International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2021 Vol. 11, pp. 36-49/Bhatt et al.
Research Article

ESTIMATION OF SOIL EROSION USING RUSLE AND GEO SPATIAL TECHNIQUES: A CASE STUDY OF VISHWAMITRI URBAN WATERSHED, GUJARAT

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ABSTRACT

Accelerated soil water erosion is one of the major global environmental problems that adversely affect both rural and urban areas. While many investigations have been initiated to efficiently understand and effectively manage water erosion problems in agricultural areas, specific knowledge on urban water erosion is less pronounced.

A key challenge in understanding and managing urban water erosion is the rapid growth of urban areas and the related on-going change of the physical environment. Since watershed forms a natural boundary to focus on all the effects of downhill runoff, a systematic assessment of soil erosion within the watershed would provide reliable information to draw strategies for sustainable development of watershed resources. In this circumstance, Revised Universal Soil Loss Equation (RUSLE) has been used to estimate soil erosion in the urban watershed of Vishwamitri River of Gujarat

This model takes into consideration the parameters including runoff-rainfall erosivity factor (R), soil erodability Factor (K), topographic factor (LS), cropping management factor (C), and support practice factor (P). All these layers are prepared in a Geographical Information System (GIS) platform using various data sources and data preparation methods. Thus, study integrates Geographic Information System (GIS) and digital data to estimate the spatial distribution of soil erosion in the urban watershed of Vishwamitri River.

Thus the aim is to provide an overview of the extent at which erosion dynamics have been explored in urban areas.

Keywords: GIS, RUSLE, Soil Erosion, Urban Watershed

INTRODUCTION

Environmental degradation in form of soil degradation directly or indirectly affects several lives through reduced agricultural products, increased flooding and habitat loss. Soil loss has been increasing in most parts of the world and is most pronounced in tropical developing countries where there is poor or zero soil and water conservation (SWC) planning and management activities. Identifying areas prone to soil erosion has also been inadequate, having not been informed by dedicated scientific studies Soil erosion is a natural and inevitable process that can become a serious environmental and economic problem when it is accelerated by human activities. Water supplies and storage reservoirs, freshwater and coastal environments, agricultural and urban productivity can all be negatively impacted by accelerated soil erosion. While the importance of minimizing soil erosion. Soil erosion and transport is a complex process that is influenced by soil type, topography, climate, and land use. In areas where soil, climate, and topography are similar, differences in erosion rates are commonly related to land use. Land use practices in this watershed have changed dramatically. Human activity such as construction of roads, highways, and dams, control works on streams and rivers, mining, and urbanization usually accelerate the process of erosion, transport, and sedimentation (Julien 2010).Increasing urban populations are evidently associated with an increase in sealing of permeable surfaces (Shuster, *et al.,* 2005; Strahler, 2010). The impervious surfaces include road networks, buildings, canalization of drainage systems, pavements and other concrete-like surfaces. Such surface changes do not only impact the kinetics of chemical soil reactions and gas diffusion but also modify water movements (Scalenghe and Marsan, 2009; Strahler, 2010). Soil erosion is one of the most significant environmental degradation processes. Mapping and assessment of soil erosion vulnerability is an important tool for planning and management of the natural resources.

Spatial and quantitative information on soil erosion on a regional scale contributes to conservation planning, erosion control and management of the environment. Identification of erosion prone areas and quantitative estimation of soil loss rates with sufficient accuracy are of extreme importance for designing and implementing appropriate erosion control or soil and water conservation practices (Shi *et al.,* 2004)

The dominant model applied worldwide to estimate the soil erosion is Universal Soil Loss Equation (USLE), which is a conservation planning tool that has been demonstrated to do a reasonably good job for estimating soil erosion for many disturbed land uses (Moore and Wilson 1992; Millward and Mersey 1999). The USLE, a paper-based model, was computerized and updated by a group of scientists (Renard *et al.,* 1997) and subsequently called as Revised Universal Soil Loss Equation (RUSLE). The RUSLE has been widely adopted for soil loss assessment at watershed scale because of its convenience in computation and application (Angima *et al.,* 2003; Pandey *et al.,* 2009; Saravanan *et al.,* 2010; Sharma *et al.,* 2011; Prasannakumar *et al.,* 2012; Balasubramani *et al.,* 2015)

Several erosion models are available to predict the soil loss and to assess the soil erosion risk. The Universal Soil Loss Equation (USLE), an empirical model (Wischmeier and Smith 1978) or the RUSLE model (Renard *et al.,* 1997) are widely used to predict potential soil water erosion. RUSLE is a set of mathematical equations that estimate average annual soil loss resulting from soil erosion. Derivation of values for RUSLE is well documented in the literatures (Wischmeier and Smith 1978; Renard *et al.,* 1997).Soil erosion conservation plan and development guides for different land-cover conditions such as crop land and forest have extensively used the revised universal soil loss equation (RUSLE) model outputs (Millward *et al.,* 1999) Moreover, RUSLE's advantages stem from its compatibility with GIS and the use of existing data .When utilized in conjunction with raster-based GIS, the RUSLE can identify areas of soil loss on a cell-by-cell premise and classify the extent of soil loss within the watershed .

The objective of the present study was to apply the Revised Universal Soil Loss Equation (RUSLE) using GIS tools to the Vishwamitri River, in order to assess soil erosion vulnerability.

Study Area

The watershed is located in the Golden Corridor of Gujarat, witnessing rapid urban and industrial development. . The surrounding area has therefore witnessed gradual land use land cover change.

The Vishwamitri Urban Watershed is delineated from the Carto-DEM with 10m resolution, it's covered the almost 91.15 Sq. km area. The elevation ranges from 85 m to 24 m above mean sea level. The location extent of the watershed from73° 16'east to 22°22 north. The total length of the meandering river in urban-sub watershed is about 34km. The climate featuresaresemi-arid due to the area high potential evapotranspiration. The climate of the area is subtropical. The watershed experiences precipitation with an annual average of mm. The mean maximum and mean minimum temperature in the watershed are 45 °C and 10 °C respectively.

The main goal of this study was to test the RUSLE model in the study area. All the RUSLE parameters determined for the study area were either in spatial format and/or in numerical format. The spatial maps and other factors were integrated using RUSLE empirical formula Equation and analysed in Arc GIS module.

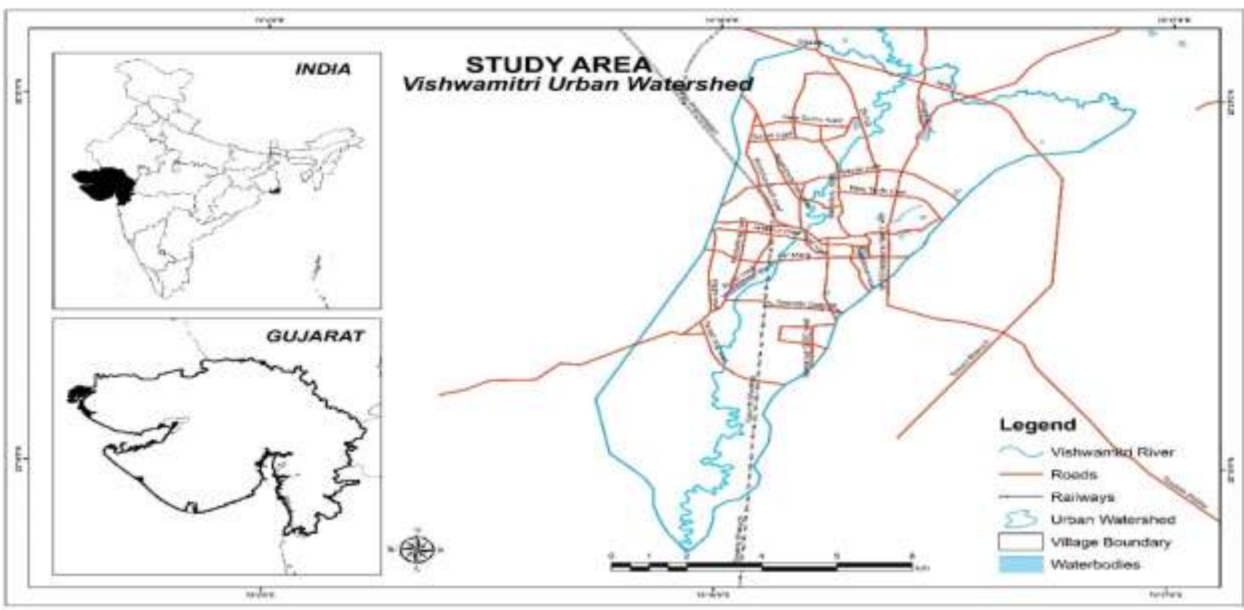
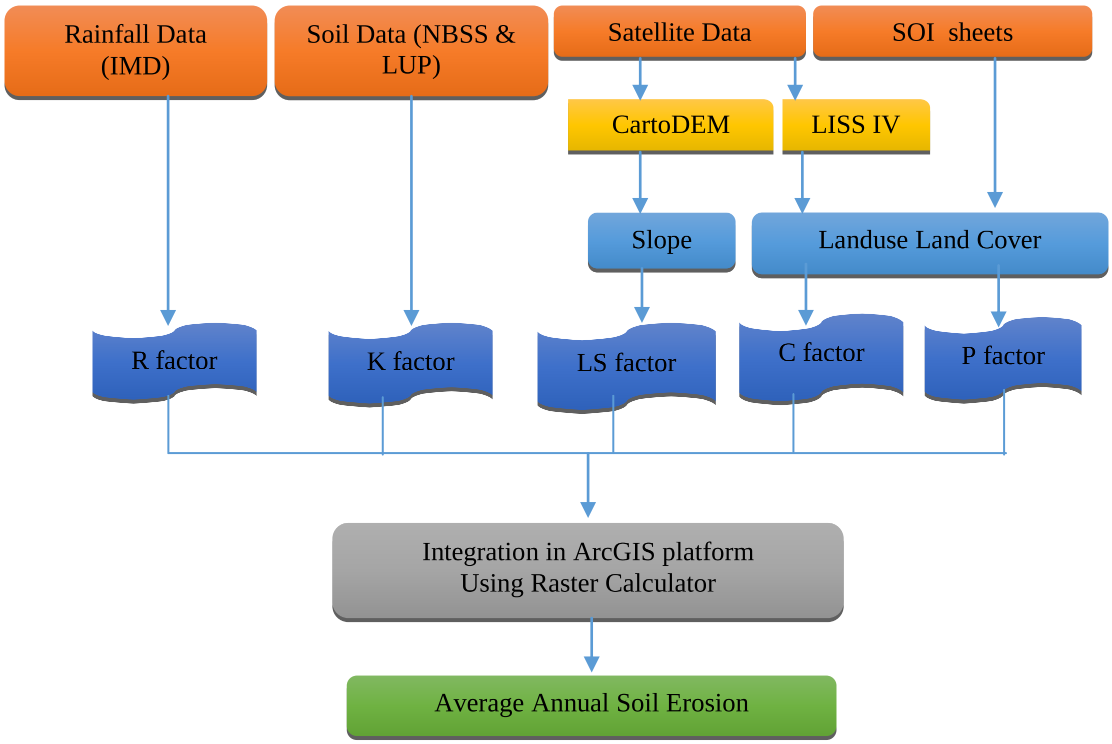


Figure 1: Study Area

MATERIALS AND METHODS

The soil loss of the watershed was calculated using RUSLE. The emergence of RUSLE has enabled the study of soil erosion, especially for conservation purposes, with efficient and satisfactory level of precision



The RUSLE model has the equation as follows;

$$A = R * K * LS * C * P$$

where A (t ha−1y−1) is the average soil loss per year of a grid cell, i.e., at a point r (geographic location of grid cell), R (mt ha-cm−1) is the rainfall intensity factor, K (t ha−1 per unit R) is the soil erodibility factor, LS(r) (dimensionless) is the topographic (length-slope) factor at a grid cell (r), C (dimensionless) is the land cover factor and P (dimensionless) is the soil conservation or prevention practices factor. The quantitative evaluation of soil erosion loss by RUSLE is based on its component factors corresponding to each of the parameters of the equation.

DATA SET

Data Type	Source
DEM	CARTOSAT 10M resolution
Land use	Aerial Photograph and LISS 4
Soil Map	National Bureau of Soil Survey and Land Use Planning, India Soil map
Rainfall data	Data Centre, Gandhinagar

Rainfall erosivity (R) factor

The rainfall erosivity indicates the soil loss potential of a given storm event. The annual erosivity was estimated by summing rainfall erosivity of individual erosive storms of the year or season (Wischmeier and Smith 1978). It requires long-term data of rainfall amounts and intensities, which is not available for most of the area and hence, the relationship between rainfall erosivity index and annual/seasonal rainfall was developed with the data available from various meteorological observatories in India (Singh *et al.*, 1981). The linear annual and seasonal (June–September) relationship to erosion index was as follows:

Y = 50+0.389X (r = 0.88) (2)

Where
Y is the average annual erosion index (mt ha-cm−1) in equation X is the average annual rainfall (mm) in equation (1) and average seasonal rainfall (mm) in equation (2).

Long term seasonal rainfall (June – Sept.) data is used for each selected local rainfall stations which is then interpolated using 30m grid cells in Arc GIS 10.1.

RESULTS AND DISCUSSION

Results

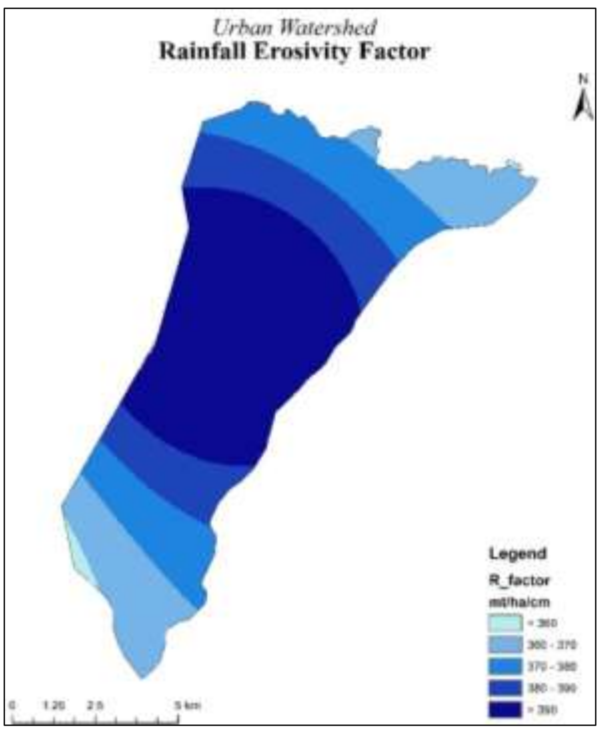


Figure 2: Rainfall Erosivity Factor

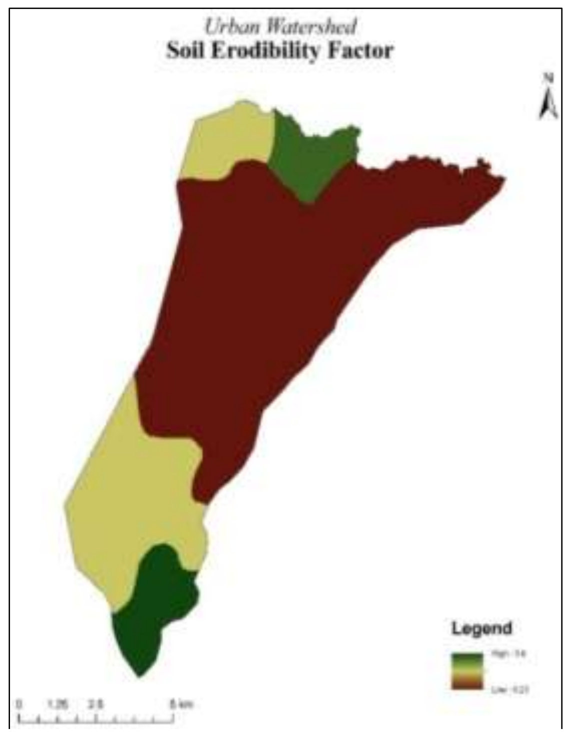


Figure 3: Soil Erosivity Factor

Soil Erodability Factor (K Factor):

Soil erodability depends on soil and, or geological characteristics, such as parent material, texture, structure, organic matter content, porosity, catena and many more.
The soil erosivity factor, K, relates to the rate at which different soils erode. However, it is different than the actual soil loss because it depends upon other factors, such as rainfall, slope, crop cover, etc. K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. Soil map of the study area was prepared from soil survey report prepared by the National Bureau of Soil and Land use Planning

Usually a soil type becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or the clay fraction. Overall, organic matter content ranked next to particle-size distribution as an indicator of erodibility. However, a soil's erodability is a function of complex interactions of a substantial number of its physical and chemical properties and often varies within a standard texture class.

Stewart *et al.*, (1975), as reported by Mills *et al.*, (1985), Mitchell and Bubenzer (1980), and Novotny and Chesters (1981), also developed a table indicating the general magnitude of the K-factor as a function of organic matter content and soil textural class.

Table 1: Soil erodibility factor K fact (Stewart *et al.*, 1975)

	Percentage organic matter (%)		
Textural Class	**< 0.5**	**2**	**4**
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silt clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silt clay	0.25	0.23	0.19
Clay		0.13-0.2	

Based on above table, <0.5 – 2 % organic matter is used for watershed area NBSS soil map the mean k factor assigned to the corresponding range of organic matter to soil texture as fallow:

Table 2: K factor for Urban Watershed

Soil Texture	K Factor (<0.5-2%om)
Fine sand	0.23
Very Fine Sand	0.60
Loamy	0.53
Clay Loam (Fine Loamy)	0.41

Slope Length and Steepnes Factor (LS)

L factor, is the function of ‘slope length’ along with the S factor (slope steepness), represents the topographical factor commonly expressed as LS factor. Slope length, defined as ‘‘the distance from the point of origin of overland flow to either the point where the slope decreases to the extent that deposition begins or the point where runoff enters well defined channels’’ (Wischmeier and Smith 1978), The slope steepness factor (S) relates to the effect of the slope gradient on erosion in comparison to the standard plot steepness of > 10 %. The effect of slope steepness is greater on soil loss compared to slope length. (Kartic Kumar *et al.*,, 2015)

The longer the slope length, the greater the amount of cumulative runoff. Also the steeper the slope of the land the higher the velocities of the runoff which contribute to erosion (Abdul Rahamana *et al.,* 2014). Digital Elevation Model (Carto-DEM) with grid cell size of 10 m in GIS. DEM was processed to generate slope gradient and LS factor maps. The average slope of each pixel (in percentage) was calculated from the greatest elevation difference between it and its eight neighbouring pixels. The empirical equation developed by Wischmeier& Smith is done by following equation

$$LS\left(\frac{L}{22.13}\right)mX\ (0.065 + 0.045 * S + 0.0065 * S^2)$$

Where:

L = slope length (meters)

S = angle of slope (degree)

m = constant dependent on the value of the slope gradient 0.5 if the slope angle is greater than 5%, 0.4 on slopes of 3% to 5%, 0.3 on slopes of 1 to 3%, and 0.2 on slopes less than 1%.

To implement LS factor in Arc GIS, the below formula of Bizwuerk *et al.*, (2008) was used.

$$LS\left(FA\,\frac{CS}{22.13}\right)mX\ (0.065 + 0.045 * S + 0.0065 * S^2)$$

Where

FA = flow-accumulation
CS = cell size
The flow-accumulation was derived from Carto- DEM.(10m)

Crop Management Factor (C)

The effect of cropping and management practices on erosion rates and the factor used most often to compare the relatives impact of management option on conservation plan the important parameter are the impacts of previous cropping and management, the protection offered the soil surface by vegetative canopy, the reduction in erosion due to surface cover and surface roughness, and in some cases the impact of low soil moisture and reduction of runoff from low intensity rainfall (USDA, handbook). The C factors are related to the land-use and are the reduction factor to soil erosion vulnerability. It is an important factor in USLE, since they represent the conditions that can be easily changed to reduce erosion.

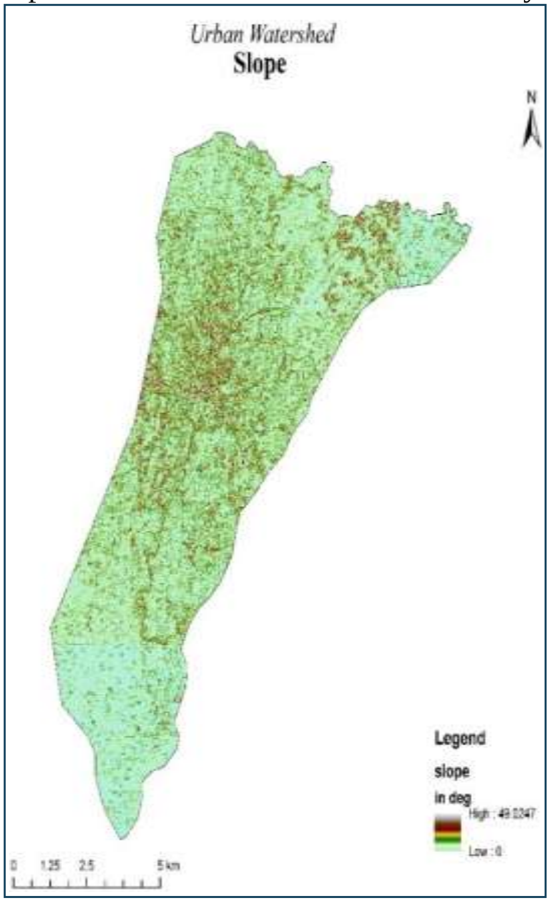


Figure 4: Slope Factor

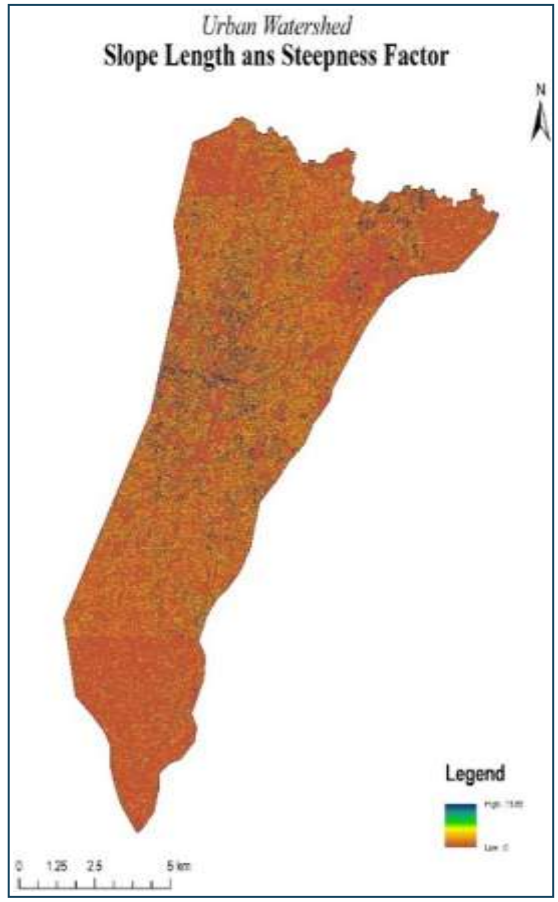


Figure 5: Slope Length and Steepness Factor

C factor is basically the vegetation cover percentage and is defined as the ratio of soil loss from specific crops to the equivalent loss from tilled, bare test-plots. The value of C depends on vegetation type, stage of growth and cover percentage. Therefore, it is very important to have good knowledge concerning land-use pattern in the basin to generate reliable C factor values

Support Practise Factor (P)

The support practice (P) factor is the ratio of soil loss using a specific support practice to the corresponding loss with upslope and downslope tillage (Renard and others 1997). In general, whenever sloping soil is to be cultivated and exposed to erosive rains, the protection offered by sod or close-growing crops in the system needs to be supported by practices that will slow the runoff water and thus reduce the amount of soil it can carry.

Information on conservation practices (P) followed in various land use/land cover classes were generated from Arial photograph and Land sat Image for the 1967 and 2017. Based on this information, C and P values (table) for each land use/cover class was assigned based on the literature (Kushwaha *et al.*, 2010) the C factor in this study varied between 0 – 0.9. The P factor range between 0.1- 1.

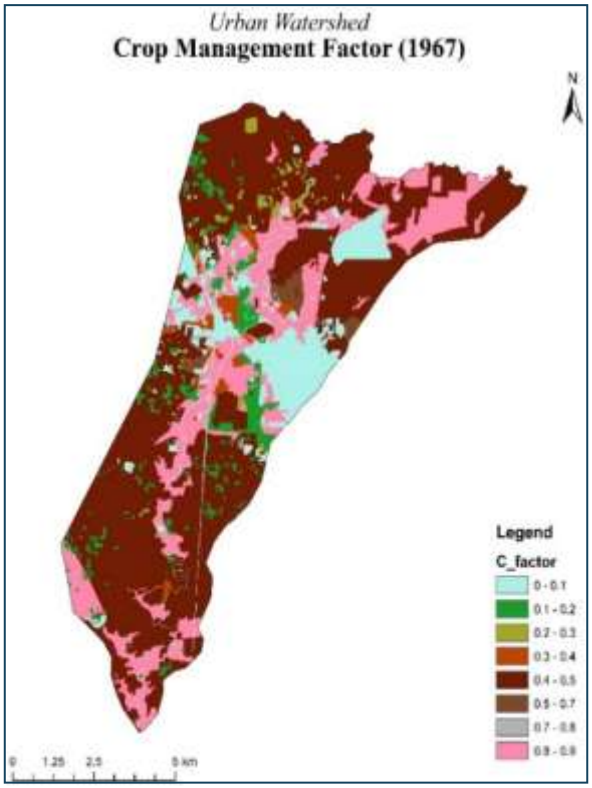


Figure 6: Crop Management Factor

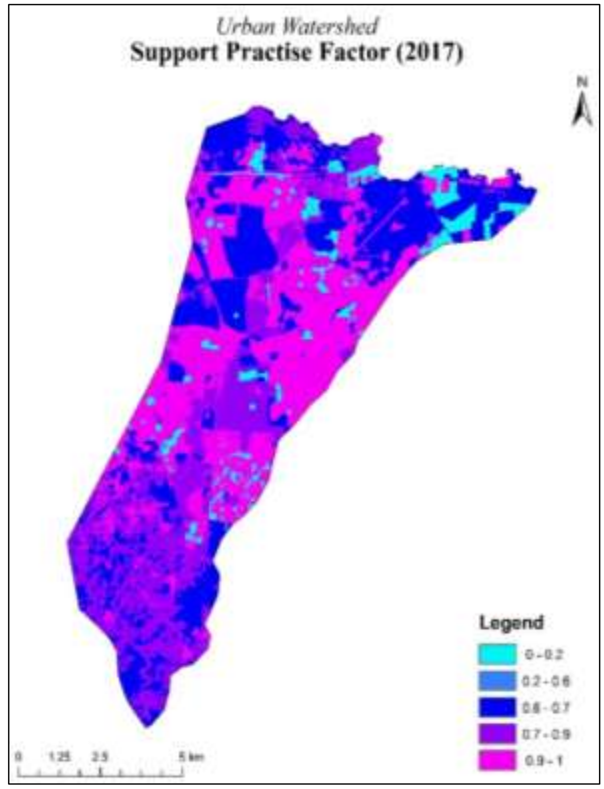


Figure 7: Crop Management Factor

Discussion

Rain fall and erosivity: The average annual rainfall data of nine surrounding rain gauge stations was used to get the rainfall distribution map of the entire watershed. The average annual rainfall in the study area varied between 880 mm to 1480 mm. The rainfall and runoff erosivity factor map was generated in Arc-GIS from average annual rainfall map. Based on seasonal rainfall, erosivity factor were calculated the range from 397- 407 Mt/ha/cm.

Soil Erodability: It is a quantitative estimation of erodability of particular soil type and the main factor affecting the capability of the soil to erode is its soil texture. However the other factors affecting K factor are soil structure, permeability and the organic matter content

Topographic factor (*LS*)

The topographic factors slope gradient and slope length significantly influence soil erosion

Crop Management Factor and Support Practise Factor

Information on conservation practices (P) followed in various land use/land cover classes were generated from Arial photograph and Land sat Image for the 1967 and 2017. Based on this information, C and P values (table) for each land use/cover class were assigned based on the literature.

The predicted average annual rate of soil loss was classified into six risk classes (figures) to assess erosion rate over the 50 years from 1967 to 2017. Nearly 75 % area in watershed is under Built-up cover with intermittent exposed land areas and 25 % area of alluvial plains which are liable to erosional forces are falling under moderate to severe category of soil erosion in the

Table 3: Cover Management (C) and Support practise Factor (P) assigned to LULC

CLASS	P_FACTOR	C_FACTOR
Agriculture Fallow	0.6	0.4
Agriculture Plantation	0.8	0.2
Airport	1	0
Dense Built-up	1	0
Sparse Built-up	1	0
Crop Land	0.9	0.1
Drainage	1	0
Laxmi Vilas Palace	1	0.5
Mix Built-up and Vegetation	0.7	0.3
Open land/Wasteland	0.2	0.8
Permanent Fallow	0.3	0.7
Playground	0.2	0.8
Pond/Lake	1	0
Railway Line	1	0
Railway Station	1	0
Ravines	0.1	0.9
Roads	0.9	0.1
Sayaji Baug	0.9	0.1
Scrub	0.7	0.3
Vegetation	0.9	0.1
Vishwamitri River	1	0
Water effluent treatment plant	1	0

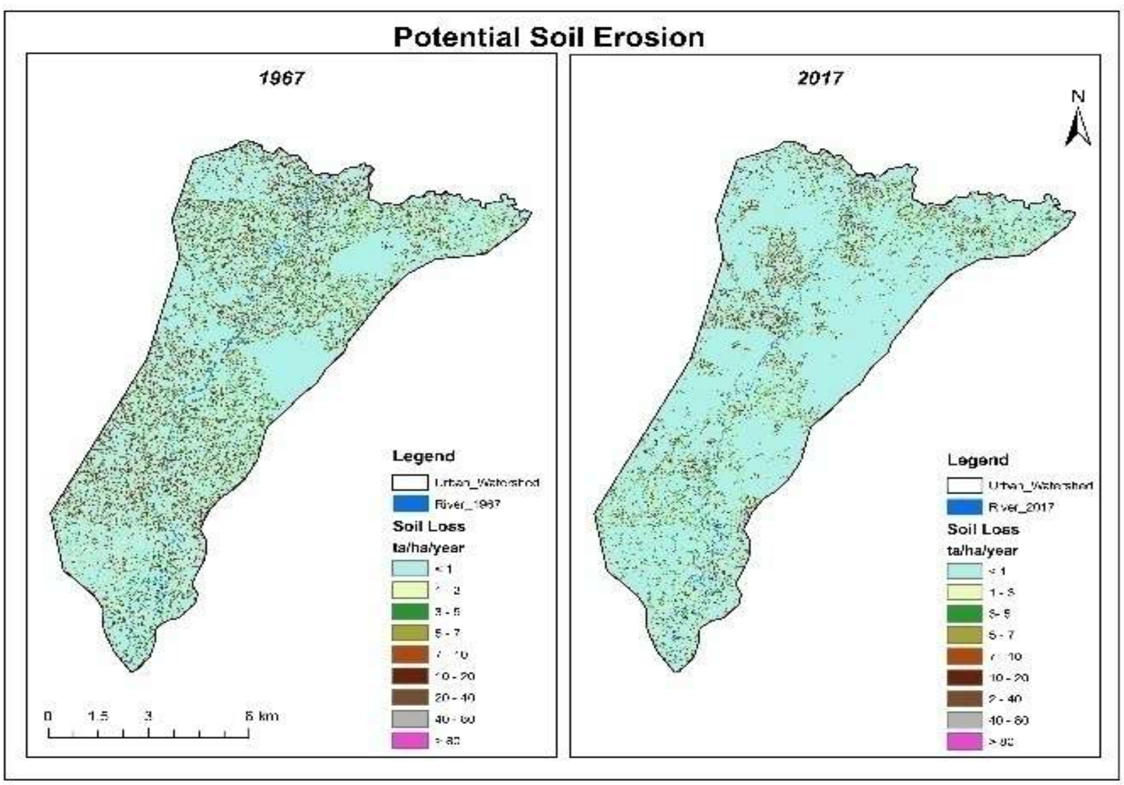


Figure 8: Potential Soil Erosion (1967) **Figure 9: Potential Soil Erosion (2017)**

watershed. The cell base analytics shows that the scattered plots are plenty owing to the open land. The quantum of soil loss is estimated for the region, few pockets having high erosion value has been reduced in the 2017. Owing to the soil stabilisation due to increase in the dense vegetation and expansion of built-up towards the river.

High-risk erosion areas in the urban watershed were found to be associated within the Vishwamitri River and its tributaries proximity. Slight to moderate erosion area. The patches of the prone area showed a decline in the recent as compared to the land use situation in1967 scenario

Table 4: Soil Erosion area under various Classes

Erosion class	**1967**		**2017**		**Difference**
	Area in ha	***%***	***Area in ha***	***%***	***Area in ha***
Slight	7926.45	87.35	8474.44	93.38	547.98
Moderate	486.45	5.36	286.93	3.16	-199.52
High	436.18	4.81	203.70	2.24	-232.49
Very High	172.42	1.90	81.34	0.90	-91.08
Severe	44.39	0.49	23.83	0.26	-20.56
Extreme	8.34	0.09	5.37	0.06	-2.97

Buffer wise Classification of Soil loss:

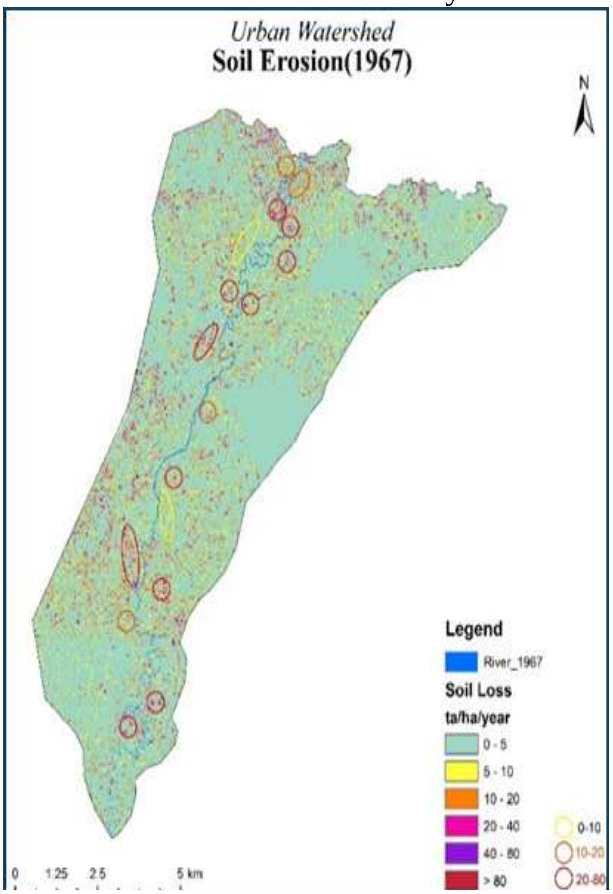
The concentration of the soil loss from the watershed, the various distance buffer from the river were generated over the soil loss model. As a result expressed, the high soil loss area was found in 10 mt buffer from the river. It indicates the river erosion and change pattern of meanders is responsible for soil loss. The vicinity of the river up to 50mt buffer zone found more or less stable soil loss. The region beyond 50 meter of the river shows the decrease in the area of the land susceptible to soil loss is attributed to the expansion of the urban area towards the riverine landform. This trends has accelerated in the last decades as new development plans like Agora city mall, Siddhartha bungalow, Ratribazar, on the north Sama area, Darshanam central in the centre of the city etc. are the few big plans developed over the time.

Table 5: Multiple-buffer wise Soil loss (Area in ha)

Proximity zone to river (in mt)	**Area (in ha)1967**	**Area (in ha)2017**
0- 10	126.54	110.52
11-20	67.95	63.18
21-30	65.07	60.75
31-40	70.65	59.85
41-50	62.37	62.19
51-100	290.16	267.39

SUMMARY AND CONCLUSION

The Revised Universal Soil Loss Equation (RUSLE) with GIS and remote sensing techniques to assess soil erosion severity in the Vishwamitri urban watershed, Vadodara city. Digital elevation model (DEM), land use/land cover (LU/LC) maps, and rainfall and soil data were used as an input to identify the most erosion-prone areas. The annual erosivity estimated by summing rainfall erosivity of individual erosive storms of the year or season. .The basis on seasonal rainfall, Erosivity factor have calculated the range from 360- 390 Mt/ha/cm. Soil erodability expressed by soil and, or geological characteristics and texture. The Fine sand, Very Fine Sand, Loamy, Fine Loamy these soil texture and the range between <0.5 – 2 % organic matter was considered to estimate soil erodability factor



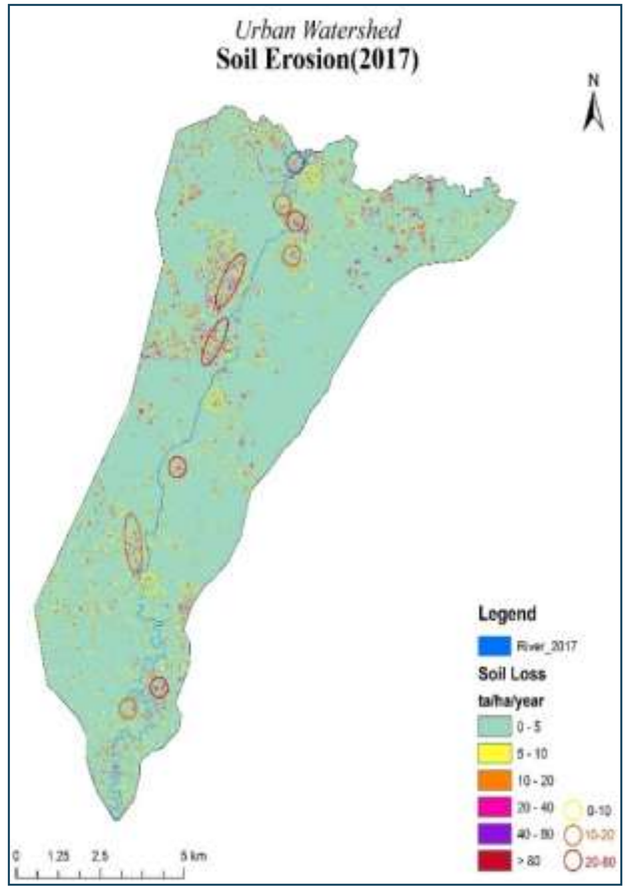


Figure 8: Potential Soil Erosion Buffer wise (1967) **Figure 9: Potential Soil Erosion Buffer wise 2017)**

Overall Soil loss is 313 ta/ha/year in 1967 whereas it reduces to 208 ta /ha/year in 2017. The relative decrease in soil erosion risk can be seen due to the higher utilization of the land by increased coverage on the soil which can be in terms of urbanization in the vicinity of the river, intense agriculture practice due to increase in irrigational sources the high maximum soil loss (313) detected in the year of 1967. The erosion prone area has shown decreases in the areal extent but the intensity of the erosion is one of the upcoming challenges as the rainfall intensity has shown a rise due to which loose soils are becoming more vulnerable to be eroded.

Conventional methods of identifying erosional risk zones even for a small watershed would require massive amount of data and involve enormous computational works. The RUSLE is a very effective technique to quantitatively assess average soil loss in a watershed. This allows us to assess quantitatively the soil erosion, identify the risk zones and draw appropriate planning measures for implementing optimal land use management practices

Further, the average annual soil loss map will be highly useful in identifying the priority areas for implementation of sustainable land use practices and soil conservation measures.

Future Scope: Also socio-economic factors, such as the level of education, the level of income, land availability, and the type of housing, were not considered in current studies on urban water erosion. The lack of such data is problematic since they could help to improve the specifics of future management strategies, and the development of suitable policies.

ACKNOWLEDGMENT

We would like to express our gratitude NRDMS (DST) for financial support (NRDMS 01/138/015(G). Authors cordially acknowledge USGS for supplying necessary satellite imagery.

REFERENCES

Abdul Rahamana S, S Aruchamyb, R Jegan kumar and S Abdul Ajeezd (2015). Estimation Of Annual Average Soil Loss, Based On RUSEL Model In Kallar Watershed, Bhavani Basin, Tamil Nadu, India ISPRS *Annals of the Photogrammetry*, Remote Sensing and Spatial Information Sciences, Volume II-2/W2, 2015 *Joint International Geoinformation Conference* 2015, 28–30 October 2015, *Kuala Lumpur, Malaysia* 207-214.

Angima SD, Stott DE, O'Neill MK, Ong CK and Weesies GA (2003). Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agriculture Ecosystem Environment* 97 295–308.

Balasubramani K, Veena Mohan, 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 (RUSEL) model through GIS Model. *Earth System and Environment* (2015) 1 10.

Julien PY (2010). *Erosion and Sedimentation*, 2nd ed. Cambridge University Press, Cambridge, 371p.

Kartic Kumar M, Annadurai R and Ravichandran P (2014). Assessment of Soil Erosion Susceptibility in KothagiriTaluk Using Revised Universal Soil Loss Equation (RUSLE) and Geo-Spatial Technology *International Journal of Scientific and Research Publications*, Volume 4, Issue 10, October ISSN 2250-3153.

Kushwaha S P S, Mukhopadhyay S, Hari Prasad V and Suresh Kumar (2010). Sustainable development planning in PathriRao sub-watershed using geospatial techniques; *Current Science*. **98**(1) 1479–1486.

Millward AA and Mersey JE (1999). Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. *CATENA* **38**(2) 109–129.

Moore ID and Wilson JP (1992). Length-slope factors for the revised universal soil loss equation: simplified method of estimation. *Journal of Soil Water Conservation* **47**(5) 423–428.

Pandey A, Mathur A, Mishra SK, Mal BC (2009). Soil erosion modeling of a Himalayan watershed using RS and GIS. *Environment Earth Science* **59**(2) 399–410.

Prasannakumar V, Vijith H, Abinod S and Geetha N (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and geo-information technology. *Geoscience Front* **3**(2) 209–215.

Renard K G, Foster G R, Weesies G A, McCool D K and Yoder D C (1997). Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE); USDA Handbook, 703, U.S. Department of Agriculture, Washington, DC.

Renard KG, Foster GR, Weesies GA, McCool DK and Yoder DC (1996). Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). Agriculture Handbook No. 703, USA Department of Agriculture, Washington.

Saravanan S, Sathiyamurthi S, Elayaraja D (2010). Soil erosion mapping of Katteri watershed using Universal Soil Loss Equation and Geographic Information System. *Journal of Indian Society of Soil Sciences* **58**(4) 418–421.

Scalenghe R, & Marsan FA (2009). The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*, **90**(1-2), 1-10.

Sharma A, Tiwari KN and Bhadoria PBS (2011). Effect of land use land cover change on soil erosion potential in an agricultural watershed. *Environment Monitoring Assessment* 173(1–4) 789–801.

Shiet ZH, SF Cai, SW Ding, TW Wang and TL Chow (2004). Soil Conservation Planning at the Small Water- shed Level Using RUSLE with GIS: A Case Study in the Three Gorge Area of China, *Catena*, **55**, 1, 33-48.

Shuster WD, Bonta J, Thurston H, Warnemuende E & Smith DR (2005). Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*, **2**(4) 263-275.

Strahler AH (2010). Introducing Physical Geography,, (5th Ed.). Chichester: John Wiley & Sons.

Wischmeier and Smith, (1978). Predicting rainfall erosion losses: A guide to conservation planning; USDA Handbook, 537.