VOL. 6, NO. 10, OCTOBER 2011 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

www.arpnjournals.com

WATERSHED DEVELOPMENT PRIORITIZATION BY APPLYING WERM MODEL AND GIS TECHNIQUES IN VEDGANGA BASIN (INDIA)

Sachin Panhalkar and C. T. Pawar
Department of Geography, Shivaji University, Kolhapur, MS, India
E-Mail: panhalkarsachin@gmail.com

ABSTRACT

Soil conservation is an expensive and cumbersome process, carried out in steps starting from the most vulnerable region. Hence, formulation of integrated water resource management program for sustainable development requires the priority classification of a basin. An area with a higher rate of erosion needs to be given higher priority for appropriate treatment measures. The main objective of the present study is to determine the vulnerability of catchments to erosion for further prioritization of Vedganga watershed. For the present investigation IRS P6 Satellite image of LISS III sensor is used to assess land use/ land cover and vegetation indices by applying NDVI technique, while a GIS system is used to evaluate the topographical conditions in conjunction with SRTM dataset. For assessing the relative vulnerability of different watersheds to soil erosion, the factors responsible for soil erosion were considered using the Watershed Erosion Response Model (WERM). This is an index-based approach, based on the surface factors mainly responsible for soil erosion. The integrated effect of all the parameters is evaluated by applying weighted overlay technique of GIS to find different areas vulnerable to soil erosion. The analysis reveals that about 27 per cent area is most susceptible to soil erosion. Based on the integrated index, a priority rating of the watersheds for soil conservation planning is recommended for watershed development and management.

Keywords: watershed, WERM, soil erosion, weighted overlay, NDVI.

INTRODUCTION

In an agrarian country like India, water and soil resources have got immense importance. However, continuous failure of monsoon, increasing demand and over exploitation of these resources leads to water and soil degradation. This problem could be sorted out to certain extent by constructing water and soil conservation structures. The development of land and water resources on a sustainable basis without deterioration and with a constant increase in productivity is the mainstay of mankind. Soil erosion is a complex dynamic process of land denudation by which productive surface soils are detached, transported and accumulated at a distant place. The detachment of soil particles occurs either by hydrological (fluvial) processes of sheet, rill or gully erosion, or through the action of wind. Soil erosion results in loss of precious soil resources for cultivation and causes siltation of reservoirs and natural streams (Kothyari, 1996; Biswas *et al*., 1999; Jain and Dolezal, 2000). In India, about 53% of the total land area is prone to erosion (Narayan and Rambabu, 1983). The problems of land degradation are prevalent in many forms throughout the country. In fact, land degradation has the most serious impact on the poorest countries of the world (Pawar, *et al*., 2009). In absence of comprehensive and periodic scientific surveys, estimates have been made on the basis of localized surveys and studies. According to National Bureau of Soil Survey and Land Use Planning (NBSS and LUP, 2005) about 146.82 million hectare area is reported to be suffering from various kinds of land degradation. It includes water erosion 93.68 million ha, wind erosion 9.48 million ha, water logging/flooding 14.30 million ha, salinity/alkalinity 5.94 million ha, soil acidity 16.04 million ha and complex problem 7.38 million ha.

Numerous treatment technologies in the form of engineering measures and agronomic practices are available. But all these measures are costly and cumbersome. Hence, identification of most vulnerable areas to apply suitable technologies as per the site conditions and their application in correct way is most important to achieve the desired results. These technologies when adopted within the boundary of watershed, facilitates favorable interaction among various watershed factors such as physiography, land slope, soil characteristics, land use, hydrological behavior etc. Drainage basins, catchments and sub-catchments are the fundamental units for the management of land and water resources (Moore *et al*., 1994). Catchments and watersheds have been identified as planning units for administrative purpose to conserve these precious resources (FAO, 1985; 1987; Honore, 1999; Khan, 1999).

One criterion, generally used to determine the vulnerability of catchments to erosion, is the sediment yield of a basin. In India, sediment yield data are generally not collected for smaller sub-catchments and it becomes difficult to identify the most vulnerable areas for erosion that can be treated on a priority basis. During the early and mid 1960s, aerial photographs were used to identify severely eroded areas in different catchments. Subsequently, soil conservation works were initiated in close vicinity of the reservoirs and sediment carrier streams (Bhan, 1997). The All India Soil and Land Use Survey (AISLUS), established in 1988, has been assigned the task of priority delineation. Initially, the AISLUS conducted soil surveys in the upper parts of catchments using Survey of India (SOI) topographic maps and village cadastral maps. Erosion control treatments were started in the upper parts of the catchments with a view that

VOL. 6, NO. 10, OCTOBER 2011 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

www.arpnjournals.com

treatments taken up in the downstream catchments at later stages would not be adversely affected by unprotected upper reaches.

A geographic information system (GIS) is a computer based system designed to store, process and analyze geo-referenced spatial data and their attributes. Using a GIS, the topographic and morphometric analysis can be carried out efficiently and different layers of information can be integrated, geographic information systems (using traditional and remotely sensed data) have already proved to play a very important role in analyzing soil erosion and sediment yield, as evident from recent studies in the Indian Peninsula and southeast Asia (Jain and Kothyari, 2000; Baban and Yusof, 2000).

The present investigation aims to put forward a scientific approach to handle the integrated watershed management strategy through a case study implemented to demonstrate the watershed prioritization exercise.

Study region

The region selected for the present study is Vedganga basin of Kolhapur district (Figure-1). This basin drains entire part of Bhudargad, southern part of Kagal and western part of Ajara tahsil of Kolhapur district. It is located between 16° 3' north to 16°30’ north latitudes and 73°48’east to 74°18’ east longitudes occupying an area of 995 sq km.

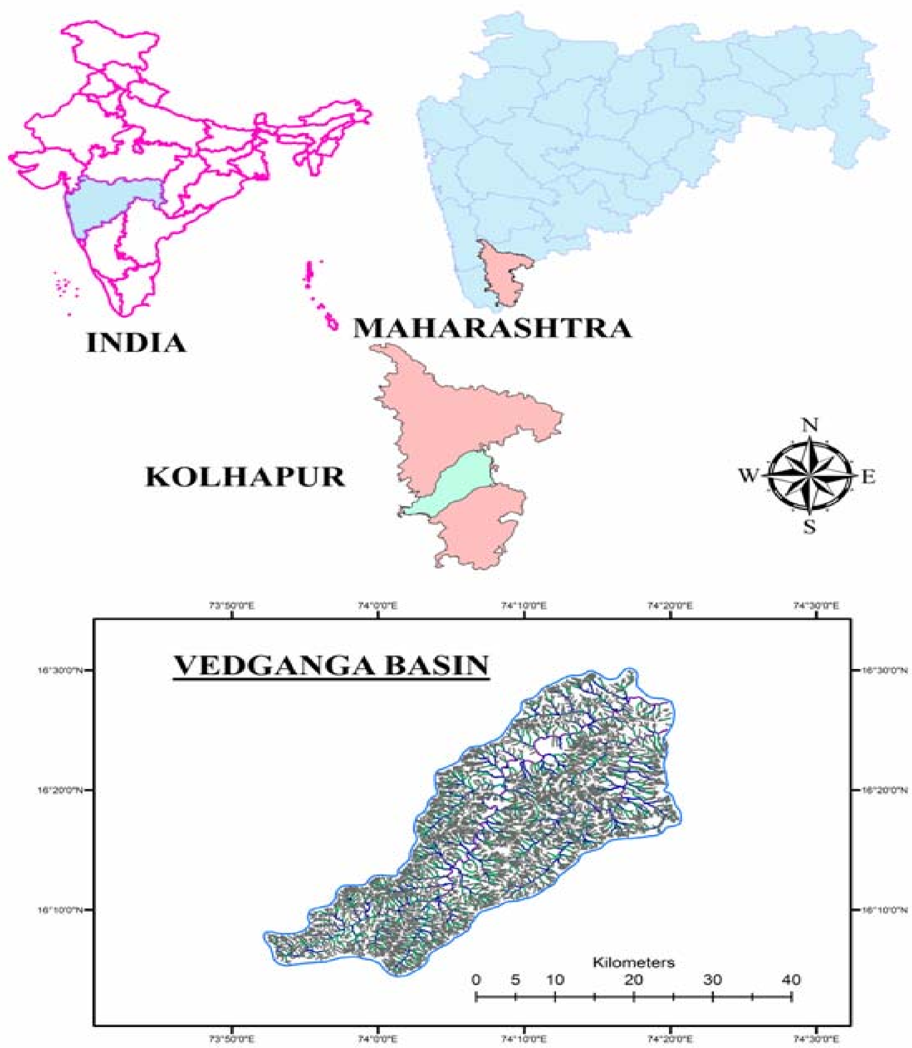

Figure-1.

The region has diversified physiography, whose western border is demarcated by Western Ghats. Chikotra River is a major tributary of Vedganga River. The soil vary from laterite patches in the west to deep medium

VOL. 6, NO. 10, OCTOBER 2011 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

black alluvial of the river tracts in the central part and poor grey soil in the east. The monsoon climate dominates the region. The region receives rainfall mainly from south west monsoon, ranging between 6000 mm in the west to 1500 mm in the east.

METHODOLOGY

Satellite remote sensing provides reliable and accurate information on natural resources, which is pre-requisite for planned and balanced development at watershed level (Ravindran *et al*., 1992). Integration of Remote sensing and GIS techniques provides reliable, accurate and update database for watershed management.

In assessing the relative vulnerability of different watersheds to soil erosion, the major factors responsible for soil erosion were considered using the Watershed Erosion Response Model (WERM). It is one of the most commonly used models for qualitative prioritization of watershed. The major factors responsible for soil erosion includes rainfall, soil type, vegetation, topographic and morphological characteristics of the basin. (Kothyari and Jain, 1997).

For land use and land cover mapping, four images of IRS P6 satellites of LISS III sensor are mosaiced by using Erdas Imagine 9.3 software. Remotely sensed data usually contains both systematic and unsystematic errors, which are being removed through rectification. Image was registered geometrically using topographic maps. The common uniformly distributed Ground Control Points (GCPs) were marked with root mean square error less than 0.002-0.008 and the images were resampled by using cubic convolution method. As the image covers adjacent areas, a subset image has been taken out for further analysis. Six classes are identified by applying supervised classification technique. To assess the biomass conditions NDVI approach is used by applying following formula.

$$NDVI=NIR-VIS/NIR+VIS \quad (1)$$

Where

NIR = near infrared
VIS = visible red

A DEM of Vedganga basin was generated by using SRTM data set and used for the estimation of slope factor. Knowledge based weight assignment was carried out for each thematic layer and they were integrated and analyzed by using the weighted overlay technique (ESRI, 1988). Weighted overlay only accepts integer rasters as input so continuous (floating point) rasters have been reclassified as integer before they can be used.

Data set

i IRS P6 image of LISS III sensor (14 February 2008)
ii SRTM data of C-band and X-band (Year 2000)

Softwares used

i Erdas Imagine 9.3
ii ArcGIS 9.0

WATERSHED PRIORITIZATION BY APPLYING WATERSHED EROSION RESPONSE MODEL (WERM)

In assessing the relative vulnerability of different watersheds to soil erosion, the factors responsible for soil erosion were considered using the Watershed Erosion Response Model (WERM). The WERM is a process-based on prediction technology built on the fundamentals of hydrology, plant science, hydraulics, and erosion mechanics (Laflen, 1991; Flanagan *et al*., 1995)

Parameters for WERM model

Parameters used for WERM are slope, vegetation density, land use/land cover conditions and rainfall. The suitable weights were assigned to each thematic layer after considering their characteristics and influence upon soil erosion.

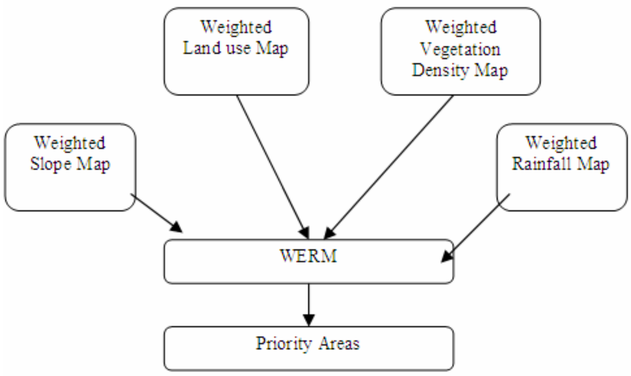

Figure-2. Methodology to derive priority areas.

Rainfall

The amount and intensity of rainfall affect the sediment yield from a basin. The high rainfall areas are highly vulnerable to soil erosion as compare to low rainfall areas. In the study region, rainfall decreases from west to east. By assessing the rainfall conditions, three rainfall classes have been identified and appropriate weightage is assigned.

Table-1. Weight assigned for rainfall classes.

Rainfall class	**Rainfall** (cm)	**Assigned weight**
High	> 500	3
Medium	250 – 500	2
Low	< 250	1

Vegetation

Vegetation reduces the raindrop's capability to detach soil particles and significantly affects the erosion process. The effectiveness of vegetation depends on the height and continuity of canopy, density of ground cover and the root density. Generally, forests are most effective in reducing erosion because of their large canopies (Jain and Dolezal, 2000). A number of methods have been used to identify different phenological stages of vegetation, including the application of the Normalized Difference Vegetation Index (NDVI), which is used as an indicator of vegetation condition (Ramamoorthi *et al*., 1991). The NDVI index is calculated and classified into the five classes (Table-2) with suitable weights.

Table-2. Weight assigned for vegetation.

Vegetation class	Assigned weight
Very dense vegetation	1
Dense vegetation	2
Medium vegetation	3
Poor vegetation	4
No vegetation	5

Slope

The topographic feature that mostly influences the erosion process is the degree of slope, a higher slope resulting in higher erosion. With the advent of G1S techniques, it is now possible to prepare the digital elevation model (DEM) of an area. Using the SRTM data, the slope on all the grids in the area can be calculated and this information can be utilized for assessing the relative vulnerability to soil erosion.

Table-3. Weight assigned for slope classes.

Slope class	Percentage slope	Assigned weight
Nearly level	0-1 %	1
Very gentle	1-3 %	2
Gentle	3-5 %	3
Moderate	5-10 %	4
Strong	10-15 %	5
Steep	15-35 %	5
Very steep	> 35 %	5

Land use/ land cover

Land use/land cover plays a very crucial role in soil vulnerability analysis. The land under vegetation cover is less vulnerable as compare to fallow and barren land. The thick forest and grassland prevents soil erosion. Land should be used properly by considering its capability and limitations otherwise it would cause severe soil erosion. Supervised classification technique is used to classify IRS P6 data set and six classes are identified and appropriate weight has been given accordingly (Table-4).

Table-4. Weight assigned for land use/ land cover classes.

Land use/ land cover	Assigned weight
Water body	Restricted
Forest	1
Grassland	2
Agricultural land	3
Fallow land	4
Barren land	5

To account for the integrated effect of all the four parameters considered in this study, the individual weights of all the parameters were added together. This sum was further sub-divided into four different categories for the purpose of assessing the relative vulnerability, and codes were assigned to each category. Areas with higher final weights were considered to be most vulnerable to soil erosion. Thus, an area with a code of above 14 is highly vulnerable to soil erosion and must be given the highest priority for the purpose of sustainable development by adopting suitable water and soil conservation measures. The range of accumulated weights and the corresponding priority code is given in Table-5.

Table-5. Range of the accumulated weights and corresponding priority areas.

Range of accumulated weights	Vulnerability	Code
> 14	Very High	1
11- 14	High	2
7-11	Medium	3
< 7	Low	4

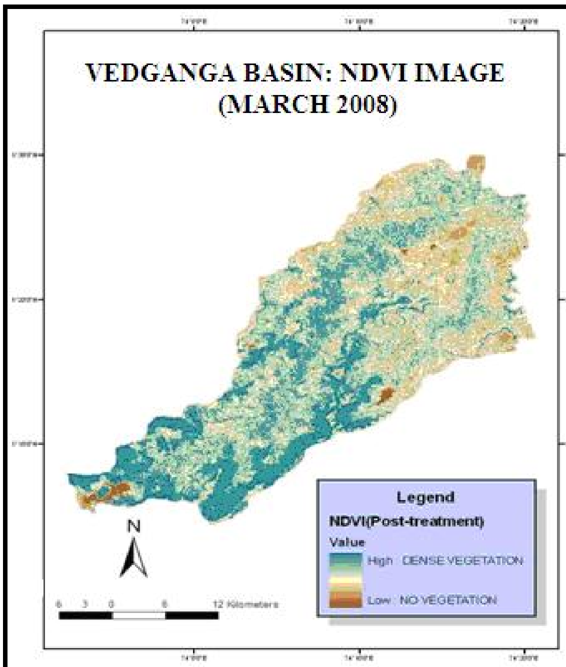

Figure-3

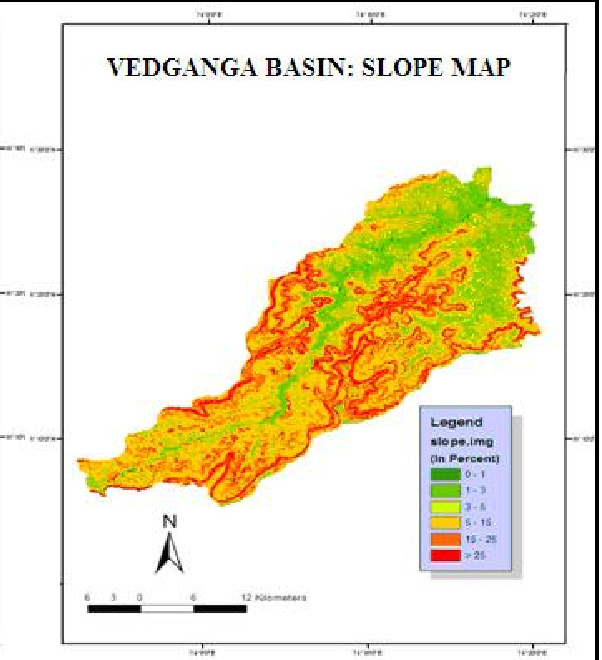

Figure-4

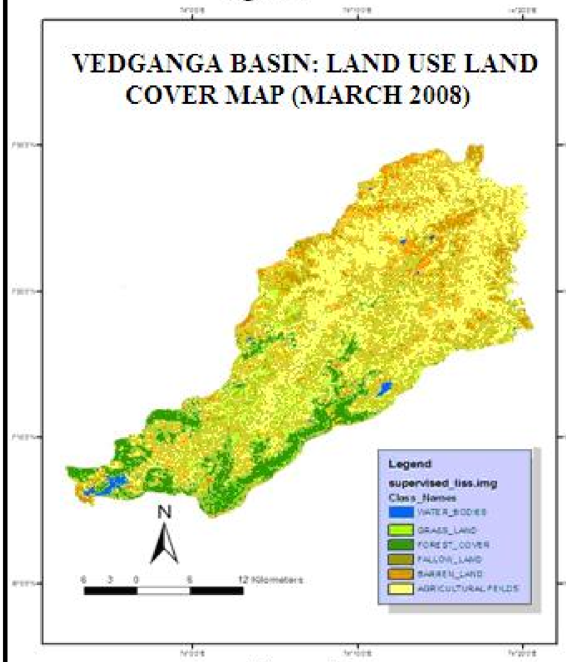

Figure-5

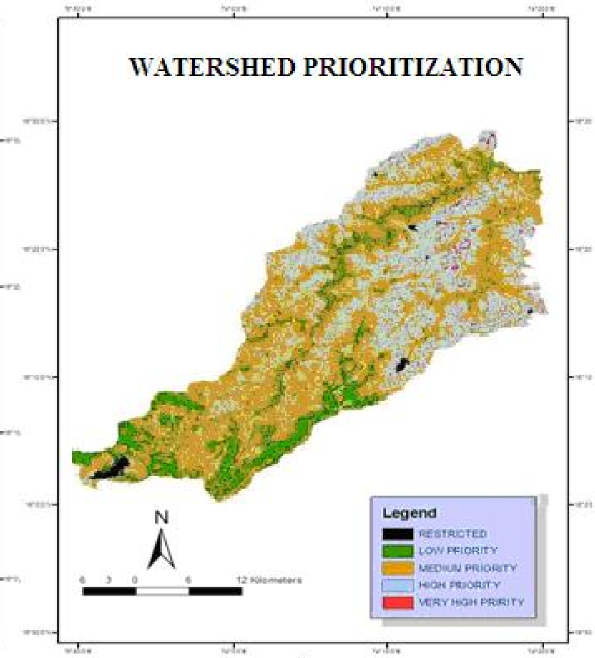

Figure-6

Prioritization of watershed

Weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. By applying this technique four priority areas (Figure-6) have been suggested by considering slope, rainfall, vegetation and land use/ land cover conditions. For the analysis purpose, water body is considered as a restricted category.

Table-6. Area statistics of prioritization.

S. No.	Prioritization	Area (sq. km)	In percent
1.	Very High	37.81	3.80
2.	High	228.85	23.00
3.	Moderate	585.15	58.81
4.	Low	124.37	12.50
5.	Restricted	18.80	1.89
Total		995.00	100

Very high priority

The analysis reveals that a very high priority should be given to central hilly areas of Kagal tehsil. This is a water divide area between Vedganga and Chikotra River. This category accounts for 37.81 sq. km (3.8%). The major factors that contribute to soil erosion potential in this area were assessed. In this area mainly steep slope, lack of vegetation and barren land are the dominant factors for soil erosion. This area must be brought under vegetation through proper afforestation program.

High priority

High priority areas are situated adjacent to very high priority areas. The total area which comes under this class is about 228.85 sq. km (23 %). Barren land, hilly areas and high rainfall are the responsible factors for soil erosion in this region. Water divide hilly areas between Chikotra and Vedganga River and northern and southern boundary of this watershed should be given high priority.

Medium/moderate priority

This region is generally dominated by gentle to moderate slope. This zone is basically running between high priority and low priority areas which accounts for 585 sq. km (58.81 %). Agricultural land use generally dominates this region. This region is less vulnerable as compare to high priority areas.

Low priority

The cultivated fields along the Vedganga and Chikotra River should be given low priority as this region belongs to very gentle slope. The thick forest areas of Vedganga basin are also not vulnerable to soil erosion. This zone is basically confined to western part of the Bhudargad tahsil. Anur, Benage, Galgale metage, Kur, Ganagpur, Nilpan, Mhasve, Shengao, Kadgao, Anturli, Tambli, Mani village areas should be given less priority

CONCLUSIONS

The analysis reveals that Vedganga basin with its significant topographical and land-use variation offers a suitable site for watershed prioritization study. Areas within watershed with different soil erosion potentials have been assessed with a view for adopting soil conservation measures.

The very high priority areas have higher erosivity values due to their location in the hilly terrain with undulating topography of Kagal tehsil. This category accounts for 37.81 sq. km (3.8%). The areas under high priority category mostly lie in the western and eastern fringe of Vedganga River. Because of the slope condition, and the rocky/stony surfaces, the soil erosivity values range from moderate to high. About 228 sq. km (23 %) area is categorized as high priority zone. Moderate priority region is generally dominated by gentle to moderate slope. This zone is basically running between high priority and low priority areas which accounts for 585 sq. km (58.81 %). The low priority areas are mostly cropped lands with gentle slope and thick forest areas of Western Ghats. These areas have good vegetation cover, and therefore do not need immediate attention. The cultivated fields along the Vedganga River and the thick forest areas of Bhudargadh tahsil should be given low priority.

This application is useful to help the watershed managers in objectively prioritizing the watersheds with respect to the stipulated norms. The application can also be used for monitoring and evaluation of the watershed programmes which is an important component, but is invariably missing.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the funding support of the UGC (New Delhi), which made this work possible.

REFERENCES

All India Soil and Land Use Survey. 1988. Watershed Atlas of India, Dept. of Agriculture and Co-operation. Government of India (1: 1 M scale).

Baban S. M. and Yusof K. W. 2001. Modeling soil erosion in tropical environments using remote sensing and geographical information systems. Hydro. Sci. J. 46(2): 191-198.

Bhan S. 1997. Strategy for watershed development and management. Soil Wat. Conserv. S. 41(1-2): 20-24.

Biswas S., Sudhakar S. and Desai V. R. 1999. Prioritizaton of sub watersheds based on morphometric analysis of drainage basin - A remote sensing and GIS approach. J. Indian Soc. Remote Sensing. 27: 155-156.

Pawar C. T., Pawar. D.H. and Panhalkar S. S. 2009. Land Degradation, land Conservation and Improvement in Panchganga Basin (Maharashtra): A Geo- Ecological Analysis, Unpublished UGC Major Research Project Report. S.U. Kop.

Environmental System Research Institute. 1988. User Guide ARC INFO. The Geographical Information System Software (Redlands. CA. USA: ESRI Inc.).

Flanagan D.C. 1995. Overview of the WEPP erosion prediction model. In USDA Water Erosion Prediction Project: Hill slope Profile and Watershed Model Documentation., D.C. Flanagan and M.A. Nearing (Ed.). Ch. 1, NSERL Rep. 10, USDAARS NSERL, West Lafayette, IN.

Food and Agricultural Organization. 1985. Watershed Development with Special Reference to Soil and Water Conservation. Soil Bulletin 44, Rome, Italy: FAO.

Food and Agricultural Organization. 1987. Soil and Water Conservation in Semi-arid Areas. Soil Bulletin 57, Rome, Italy: FAO.

Honore G. 1999. Our Land, Ourselves-a Guide to Watershed Management in India. New Delhi: Government of India. p. 238.

Jain M. K. and Kothvari. U. C. 2000. Estimation of soil erosion and sediment vield usint» GIS. Hydrological Sci. J. 45(5): 771-786.

Jain S. K. and Dolezal F. 2000. Modeling soil erosion using EPIC supported by GIS, Bohemia, Czech Republic.

Khan M.A. 1999. Water balance and hydrochemistry of precipitation components in forested ecosystem in the arid zone of Rajasthan, India. Hydrological Science Journal. 44: 149-161.

Kothvari U. C. 1996. Erosion and sedimentation problems in India. In: Erosion and Sediment Yield: Global and Regional Perspectives. D. E. Wailing and B. W. Webb (Ed.). Proc. Exeter Symp. July. IAIIS Publ. no. 236. 531-540.

Kothvari U. C. and Jain S. K. 1997. Sediment yield estimation using GIS. Hydro. Sci. J. 46(2): 833-843.

Laflen J.M. 1991. WERM A next generation of erosion prediction technology. J. Soil Water Cons. 46: 34-38.

Naravan Dhurva and Rambabu. 1983. Estimation of soil erosion in India. J. Irrig Drain. ASCE. 109(4): 419-435.

Ramamoorthi A. S., Thiruvengadaehari S. and Kulkarni A. V. 1991. IRS-1A applications in hydrology and water resources. J. Current Sci. 61(3-4): 180-189.

Ravindran K.R., Promod Kumar Tiwari, A.K., Kudrat M, Ravi Shankar and Bhave S.K. 1992. Integrated approach for resources planning using remote sensing and GIS- A case study of Song Watershed. Proceeding of National Symposium on Remote Sensing for Sustainable Development. pp. 11-15.