Research Paper EARTH SCIENCE

Gis – Based Sediment Assessment Tools In And Around Chamarajanagar District

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ABSTRACT

Accelerated soil erosion is a worldwide problem because of its economic and environmental impacts. To estimate soil erosion and to establish soil erosion management plans, many computer models have been developed and used. The Revised Universal Soil Loss Equation (RUSLE) has been used in many countries and input parameter data for RUSLE have been well established over the years. However, RUSLE cannot be used to estimate the sediment yield for a watershed. Thus, the GIS-based Sediment Assessment Tool for Effective Erosion Control (SATEEC) was developed to estimate soil loss and sediment yield for any location within a watershed using RUSLE and a spatially distributed sediment delivery ratio. SATEEC was enhanced in this study by developing new modules to: 1) simulate the effects of sediment retention basins on the receiving water bodies, 2) estimate the sediment yield from a single storm event and 3) prepare input parameters for the Web-based sediment decision support system using a GIS interface. The enhanced SATEEC system was applied to study the watershed to demonstrate how the enhanced system can be effectively used for soil erosion control. All the procedures are fully automated with Avenue, CGI, and database programming; thus the enhanced SATEEC system does not require experienced GIS users to operate the system. This easy-to-operate SATEEC system can be used to identify areas vulnerable to soil loss and to develop efficient soil erosion management plans.

Keywords : Soil erosion, Sediment delivery ratio, Sediment yield, GIS, Chamarajanagar

INTRODUCTION

Soil is one of the biotic factors support many forms of life on earth surface which formed by process of weathering over a long period of time. Soil forms based on physical, biological, and chemical modification of sediment or rock exposed at the earth surface.

To estimate soil erosion and to develop optimal soil erosion management plans, many erosion models, such as Universal Soil Loss Equation (USLE), have been developed and used over the years. Among these models, the USLE has remained the most practical method of estimating soil erosion potential in fields and to estimate the effects of different control management practices on soil erosion for nearly 40 years (Dennis and Rorke, 1999; Kinnell, 2000) while other process-based erosion models have intensive data and computation requirements. The new version of the USLE, called the Revised Universal Soil Loss Equation (RUSLE), was developed by modifying the USLE to more accurately estimate R, K, C, P factors, and soil erosion (Renard et al., 1991). Van Remortel et al. (2004) developed an array-based C++ program to automate the calculation of the LS factor from a digital elevation data because the ArcInfo Macro Language (AML) program was not efficient and fast. The USLE has been used / integrated with Geographic Information Systems (GIS) to estimate soil erosion as GIS helps users manipulate and analyze the spatial data easily, and it also helps users identify the spatial locations vulnerable to soil erosion. However, these studies using the USLE did not consider the sediment delivery ratio to estimate the sediment delivered to the downstream point of interest. Regional variations in sediment yields are very important since sediment delivery processes vary in space and time. The Win Grid system by Lin et al. (2002) considered the sediment delivery ratio based on receiving drainage length ratio to total drainage length to compute soil erosion and sediment yield using USLE and a sediment delivery ratio. However, this system has separate component programs rather than being fully integrated with a GIS system. Hence, it is not readily available to soil erosion decision makers because it was developed for research purposes. Thus, a GIS integrated prototype version of the Sediment Assessment Tool for Effective Erosion Control (SATEEC) (Lim et al., 2003) was developed to provide an easy-to-use GIS interface to estimate soil erosion and sediment yield without additional input parameter data other than those for the USLE model. With the USLE input parameter maps, the SATEEC can estimate soil erosion and the sediment yield at any point within a watershed with a menu-driven SATEEC GIS interface. However, the prototype version of the SATEEC GIS system cannot be used to assess the effects of sediment retention basins on the sediment yield of the receiving water bodies. Also, it cannot be used to estimate the sediment yield from a single storm event for an effective sediment control management. In addition, the SATEEC GIS system does not have any sediment and erosion control structure design capability. In the prototype version of the SATEEC GIS system, three methods are provided to compute the spatially distributed sediment delivery ratios (SDR), derived from measured data from hundreds of watersheds. However, users may need to use their watershed-specific SDR power function for better estimation of sediment yield. Therefore, there is a need to enhance the functionalities of the prototype SATEEC GIS system.

METHODOLOGY

Chamarajanagar district is one of the 7 new districts formed during 1997, located in the southern tip of Karnataka state. The district does not have any major river flowing, however it is drained by Suvarnavathy and Chikkahole, which are the tributaries of Cauvery River. There are no mineral based industries in the district. The total population in the district is around 9, 65,462 (as per 2001 census), out of which rural population constitutes 8, 17,372 (84.66%). The density of population is 189 per sq. km. Small pockets of Kollegal and Yalandur taluks are covered under canal irrigation. The district falls in Cauvery River basin. The cultivable land is about 2, 09,009 ha, out of which only around 34246 ha (16%) is irrigated.

Location of the study area

The geographical area of Chamarajanagar district is about 5,101 Km2. The district is located in the southern tip of Karnataka state and lies between the North latitude 11º 151and 11º 59'' and East longitude 76º 48'and 77º 59'. It falls in the southern dry zone. Topography is undulating and mountainous with north south trending hill ranges of Eastern Ghats. Salem and Coimbatore districts of Tamilnadu in the east, Mandya and Bangalore districts in the north, parts of Mysore district in the west and Nilgiris district of Tamilnadu in the south, bound the Chamarajanagar district.

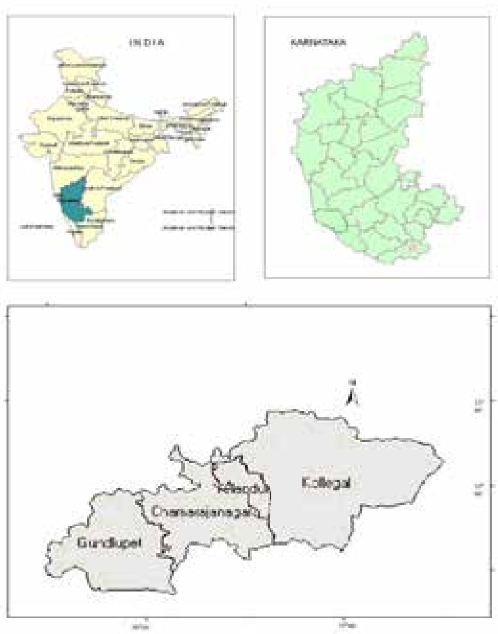
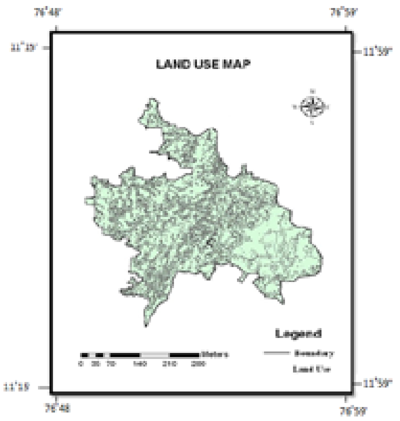


Fig. 1: Map of the study area

Geomorphology and Soil Types

The district may be classified as partly maidan and general tableland with plain, undulating and mountainous. The southern and eastern ghats in the district converge into group of hills. The landmass of the area forms an undulating tableland and lofty mountain ranges covered with vast forests. Master slope runs from south to north towards Cauvery River. Normally the slopes are covered by debris and colluvium filled channels. The general elevation is 656.58m above msl. The Shivanasamudra island and Edacura village towards north of Kollegal taluk

forms the important features formed due to meandering and confluence of Cauvery river. The soils of the district are derived mainly from Granitic gneisses and Charnockite rocks.



Development of effective erosion control plans requires the identification of areas vulnerable to soil erosion and quantification of the amounts of soil erosion from various areas. The empirically based USLE and newly revised RUSLE have been used in many countries since the late 1960s (Wischmeier and Smith, 1978). It is designed to estimate the long-term average annual soil loss for fields with specified cropping and management systems as well as rangeland (Renard et al., 1997). RUSLE estimates annual soil loss per unit area from rill and interill erosion caused by rainfall splash and overland flow, but not from gully and channel erosion. The RUSLE does not consider the runoff process explicitly, nor soil detachment, transport, and deposition individually (Renard et al., 1994).

Eq. (1) shows how the RUSLE computes the average annual soil loss.

A = RKLSCP

Where

A - Average annual soil loss (ton/ac/year),
R - Rainfall/runoff erosivity,
K - Soil erodibility,
LS- Slope length and steepness,
C - Cover management,
P- Support practice.
The R factor in RUSLE is composed of total storm kinetic energy (E) times the maximum 30 min intensity (I30), and the numerical value of R is the average annual value for storm events for at least 22 years (Wischmeier and Smith, 1978; Renard et al., 1997). Hence, RUSLE cannot be used to estimate soil erosion and sediment yield for a single

Storm event. Thus, the Modified Universal Soil Loss Equation (MUSLE) has been widely used to estimate the sediment yield from a single storm event (Williams and Berndt, 1977).

Eq. (2) shows how the MUSLE computes sediment yield from a single storm event.

Y = 11.8 (Q * qp)0.56 KCPLS

Where

Y sediment yield from a single storm event (ton),
Q storm runoff volume (m3),
qp peak runoff rate (m3/s),
K soil erodibility,
LS slope length and steepness,
C cover management,
P support practice.
RUSLE is a field scale model, thus it cannot be directly used to estimate the amount of sediment reaching downstream areas because some portion of the eroded soil may be deposited while traveling to the watershed outlet, or the downstream point of interest. To account for these processes, the Sediment Delivery Ratio (SDR) for a given watershed should be used to estimate the total sediment transported to the watershed outlet. The SDR can be expressed as follows (Eq. (3)).

SDR = SY/E

Where

SDR Sediment Delivery Ratio,

SY Sediment Yield,

E Gross Erosion for Entire Watershed.

Prototype version of the SATEEC GIS system the prototype version of the SATEEC GIS system was developed to provide an easy-to- use sediment assessment tool for soil erosion decision makers with Avenue programming within the ArcView GIS software (Lim et al., 2003). Fig. 1 provides an overview of the prototype version of the SATEEC GIS system. Soil loss is estimated with RUSLE, and a spatially distributed sediment yield map is generated with RUSLE estimated soil loss multiplied by the spatially distributed sediment delivery ratio map. To compute soil loss from rill and interrill erosion, RUSLE was first integrated with the GIS system. In the prototype version of the SATEEC GIS system, the method developed by Moore and Burch (1986a,b) was used to calculate the LS factor from the Digital Elevation Model (DEM). All DEM pre-processing and map algebra were automated with Avenue programming. According to the RUSLE User's Guide (Foster et al., 1996), the length of hill slopes in the USLE experimental plots ranged from 10.7 m (35 ft) to 91.4 m (300 ft). Thus, it was recommended that the use of slope lengths less than 122 m (400 ft) are desired because overland flow becomes concentrated into the rills in less than 122 m (400 ft) under natural condition (Foster et al., 1996). Thus, SATEEC computes the LS factor using the method developed by Moore and Burch (1986a,b) (Eq. (7)) and an upper bound of slope length is provided by users, such as 122 m (400 ft).

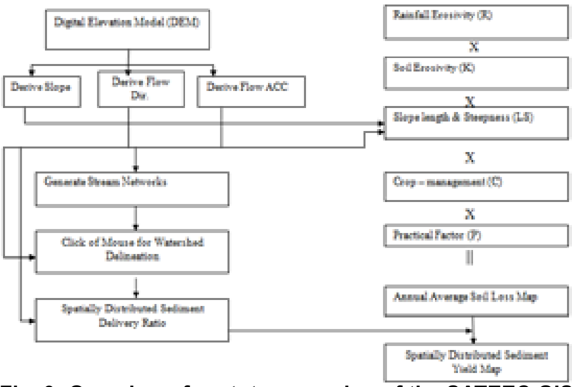


Fig. 3: Overview of prototype version of the SATEEC GIS system

RESULTS

Enhanced SATEEC GIS system

The SATEEC GIS system was enhanced with additional functions incorporated in the SATEEC menus to simulate the effects of sediment retention basins in the watershed, estimate the sediment yield from a single storm event, and provide a GIS interface to the Web-based SEDSPEC retention basin module. With the enhanced SATEEC GIS system, users are able to use a watershed specific SDR power function for improved sediment estimation. All functionalities described in section were fully automated with ArcView and Oracle SQL programming. SATEEC Version 1.5 is available in the ArcView GIS project file

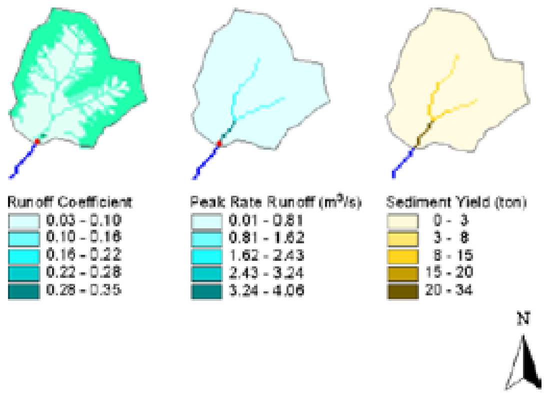
Application of the enhanced SATEEC GIS system

The enhanced SATEEC GIS system was not compared with measured data for validation purposes in this study because the USLE has been widely used and validated in many countries (Lal, 1990; Mati et al., 2000; Moehansyah et al., 2004). Also, the sediment delivery ratio equation incorporated in the SATEEC system was derived from measured data from hundreds of watersheds (USDA, 1972; Boyce, 1975; Vanoni, 1975).

To estimate the effects of a sediment retention basin on the receiving water bodies. Second, the sediment yield from a single storm event is estimated using the newly developed module. Third, the enhanced SATEEC GIS system and the Web-based SEDSPEC system are used to design a sediment basin.

Summary and conclusions

The prototype version of the SATEEC GIS system was enhanced in this study by adding three new modules. New modules were developed to: 1) simulate the effects of



Sediment retention basins on the downstream sediment loading, 2) estimate the sediment yield from a single storm event, and 3) provide a GIS interface system for the design of sediment retention basins. These three modules are fully automated through ArcView, Java Script and SQL programming. Thus, the SATEEC GIS system does not require experienced GIS users to operate the system. Soil erosion management plans need to be targeted to the major problem areas rather than to the entire region of interest. Thus, this easy-to-use SATEEC GIS system can be used by soil erosion decision makers to estimate soil loss and sediment yield, to identify areas vulnerable to soil loss, and to establish efficient erosion control plans with a fully automated menu driven system. Although the enhanced SATEEC is an efficient tool for soil erosion management, SATEEC does not estimate soil loss from gully and channel erosion processes. Thus, it should not be used for large watersheds if the soil loss from gullies and channels is dominant. Also only area-based SDR estimation methods are utilized in the enhanced SATEEC GIS system. Thus, other SDR estimation methods, considering watershed shape, rainfall pattern, direct runoff, peak runoff, land use, cover crop, particle size, and channel density, need to be incorporated into the SATEEC GIS system.

REFERENCES

1.Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment part I: model development. Journal of American Water Resources Association, 34 (1): 73– 89. | | 2.Bahadur, K.C.K. 2009. Mapping Soil Erosion Susceptibility Using Remote Sensing and GIS: A Case of the Upper Name Wa Watershed, Nan Province, Thailand. Environmental Geology, 57(3): 695–705. | | 3.Bartsch, K. P., van Miegroet, H., Boettinger, J., et al., 2002. Using Empirical Erosion Models and GIS to Determine Erosion Risk at Camp William, Utah. J. Soil Water Conserv., 57(1): 29–37. | | 4.Black C.A. (Ed) 1965 Methods of Soil Analysis, Part I. Physical and Mineralogical Properties including Statistics of measurement and sampling. Amer.Soc.Agron.,Inc.,Madison, Wisconsin. | 5.Blaszczynski, J., 1992. ASTM STP 1126. Regional soil loss prediction utilizing the RUSLE/GIS interface. In: Johnson, A.I., Pettersson, C.B., Fulton, J.L. (Eds.), Geographic Information Systems (GIS) and mapping—practices and standards. American Society for Testing and Materials, Philadelphia, PA, pp. 122–131. | | 6.Collins, A. L. and Walling, D. E.: Documenting catchment suspended sediment sources: problems, approaches and prospects, Prog. Phys. Geog., 28(2), 159–196, 2004. | | 7.Doneen L.D., 1948. The quality of irrigation water and soil permeability, Proc. Soil Sci. Amer., Vol. 13, pp. 523. | | 8.Hickey, R., 2000. Slope Angle and Slope Length Solutions for GIS. Cartography, 29(1): 1–8. | | 9.Moore, I., Burch, G., 1986a. Physical basis of the length–slope factor in the universal soil loss equation. Soil Science Society of America Journal 50, 1294– 1298. | | 10. Moore, I., Burch, G., 1986b. Modeling erosion and deposition: topographic effects. Transactions of the ASAE 29(6), 1624– 1630. | | 11.Shadakshara Swamy, 1985. Petrological and structural studies of the Sargur supracrustal and associated gneisses around Terakanambi region, South Karnataka. Ph.D. Thesis, University of Mysore, Mysore. | | 12.Stone, M. and Krishnappan, B. G. 2002. The effect of irrigation on tile sediment transport in a headwater stream, Water Res. 36: 3439–3448. | | 13.Strahler, A.N. 1952. Dynamic basis of geomorphology. Bull. Geol. Soc., Am., 63: 923-928. | | 14.Zernitz, E.R., 1932. Drainage patterns and their significance, Jour. Geol. 40, pp. 498-521. |