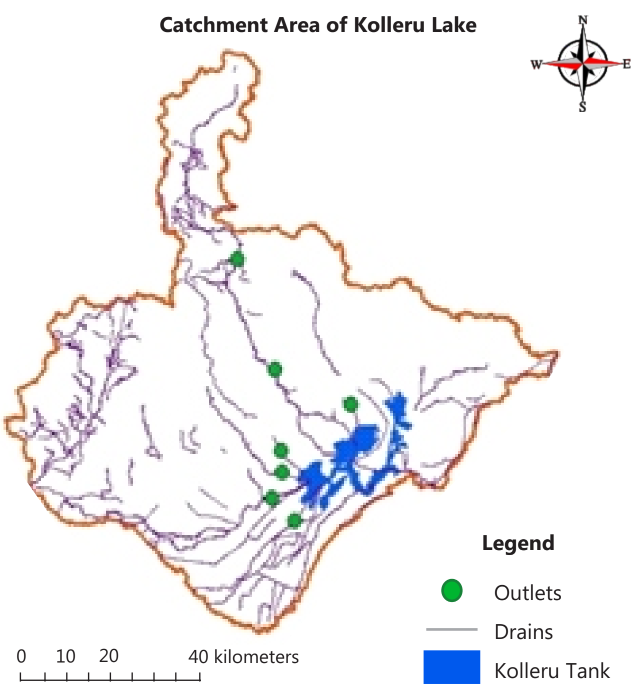

Fig. 2. Catchment area of Kolleru Lake Andhra Pradesh

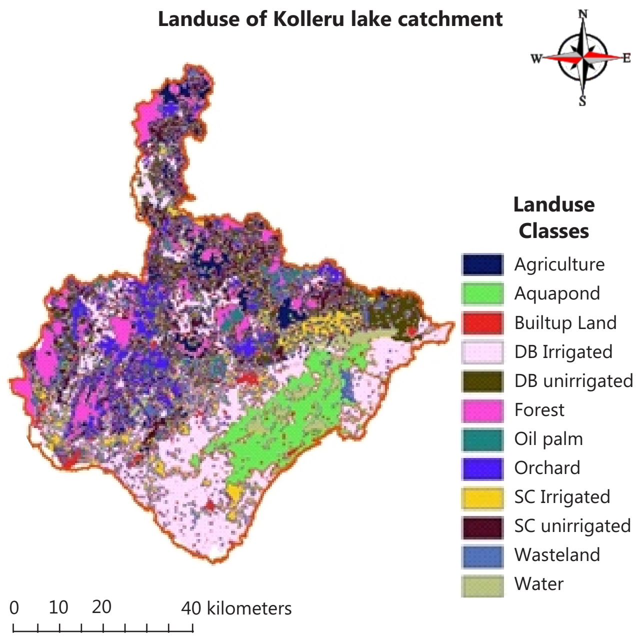

Fig. 3. Landuse of the catchment

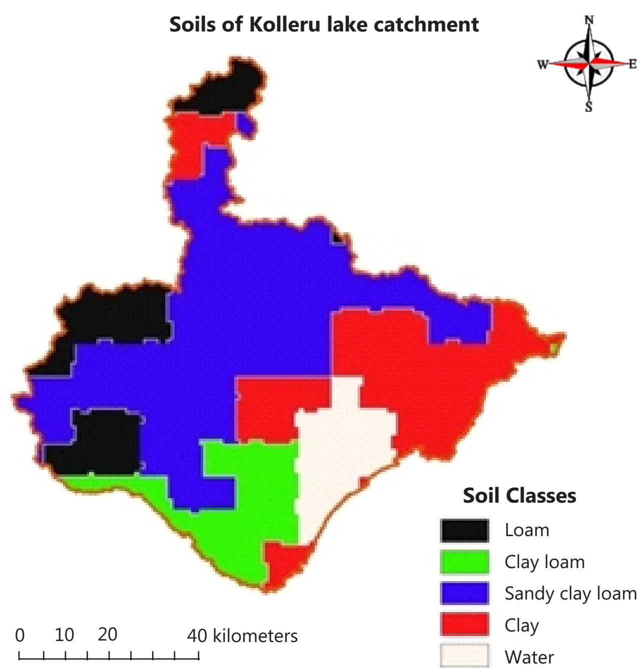

Fig. 4. Soils of the catchment

Universal Soil Loss Equation (USLE)

The USLE is the most commonly used erosion model for the assessment of soil loss caused by overland erosion. It was developed to estimate average annual soil loss from sheet and rill erosion. The USLE may be used to (Wishmeier and Smith, 1978) predict average annual soil movement from a given field slope under specified land use and management conditions. The rate of soil erosion can provide the guidance in the selection of conservation practices for specific sites. The equation can be expressed as:

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

This equation is explained in detail in Wishmeier and Smith (1978) which describes soil loss (A) as a function of rainfall (R) amount and intensity; soil erodibility (K) related to texture, percentage of organic matter, structure, and permeability of soil; morphology, especially the length of the slope (L) and the slope gradient (S); vegetation cover (C); and erosion control practices (P).

Each of the five factors in the USLE has been formulated by Wishmeier and Smith (1978) in such a way that it is linearly related to soil loss. The five parameters of USLE were obtained for the study area using GIS, remotely sensed ground observation, field survey and existing map data (Sheikh *et al.*, 2011; Balasubramani *et al.*, 2015).

1. Rainfall Factor (R): The rainfall factor (R) in the USLE equation defines the erosivity of rain and is a major input variable. Rainfall data for Kolleru lake catchment were collected for 23 years from 1990 to 2012. The rainfall runoff erosive factor, R, was calculated from the following relationship (Singh *et al.*, 1981). R is expressed in terms of average annual erosion index. The formula is shown below:

$$R = 79 + 0.363P \qquad ...(2)$$

Where, P = Annual rainfall amount in mm.

The eq. 2 was used to compute annual erosion-index values for 43 raingauge stations well distributed in catchment by using average annual rainfall data for 23 years for each station. The R-factor map developed for the catchment is shown in Fig. 5.

2. Soil erodibility factor (K): Erodibility factor (K) is a measure of potential erodibility of a particular soil under a set of conditions. It represents both susceptibility of soil to erosion and amount and rate of runoff as measured under standard plot condition. The soil properties influence greatly the rate at which the different soils erode. The important soil properties that influence soil erodibility are soil texture, stability of structure, soil permeability, infiltration, organic matter and soil mineralogy. Usually the deep, permeable coarse sands are the least erosive. Based on soil properties, the soil erodibility factor has been calculated and map has been prepared (Fig. 6).

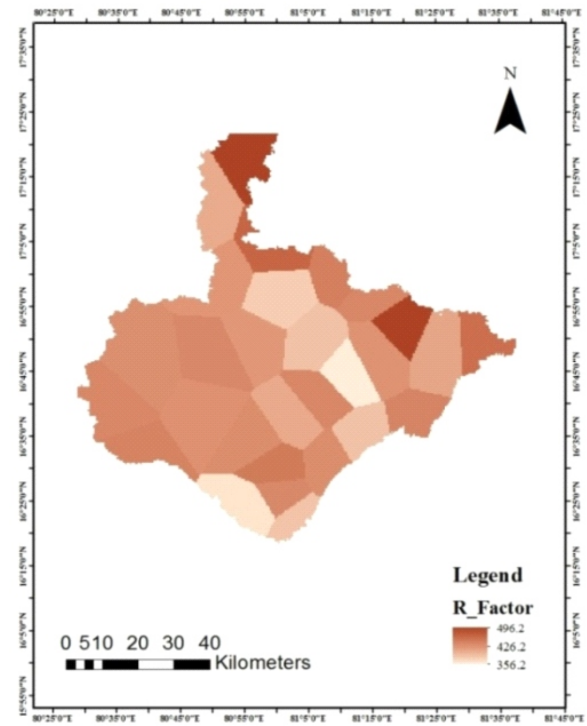

Fig. 5. R-Factor for Kolleru lake catchment

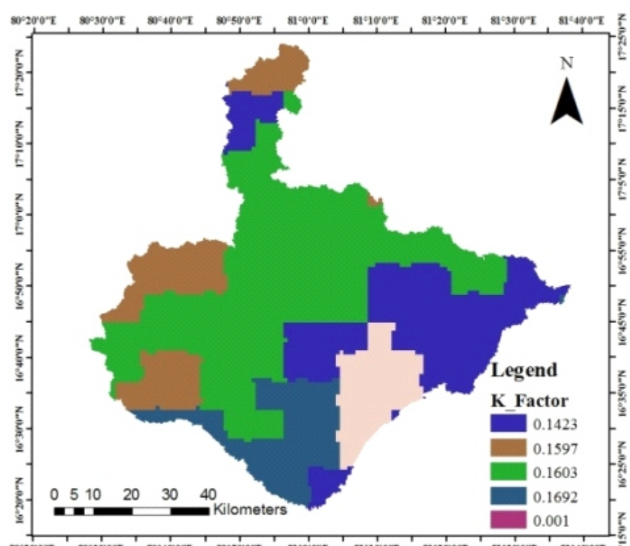

Fig. 6. K-Factor for Kollerulake Catchment

Soil erodibility factor (K) classes range from 0.1 to 0.169. The soil erodibility values of kolleru catchment are presented in Table 1.

3. Slope factor (LS): It is the length (L) and degree of slope (S) that affect soil erosion by water in a landscape. Erosion normally increases with increase in slope steepness and slope length as a result of respective increase in velocity and volume of surface runoff. The factor of slope length (L) and slope steepness (S) are combined in a single index. The factor LS of USLE can be determined as given below:

$$LS = (L/100)^{0.5}\,(0.136 + 0.097\,S + 0.0139\,S^2) \qquad ...(3)$$

Where, L is slope length (m) and S is slope (%).

The computed LS values at each sub watershed were used as input to generate LS factor map through GIS. Topographic factor classes in the catchment range from < 1.0 to 3.0. The area under each LS factor class in the catchment is given in Table 2 and their distribution in different sub watersheds is shown in Fig. 7.

4. Vegetation cover factor (C): It is the ratio of soil loss from land with specified cover and management conditions to that from continuous bare fallow conditions under the same soil, slope and rainfall conditions. It reflects the effect that vegetation cover, cropping, and management practices have on the erosion rate. Based on land use land cover map, the C values are assigned from the data obtained from research stations. The LU/LC data has been used for the calculation of C-factor. The cover and management (C) factor map for the entire catchment was generated through GIS. The cover factor (C) classes range from 0.001 to 0.8. The area under each class in the catchment is given in Table 3. The cover and management (C) factor map is presented in Fig. 8.

5. Conservation practice factor (P): It is the ratio of soil loss with a specific supporting practice to the corresponding soil loss with up and down cultivation. The P-factor layer can be created by reclassifying the DEM layer for catchment. The values for P-factor are assigned based on slope and land cover map (Fig. 10) The P-factor classes range from 0.25 to 1.00.

After completing data input and preparation of appropriate maps as data layers, the vector layers are multiplied in the GIS to obtain soil loss. The spatial

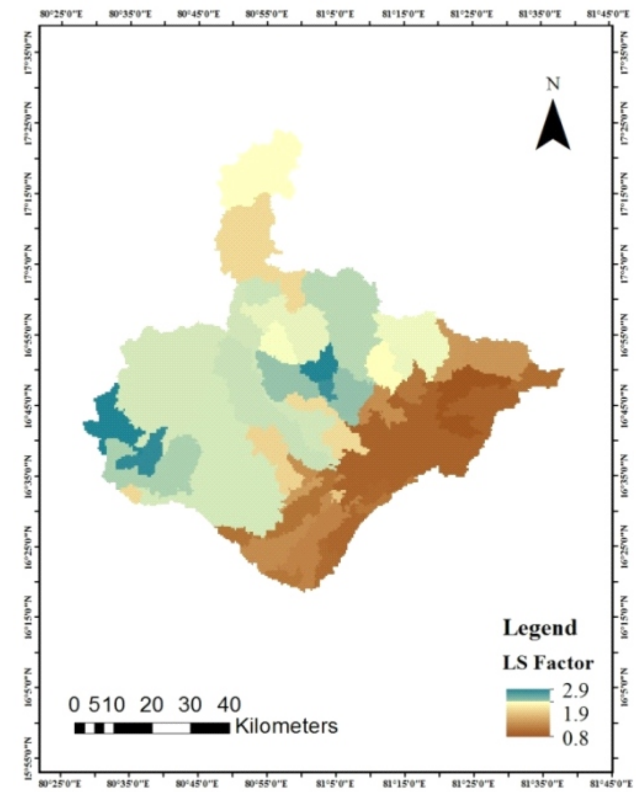

Fig. 7. LS factor of Kolleru lake catchment

Table: 1
Soil erodibility (K-factor) classes for Kolleru lake catchment

Class	K Factor	Area (km²)
1	Clay (0.1423)	1475.79
2	Loam (0.1597)	809.95
3	Sandy Clay Loam (0.1603)	2793.09
4	Clay Loam (0.1692)	684.98
5	Water (0.0)	498.44

Table: 2
Topographic factor (LS) classes for Kolleru lake catchment

Class	LS Values	Area (km²)
1	<1.0	1246.5
2	1.0 - 1.5	1133.8
3	1.5 - 2.0	3145.4
4	2.0 - 3.0	736.6

Table: 3
Cover and management factor (C) classes for Kolleru lake catchment

Class	C-Factor	Area (km²)
1	Agriculture (0.04)	610.84
2	Aquaponds (0.001)	574.37
3	Builtup Land (0.8)	268.67
4	Double Crop (0.03)	1471.50
5	Forest (0.04)	519.97
6	Un Irrigated Double crop (0.5)	461.58
7	Single Crop (0.45)	122.62
8	Horticulture (0.28)	492.48
9	Single Crop, (0.2)	540.24
10	Wasteland (0.2)	275.15

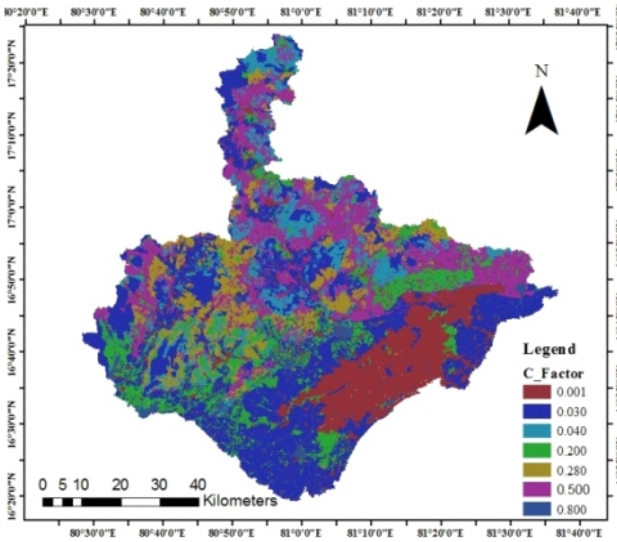

Fig. 8. C-factor of Kolleru lake catchment

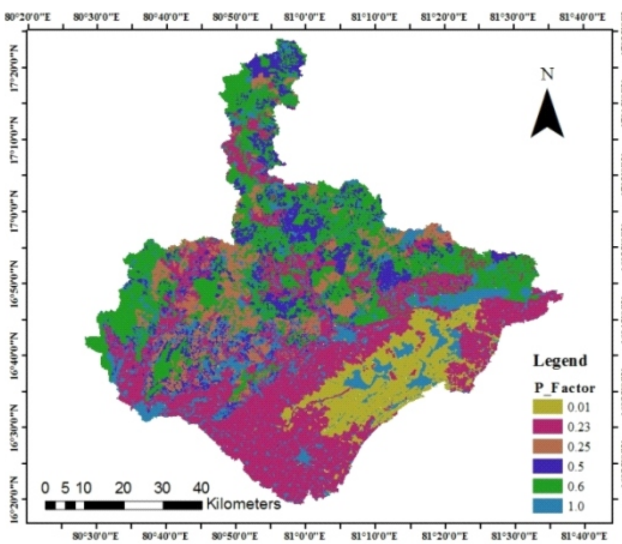

Fig. 9. P-factor of Kolleru lake catchment

Table: 4
Estimation of soil loss in Kolleru catchment

Type	Class (t $ha^{-1}yr^{-1}$)	Area (km^2)	Percentage
Slight erosion	0 - 5	960.27	16
Moderate erosion	5 - 10	2311.01	37
High erosion	10 - 15	814.6	13
Very high erosion	15 - 20	900.24	14
Severe erosion	>20	1266.12	20

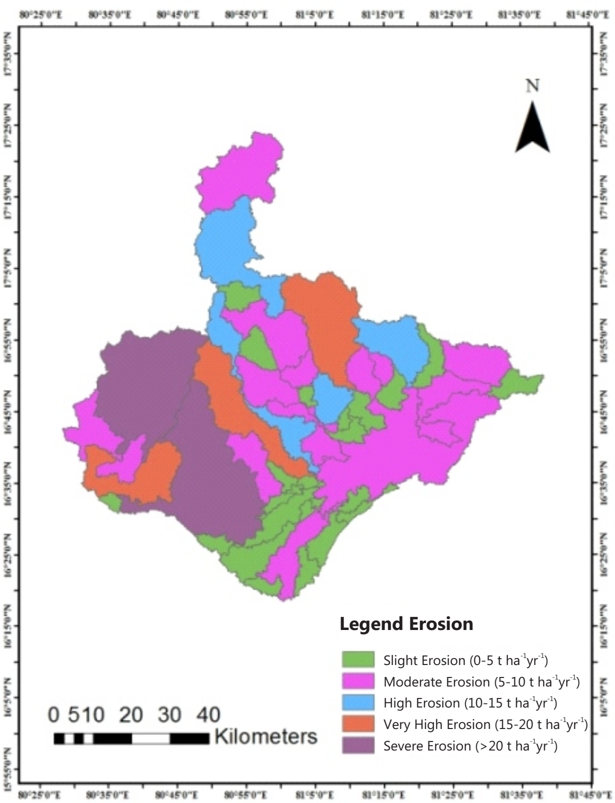

Fig. 10. Soil loss Map of Kolleru lake

distribution of the soil loss map of Kolleru lake catchment was obtained. Accordingly the catchment has been classified into five classes of soil loss starting from slight erosion to severe erosionas given below:

Slight (<5 t $ha^{-1}yr^{-1}$); Moderate (5-10 t $ha^{-1}yr^{-1}$); High (10-15 t $ha^{-1}yr^{-1}$); Very high (15-20 t $ha^{-1}yr^{-1}$); Severe (>20-40 t $ha^{-1}yr^{-1}$).

The potential soil loss estimated across the catchment under different classes is presented in Table 4 and their distribution in different sub watersheds is shown in Fig. 10.

It can be observed from Fig. 10 that about 16% of total area of catchment was found under slight risk of erosion. Around 37% of catchment lies in moderate risk of erosion. About 27% of area shows high to very high risk of soil erosion. Severe erosion occurs in 1266.12 km^2 area (20%). The highest computed soil erosion is 37.75 t $ha^{-1}yr^{-1}$ and the lowest value is 0.000248 t $ha^{-1}yr^{-1}$. The mean annual soil loss for the whole watershed area was 6.69 t $ha^{-1}yr^{-1}$.

The annual rainfall in this region ranges from 600 to 1391. 4 mm. The R-values are ranged from 356-496 mm. Soil erosion is highly variable in the spatial as well temporal domain. The temporal variation of soil loss has been estimated during 1990 to 2012 to study the impact of rainfall amount and intensity on soil loss. The soil loss for different years of annual rainfall for different sub watersheds have been calculated and presented in the Table 5a and 5b in terms of area (km^2) and percentage, respectively.

The results clearly indicated the effect of rainfall

Table: 5a
Soil loss for different years in Kolleru lake catchment area

Year	Area (km^2)				
	Slight	Moderate	High	Very High	Severe
1990	525.4	1602.2	1143.6	480.2	2500.8
1991	525.4	1943.0	1287.1	326.4	2170.4
1992	1159.8	2032.1	563.5	1226.7	1270.1
1993	1159.8	2400.4	1426.0	600.5	665.7
1994	717.4	2284.4	753.7	1226.7	1270.1
1995	525.4	1677.5	1068.1	808.9	2172.4
1996	525.4	2014.4	1215.6	925.2	1571.7
1997	960.3	2311.0	814.6	895.2	1271.1
1998	776.6	1591.6	1192.0	1056.9	1635.2
1999	771.6	2385.4	929.0	1500.7	665.7
2000	896.3	2063.9	519.2	1501.7	1271.1
2001	1183.3	2408.5	1160.7	228.7	1271.1
2002	1454.9	2300.6	1230.7	600.5	665.7
2003	1035.8	2719.7	1230.7	50.0	1216.19
2004	2233.2	1502.2	1801.1	50.0	665.7
2005	525.4	1842.8	1019.0	665.8	2199.3
2006	1159.8	2595.7	1230.7	604.5	661.7
2007	772.3	2116.4	866.7	1226.7	1270.1
2008	525.4	1727.8	1214.8	613.9	2170.4
2009	1159.8	2236.7	1355.9	229.7	1270.1
2010	453.9	705.9	1764.0	827.7	2500.8
2011	836.3	2435.0	814.6	662.6	1503.8
2012	652.7	1876.7	937.3	615.3	2170.4

Table: 5b
Soil loss for different years in Kolleru lake catchment area

Year	Area (%)				
	Slight	Moderate	High	Very High	Severe
1990	8.4	25.6	18.3	7.7	40.0
1991	8.4	31.1	20.6	5.2	34.7
1992	18.5	32.5	9.0	19.6	20.3
1993	18.5	38.4	22.8	9.6	10.6
1994	11.5	36.5	12.1	19.6	20.3
1995	8.4	26.8	17.1	12.9	34.7
1996	8.4	32.2	19.4	14.8	25.1
1997	15.4	37.0	13.0	14.3	20.3
1998	12.4	25.5	19.1	16.9	26.2
1999	12.3	38.2	14.9	24.0	10.6
2000	14.3	33.0	8.3	24.0	20.3
2001	18.9	38.5	18.6	3.7	20.3
2002	23.3	36.8	19.7	9.6	10.6
2003	16.6	43.5	19.7	0.8	19.5
2004	35.7	24.0	28.8	0.8	10.6
2005	8.4	29.5	16.3	10.6	35.2
2006	18.5	41.5	19.7	9.7	10.6
2007	12.4	33.9	13.9	19.6	20.3
2008	8.4	27.6	19.4	9.8	34.7
2009	18.5	35.8	21.7	3.7	20.3
2010	7.3	11.3	28.2	13.2	40.0
2011	13.4	38.9	13.0	10.6	24.1
2012	10.4	30.0	15.0	9.8	34.7

on erosion. Soil erosion is more during the years of high rainfall compared to the years of low rainfall. Among the various land use land cover, the average soil loss was predicted to be higher in barren lands and lowest in aqua ponds. The estimated soil loss was higher in single unirrigated crop land followed by double unirrigated crop. The severity of erosion is minimal because of high intensive irrigated agriculture and good management practices in part of west Godavari district.

According to Wishmeier and Smith (1978), the maximum tolerable soil loss (12 t $ha^{-1}yr^{-1}$) is defined as "the maximum level of soil erosion that will permit a level of crop productivity to be sustained economically and indefinitely". In India a default soil loss tolerance limit of 11.2 t $ha^{-1}yr^{-1}$ is followed for planning soil conservation activities (Mandal *et al.*, 2010). Therefore, if a soil loss of about 11.2 t $ha^{-1}yr^{-1}$ is considered as tolerable limit, then 40% of the total area of Kolleru lake catchment is predicted to be vulnerable to very high to severe soil erosion risk class. Thus, the catchment needs to be planned for soil conservation measures.

Soil and Soil and Water Conservation Measures

Soil and water conservation measures were planned for catchment area treatment based on estimated soil erosion data.

Severe erosion areas: In arable deep soils, contour bunds with waste weir, graded border strips, waterways with drop structures, vegetative bunds at 15 m horizontal interval, planting of agroforestry species in the upstream side of the bund at a distance of 2 m is recommended. On non-arable lands including gullied lands, gully stabilization structures like check dams and gabion structures, contour trenching and planting of forestry species is suggested. In black soils, graded bunds with waterways, farm ponds, gully stabilization structures like check dams and gabion structures and horticultural programmes involving pomegranate, amla and guava should be implemented.

Soil loss below tolerable limit areas: Only simple agronomic measures like contour cultivation, strip cropping, proper crop rotations, mulching, planting of grasses for stabilizing bunds, ploughing and inverting the soil using a tractor drawn mould board plough to a depth of 40 cm once in three years in deep black soils will help to reduce soil loss has to be popularized.

Watershed-based approach to harvest available water through farm ponds and percolation tanks will increase the water table in the surrounding areas. Deep ploughing before the onset of monsoon to restrict the runoff during the initial rains has to be advocated. Vegetative bunds and management practices like broad bed furrow and raised sunken beds may be followed. Agri-horticultural system to cover the areas may be adopted. Watershed based approach to conserve both soil and water resources may be practiced.

Site selection for water conservation measures is carried out by overlying the slope, soil, land use/land cover and stream order maps. The multi layer integration of land use/land cover, soil, slope, flow direction, drainage and settlement gave the suitability units for identifying sites for percolation tanks and check dams (Pandey *et al.*, 2011; Prasad *et al.*, 2014; Babatunde *et al.*, 2016). Factor layers (maps) were incorporated in ArcMap multi criteria evaluation analysis, using the weighted overlay function in the ArcGIS analyst. Finally, a suitability map was developed that show the potential sites for different conservation structures in study area.

The criterion has been decided for identifying the suitable sites for conservation measures, namely check dams and percolation tanks. The site for check dam can be selected on 2nd/3rd order streams in moderate to well drained conditions with slope <10% and land use may be agricultural areas/waste land/forest areas. Criteria for selection of site for percolation tank is 2nd /3rd order streams on well drained to excessively drained conditions with slope <3% and landuse may be waste land. The identified sites for check dams and percolation tanks were shown in Fig. 11 and 12.

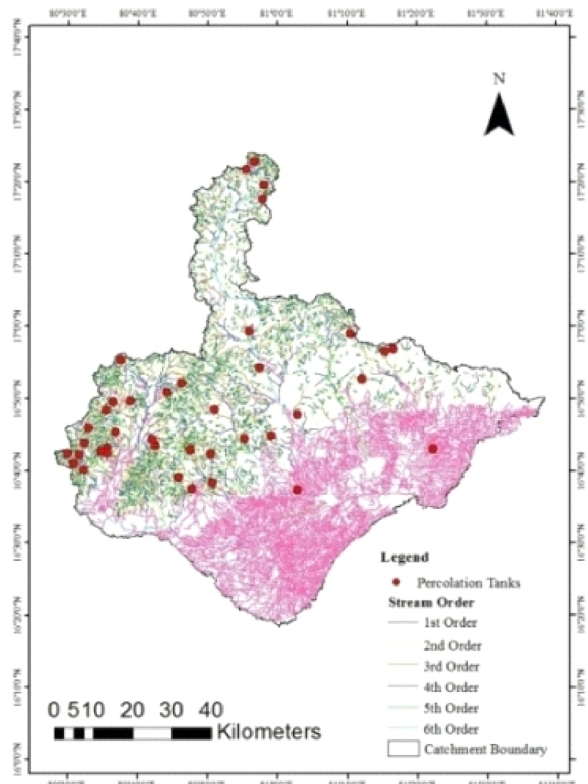

Fig. 12. Suitable sites for Percolation tanks

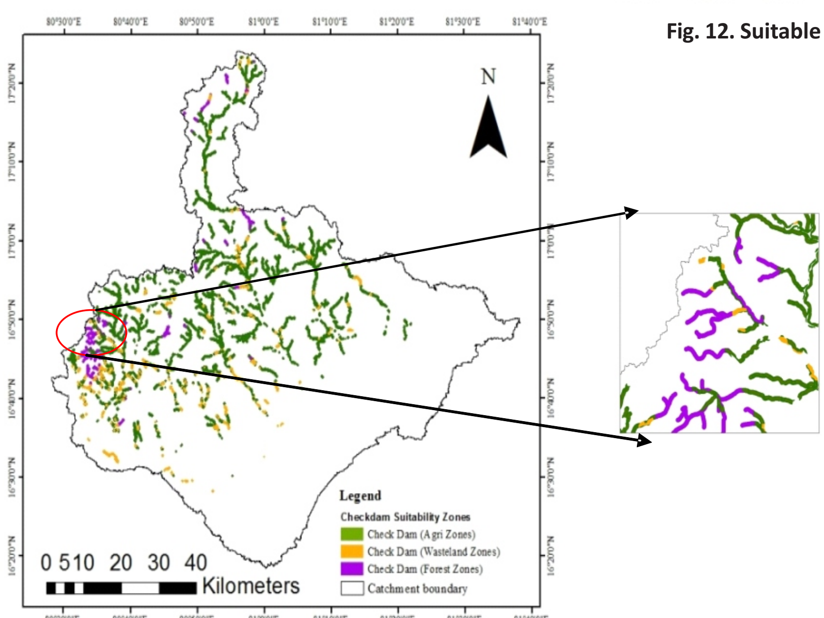

Fig. 11. Suitable sites for Check dams

Check dams are recommended for drainage line treatment. This structure helps in reducing velocity of runoff water, water harvesting and also ground water recharge. Percolation tanks are suggested across streams and bigger gullies to impound part of runoff water and thereby recharging of ground water.

3. CONCLUSIONS

The spatial and temporal variation of soil erosion in Kolleru lake catchment area has been estimated using USLE integrated with GIS. Soil loss was predicted high for the years of higher rainfall and low for the years of less rainfall. Soil loss did not occur in a uniform manner in each landuse. Barren lands have shown maximum soil erosion where as the occurrence of soil erosion was very less in aqua ponds. Quantitative estimates of soil loss under various land uses helped in identifying the priority areas for planning and designing of soil and water conservation works. Spatial distribution map depicting appropriate conservation measures, namely, check dams and percolation tanks was generated to prevent the soil erosion and further degradation and siltation of Kolleru lake.

ACKNOWLEDGEMENTS

The Authors are extremely grateful to Prof. Rajendra Prasad for providing the valuable guidance and encouragement. Our thanks are due to NRDMS Division, DST, New Delhi for funding the project to carry out this study. Our special thanks to APSRAC, Hyderabad and EPTRI for providing the required geo spatial layers.

REFERENCES

Babatunde, J. Fagbohun, Adeleye, Y.B., Anifowose, Chris Odeyemi, Olabanji, O. Aladejana, Adegoke, Aladeboyeje, I. 2016. GIS-based estimation of soil erosion rates and identification of critical areas in Anambra sub-basin, Nigeria, Model. *Earth Syst. Environ.*, 2:159.

Balasubramani, K., Mohan, Veena, Kumaraswamy, K. and Saravanabavan, V. 2015. Estimation of soil erosion in a semi-arid watershed of Tamil Nadu (India) using revised universal soil loss equation (RUSLE) model through GIS, Model. *Earth Syst. Environ.*, 1:10.

Beasley, D.B., Huggins, L.F. and Monke, E.J. 1980. ANSWERS: A model for watershed planning. *Trans. ASAE*, 23(4): 938-944.

Dhruva Narayana, V.V. and Ram Babu, 1983. Estimation of soil erosion in India. *J. Irrig. Drain. Eng. ASCE*, 109(4): 419-433.

Mandal, D. and Sharda, V.N. 2011. Assessment of permissible soil loss in India employing a quantitative bio-physical model. *Curr. Sci.*, 100(3): 383-390.

Mandal, D., Sharda, V. N. and Tripathi, K.P. 2010. Relative efficacy of two biophysical approaches to assess soil loss tolerance for Doon Valley soils of India. *J. Soil Water Cons.*, 65: 42-49.

NBSS&LUP. 2015. *Agro-Ecological regions of India (Rev. Ed.)*. NBSS Pub., 170: 2015. ISBN:978-81-89043-46-9.

Nearing, M.A., Foster, G.R., Lane, L.J. and Finkner, S.C. 1989. A process based soil erosion model for USDA-water Erosion Prediction Project technology. *Trans. Am. Soc. Agri. Eng.*, 32: 1587-1593.

Pandey, A., Chowdary, V.M., Mal, B.C. and Dabral, P.P. 2011. Remote sensing and GIS for identification of suitable sites for soil and water conservation structures. *Land Degrad. Dev.*, 22(3): 359-372.

Prasad, H.C., Parul Bhalla and Sarvesh Palria. 2014. Site suitability analysis water harvesting structures using Remote Sensing and GIS – A Case Study of Pisangan Watershed, Ajmer District, Rajasthan.The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-8. *ISPRS Technical Commission VIII Symposium, 09-12 December 2014, Hyderabad, India*, pp1471-1482.

Reddy G.P. Obi, Kurothe, R.S., Sena, D.R., Harindranath, C.S., Niranjana, K.V., Naidu, L.G.K., Singh, S.K., Sarkar, Dipak, Mishra, P.K., Sharda, V.N. 2016. Assessment of soil erosion in tropical ecosystem of Goa, India using Universal Soil Loss Equation, geostatistics and GIS. *Indian J. Soil Cons.*, 44(1): 1-7.

Renard, K.G., Foster, G.R., Weesies, G.A. and Porter, J.P. 1991. RUSLE: Revised Universal Soil Loss Equation. *J. Soil Water Cons.*, 46: 30-33.

Parveen, Reshma and Kumar, Uday. 2012. Integrated approach of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil loss risk assessment in Upper South Koel Basin, Jharkhand. *J. Geogra. Infor. Syst.*, (4): 588-596.

Sakthivel, R., Jawahar, Raj, N., Pugazhendi, V., Rajendran, S. and Alagappamoses, A., 2011.Remote Sensing and GIS for Soil Erosion Prone areas Assessment: A case study from Kalrayan hills, Part of Eastern Ghats, Tamil Nadu, India. *Arch. Appli. Sci. Res.*, 3(6): 369-376.

Saygin, S.D., Ozcan, A.U., Basaran, M., Timur, O.B., Dolarslan, M., Yilman, F.E. and Erpul, G. 2014. The combined RUSLE/SDR approach integrated with GIS and geostatistics to estimate annual sediment flux rates in the semi-arid catchment, Turkey. *Environ. Earth Sci.*, 71: 1605-1618.

Sheikh, A.H., Palria, H. and Alam, A. 2011. Integration of GIS and Universal Soil Loss Equation (USLE) for Soil Loss estimation in a Himalayan Watershed. *Recent Res. Sci. Tech.*, 3(3): 51-57.

Singh, G., Chandra, S. and Babue, R. 1981. Soil Loss and Prediction Research in India, Central Soil and Water Conservation Research Training Institute, Bull. No. T- 12/D9.

Singh, G., Ram Babu and Chandra, Subhash. 1981. Soil Loss Prediction Research in India. Central Soil & Water Conservation Research & Training Institute, Dehradun, Bull. No. T-12ID-9 70 p.

Vemu, S. and Pinnamaneni. 2012. Sediment yield estimation and prioritization of watershed using RS and GIS, Intenational archives of the photogrammetry, *Remote Sens. Spat. Infor. Sci.*, doi: 10.5194/isprsarchives-XXXIX-B8-529-2012.

Vemu, S. and Pinnamaneni, U.B., 2011. Estimation of spatial patterns of soil erosion using remote sensing and GIS: A case study of Indravati catchment. *Nat. Hazards*, 59: 1299-1315.

Williams, J.R. 1975. Sediment routing for agricultural watersheds. *Water Resour. Bull.*, 11: 965-974.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall Erosion Losses - A Guide to Conservation Planning, Agriculture Handbook No. 537, Agriculture Science and Education Administration, Washington, District of Colum, USA.

Woolhiser, D.A., Smith, R.E. and Goodrich, D.C. 1990. KINEROS - A kinematic runoff and erosion model: documentation and user manual. USDA-Agricultural Research Service, ARS-77: 130 p.