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A MULTI- DISCIPLINARY PERSPECTIVE IN EVALUATION OF SPATIALLY DISTRIBUTED ACCUMULATED SEDIMENT YIELD USING GEOGRAPHICAL INFORMATION SYSTEM(GIS) BASED HYDROLOGICAL INTERFACES OF 'OpenNSPECT' AND 'N-SPECT' MODELS WITH DIFFERENT GIS SOFTWARE PACKAGES

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Keywords: Soil Erosion, RUSLE, Sediment Yield, OpenNSPECT, GIS.

ABSTRACT

One of the major concern in landscape management and conservation planning is the reduction of the risk of soil erosion, which requires a perfect assessment of the potential transport capabilities of runoff generated by erosive storms. In this context, the use of new technologies and science developments such as Remote Sensing (RS) and Geographical Information System (GIS), database developments have made possible to approach the study of soil erosion and corresponding sediment yield. The revised Universal Soil Loss Equation (RUSLE) is an easily and widely used computer programme that estimates rates of soil erosion caused by rainfall and associated overland flow. This paper enabled to estimate accumulated sediment load by water in the area of Karha basin situated in Pune Dist. of Maharashtra state. The erosion process in the area highly depends on the nature of parent materials, soils topography, climate, cover management and support practice. These erosive factors estimated in the form of Rainfall Erosivity factor (R), Soil erodability factors, spatial distribution of slope factors (LS) in terms of their erosion status, computation of cover management factor (C), and supporting practice factor (P). This paper investigate a comparison study of accumulated sediment yield for karha basin using 'Non-Point Source Pollution and Erosion Comparison Tool' named as OpenNSPECT and N-SPECT with two different GIS softwares of Map Window GIS and Arc Map. The input maps prepared from spatial data in the form of Digital Elevation Model (DEM), Land Use-Land Cover map from satellite image, Hydrological Soil Group Map from soil data and R-factor map from rainfall data for evaluation of accumulated sediment yield. The results indicate that the sediment yield obtained from N-SPECT model is higher to OpenNSPECT model. The quantitative value of sediment load obtained 91609 (kg), and 86253 (kg) from N-SPECT and OpenNSPECT models respectively.
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INTRODUCTION

Soil erosion is one form of soil degradation along with soil compaction, low organic matter, loss of soil structure, poor internal drainage, Stalinization and soil acidity problem [1]. Infact soil erosion is a naturally occurring process on all land and it becomes a problem when human activity causes it to occur much faster than under natural conditions [2]. Determining the intensity, amount and distribution of erosion has a big important for environmental management specialists to make an informed decision on the suitable soil and water conservation measures that should be installed in a given area. The Universal Soil Loss Equation (USLE), or Revised Universal Soil Loss Equation (RUSLE) is often used to predict rainfall erosion in landscape/watersheds using GIS. Soil erosion is a wide spread phenomenon and is usually irreversible. Erosion, the detachment of particles of soil and surface sediments and rocks, occurs by hydrological (fluvial) processes of sheet erosion, rill and gully erosion and through mass wasting and the action of wind [3]. Erosion both fluvial and aeloan (wind) is generally greatest in arid and semi arid regions, where soil is poorly developed and vegetation provides relatively little protection. Where land use causes soil disturbance erosion may increase greatly above natural rates. In many areas, however, the storage of eroded sediment on hill slopes of lower inclination, in bottom lands, and in lakes and reservoirs leads to rates of stream sediment transport much lower than the rate of denudation [4]. The application and integration of multi-sources of information represent a major goal to achieve more satisfactory results in the assessment of many environmental issues. The use of modern technologies and scientific developments such as Remote Sensing and Geographical Information Systems, field data collection, database development have made it possible to approach the study of soil erosion from multi-disciplinary perspective [5]. The capabilities of these technologies even increase when they are integrated with

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empirical erosion prediction models [6]. While soil erosion models only calculate the amount of soil erosion based on the relationships between various erosion factors [7], RS and GIS integrated erosion prediction models do not only estimate soil loss but also provide the spatial distributions of the erosion [8]. The RUSLE was developed to estimate the annual soil loss per unit area based on erosion factors including soil erodability, topography, rainfall, and vegetation cover [9]. In the WEPP model, sediment yield and erosion rates were estimated for multiple time periods based on specific erosion factors [10]. The approach that will be allowed to assess those indicates is based on the use of Remote Sensing and Geographical Information System and ancillary data that which will support to estimate accumulated sediment yield using with hydrological model of 'Non-Point Source Pollution and Erosion Comparison Tool'. In this paper the author has made an attempt to depict spatial distribution of sediment yield with hydrological interface model of OpenNSPECT version 1.1, which is plug-in to Map Window GIS and another model of N-SPECT is interface to ArcMap 9.3 software packages.

STUDY AREA

Karha river basin in Maharashtra State is a part of Neera basin which is a sub-basin of Bhima river basin. Karha is the principal river of the Karha basin. The river originates in the hills of Sahyadri, upstream of village Garade and flows through Purandar hills, plateau region of Kade Pathar, plains of Baramati region of Pune District and then joins river Neera. The basin is landlocked between Upper Bhima basin and the remaining Neera basin. The river is seasonal in nature, flows in monsoon months only. The river is intermittent since i.e. stream flow falls to zero most of the time, especially during non-monsoon period. It is one of the driest watersheds of the Bhima basin classified under drought-prone zone. The location map of the Karha basin is shown in Fig. 1. With an area of 1317 km^2. The commencement of the hydrologic year for the Karha basin in the month of June, when groundwater is at its lowest water level.

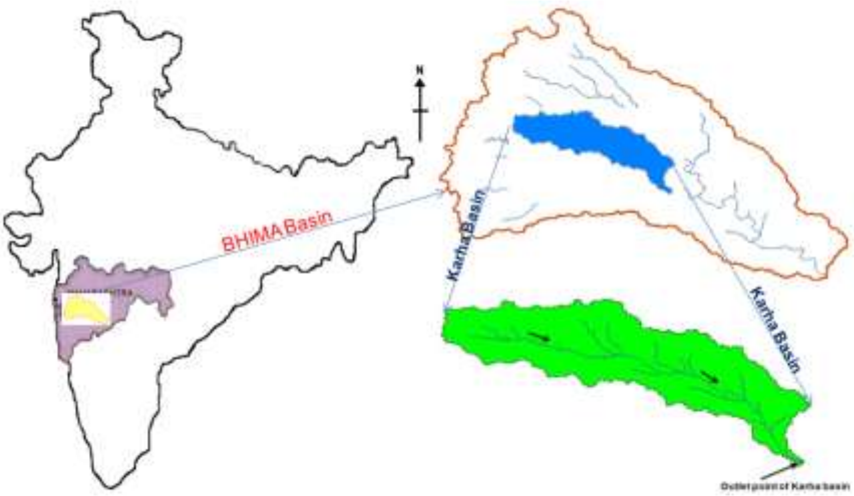

Fig 1 :Location Map of Karha Basin

MATERIALS

The input data sets required for N-PSECT and OpenNSPECT models are identical for evaluation accumulated sediment yield. The fallowing spatial and non spatial data sets are as follows:

- Digital Elevation Model (DEM)
- Land use Land cover data
- Soil data
- Rainfall Data

The acquisition and preparation of each data set into digital thematic maps are described in the fallowing paragraphs under sub-headings separately.

Digital Elevation Model (DEM):

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The topographical information available in the form of Digital Elevation Model (DEM). The DEM is downloaded from Cartosat-1, having a resolution of 2.5 m in panchromatic band. which is freely available from National Remote Sensing Centre (NRSC) website [11]. For the application of RUSLE model, Length-Slope factor 'LS' is one of the important factor for this model. This important factor can be derived using elevation data in the form of DEM (Fig.2). Length-slope is calculated by deriving the down slope angle for each cell in degrees. Next, a grid showing relative change in down slope angle is created. Areas where down slope angle exceeds 5 percent and the relative change in down slope angle exceeds 50 percent are flagged as breaks in the cumulative slope. Areas where down slope angle is less than or equal to 5 percent and the relative change in down slope angle exceeds 70 percent are also flagged as breaks in the cumulative slope.

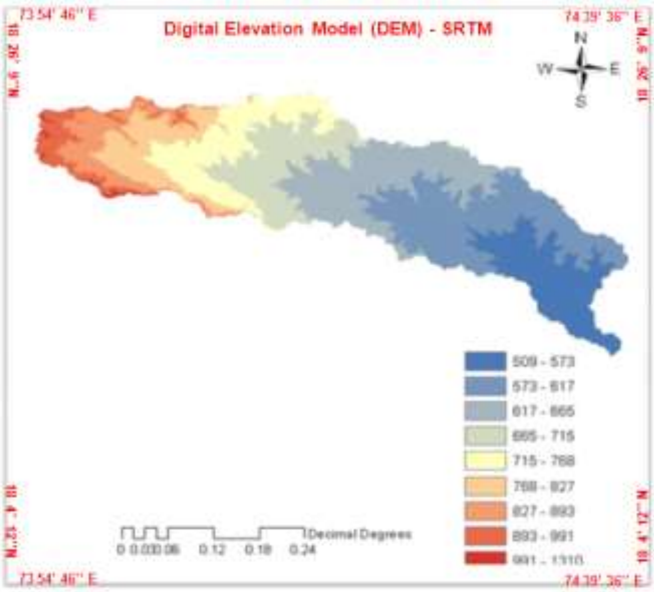

Fig 2 :Digital Elevation Model of Karha Basin

Land Use Land Cover:
A resourcesat-1 satellite image downloaded from BHUVAN website of NRSC [12] for the year 2011 Nov. and Dec. 2011 to prepare a land use-land cover map. The downloaded satellite images are mosaic into a single tile and extracted into the desired area of interest of karha watershed in ArcGIS environment. The satellite image is derived into 9 land use-land cover classes as shown in Fig.3. The NRSC-BHUVAN web site supply the digital land cover classes of the entire India. This thematic layer establish a preliminary idea to classify the Karha basin into 9 different land use /land cover classifications. From 1317 kmn^2 area of the karha basin, Agricultural group of land classes covered a higher percentage of about 36, forest classes covered 32% and lowest percentage of 0.38% of area covered water bodies. This land use-land classification map is used to predict crop cover factor 'C' and support practice factor 'P'. These two parameters are used for estimation of erosion from RUSLE model.

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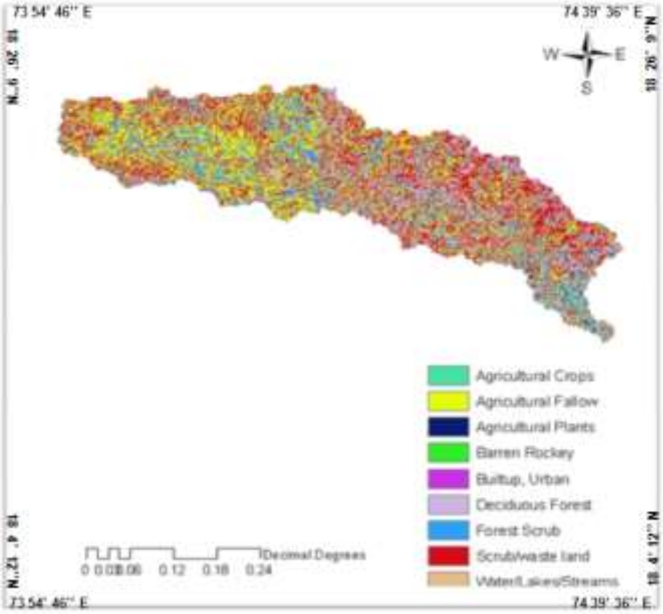

Fig 3 : Land use-Land Cover Map of Karha Basin

Soil data:

The soils data collected from the U.S. Department of Agriculture's (USDA) Food and Agricultural Organization (FAO) database [13], specifications are necessary before the data can be loaded into these models. The *layer* table contains the k-factor values, the *comp* table contains the hydrologic soil group attributes to the soil shapefile. The karha basin has 854 km^2 area covered under Hydrologic Soil Group (HSG) of C, HSG of B covered an area of 268 km^2, and 175 km^2, 9.14 km^2 area under A and D. The study area of Karha basin covered a highest percentage of about 65% contains HSG of C and least percentage of 0.7% contains HSG of D type of soils as shown in Fig: 4.

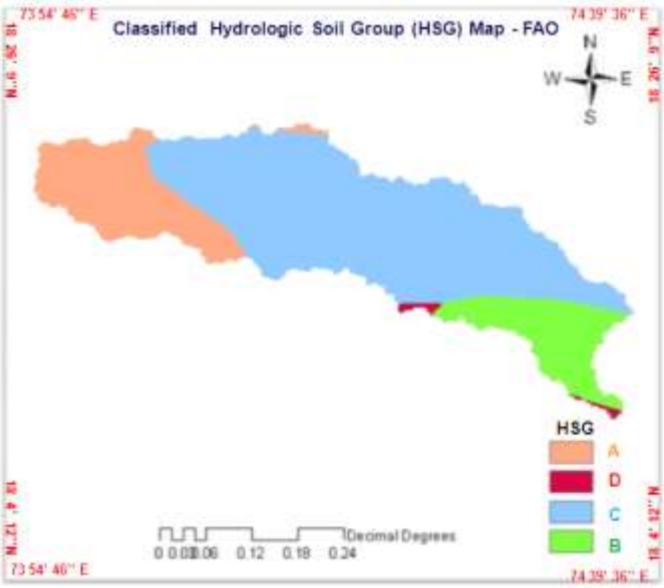

Fig 4 :Hydrologic Soil Group (HSG) Map of Karha Basin

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Rainfall Data:

The Indian Meteorological Department (IMD) is the primary repository for precipitation data collected by stations in the present watershed. There are 7 rain gage stations are available in the Karha basin namely Tapewadi, Saswadi, Jejuri, Tekodi, Malshiras, Morgaon, and Barhanpur. Each station contains 28 years daily rainfall data from 1983 to 2007. Each rain gauge station prepared as shape file in ArcGIS environment and enters average annual rainfall for each station in attribute table. After preparation of a rainfall data for each station, the shape file is converted in to a raster map using raster calculator in spatial analyst tools. This point map of rainfall is interpolate to raster map using Inverse Distance Weighted (IDW) method and converted into a grid map. The prepared grid map of R-factor (Fig.5.) is used as one of the input data set for OpenNSPECT&N-SPECT models.

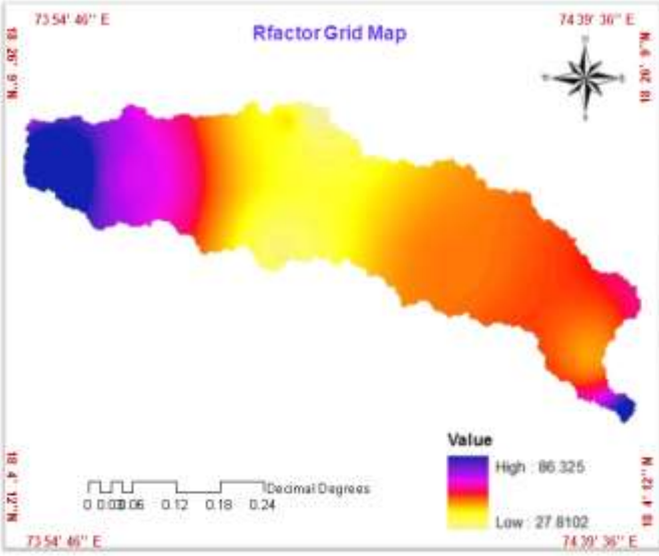

Fig 5: R-factor Map of Karha Basin

METHODOLOGY

Erosion and sedimentation are significant problems in the 'Karha' region, and suspended sediments are one of the most serious and widespread nonpoint source pollution issues in the nation. The methodology applied for OpenNSPECT and N-SPECT models uses to estimate suspended sediment concentrations is explained in the coming paragraphs. Prior to proceed for estimation of sediment delivered in the watershed, it is necessary to estimate the soil erosion takes place in the watershed. The current standard for estimating annual soil erosion is the Revised Universal Soil Loss Equation (RUSLE), a variant of the original USLE. The Revised Universal Soil Loss Equation is as follows:

$$A = R * K * L * S * C * P$$

Where:

A = average annual soil loss
R = rainfall/runoff erosivity factor
K = soil erodibility factor
L = length-slope factor
S = slope steepness factor
C = cover management factor
P = supporting practices factor

The rainfall/runoff erosivity factor map (R-factor), and Soil erodability factor (K-factor) map were prepared and used in the equation. The LS factor will be generated using a script written by Bob Hickey at Central

 ISSN 2349-6193
Impact Factor (PIF): 2.243

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Washington University [14]. Stream flow length is calculated as the sum of these values along the flow paths until one of the break points, a ridge, or a pour point is encountered. This yields the estimate of length-slope *lamda* used to calculate the L factor in the equation:

$$L = (lamda / 72.6)^m$$

Length-slope exponent m, derived from down slope angle from standard table derived by Renard (1997).

The S factor is calculated using the following equations (Renard and others, 1997):

Where slope < 9% $\quad S = 10.8 * (\sin theta) + 0.03$
Where slope > 9% $\quad S = 16.8 * (\sin theta) – 0.50$

The LS factor units are feet.

Cover management factor (C) values are entered while run the model for both OpenNSPECT and N-SPECT models. The supporting practices factor (P) is not included in this version of both 'Non-Point Source Pollution and Erosion Comparison Tool' models of OpenNSPECT and N-SPECT but may be incorporated in future releases as data availability permits.

Sediment Delivery Ratio (SDR):

RUSLE produces an estimate of gross erosion, but does not indicate how much eroded soil is actually transported by streams. To encounter this fact SDR value is calculated using the equation develop by Williams, 1977 [15].

$$SDR = 1.366 * 10\text{-}11 * (DA)^{-0.0998} * (ZL)^{0.3629} * (CN)^{5.444}$$

Where:
DA = drainage area (km^2)
ZL = the relief-length ratio (m/km)
CN = SCS curve number

The sediment delivery ratio is applied at the cell level rather than at the watershed or catchment level. The drainage area parameter represents the area of each individual grid cell. Relief-Length Ratio is calculated based on the DEM and flow direction grid. The elevation change along the down slope flow path is calculated from the DEM and divided by the distance from the center of the current cell to the center of the next cell along the flow path. The runoff curve number grid is derived from the land cover grid and soil map shapefile. Filnally, multiplying the resulting sediment delivery ratio grid by the annual soil loss grid from the previous step will produce a true annual sediment yield grid. The whole methodology applied in this study is shown in the form of flow chart as shown in Fig: 6.

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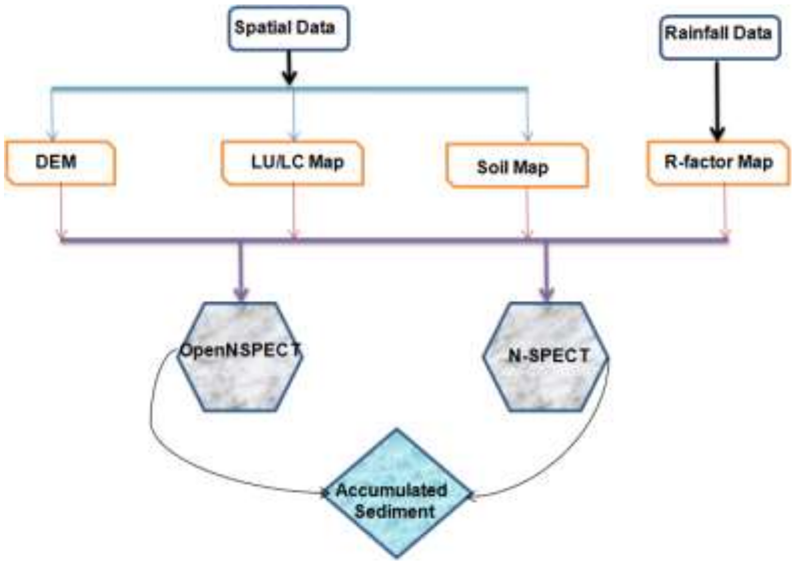


Fig 6: Flow Chart of Methodology

Glimpses of the OpenNSPECT & N-SPECT:

OpenNSPECT, the open-source version of the ‘Non-point Source Pollution and Erosion Comparison Tool’ developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center in September 2012 to accompany the Wai‘anae Ecological Characterization. The tool is a plug-in to the free, open-source geographic information system (GIS), Map Window GIS, and allows users to examine relationships between land cover, nonpoint source pollution, and erosion. OpenNSPECT is useful for understanding and predicting the impacts of management decisions on water quality and, potentially, on near shore ecosystem health. OpenNSPECT is a very flexible tool and it has the capabilities of Estimating runoff volume, Estimating pollutant loads and concentrations, Identifying areas highly susceptible to erosion by water, Estimating sediment loads, assessing the relative impacts of land use changes with scenario analysis.

N-SPECT Ver. 1.5, developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center in May 2008 to accompany the Wai‘anae Ecological Characterization. The tool is an extension to ESRI’s ArcGIS software package and allows users to examine relationships between land cover, nonpoint-source pollution, and erosion. The functional capabilities of this interface is similar to the OpenNSPECT as mentioned in the previous paragraph. The overview of OpenNSPECT and N-SPECT shown in Fig. 7.

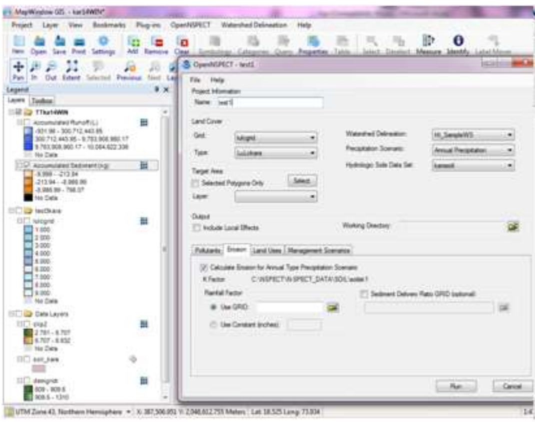
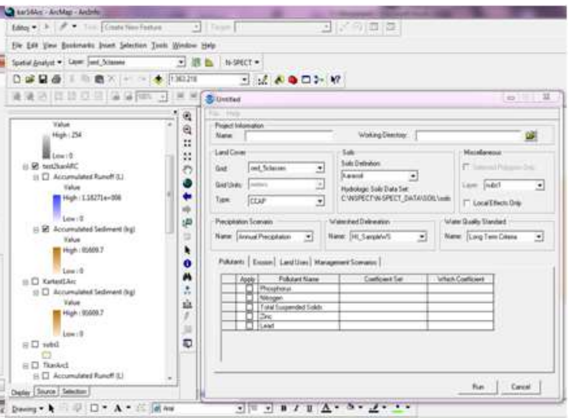


Fig 7: Over view of OpenNSPECT Model



Over view of N-SPECT Model

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MODEL APPLICATION & DISCUSSION

OpenNSPECT and N-SPECT Models produces two primary output data sets for both annual and event-driven scenarios, depending on the user's specification of accumulated or non-accumulated sediment yield. Each cell of the accumulated sediment grid represents the total value of all upstream cells, which flow into the current cell along the paths delineated in the flow direction grid. The accumulated sediment yield estimated through OpenNSPECT model for the Karha basin is 86253.4 (kg). The spatial pattern of Accumulated Sediment yield is shown in Fig. 8. The results of this study show that soil loss in the basin is positively skewed, with minimum, maximum and average values of 0, 86253, and 44.35 (kg), respectively. A very low risk soil loss is found in the eastern and mid region of the basin, and a very high soil loss risk is predominately in the western mountainous areas. However, RUSLE estimates low soil loss in the valleys and deposition areas. The accumulated sediment at the outlet of karha basin from OpenNSPECT is 8.62 t/year.

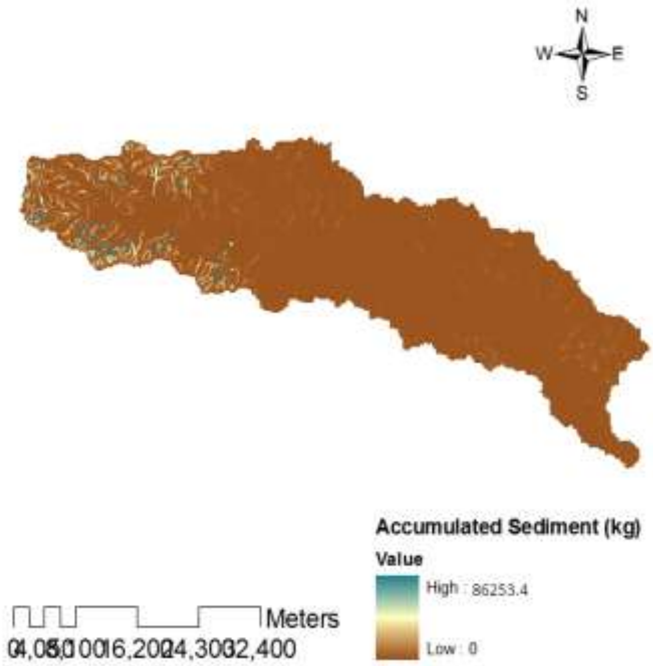

Fig 8: Spatial distribution of Accumulated sediment map from OpenNSPECT Model

Through N-SPECT model the accumulated sediment yield for the Karha basin area is estimated 91609.3 (kg). The spatial distribution of accumulated sediment yield is shown in Fig. 9. As indicated spatial pattern in the figure 9 the soil loss in the basin is positively skewed, with minimum, maximum and average values of 0, 91609, and 50.34 (kg), respectively. A very low risk soil loss is found in the eastern and mid region of the basin as occurred in the case of OpenNSPECT model. There and a very high soil loss risk is predominately in the western mountainous areas. However, the sediment yield deposition occurs low in the valleys and deposition areas. In case of N-SPECT model 5356 kg of more sediment load occur than OpenNSPECT model. The results reveals that it is equivalent to 6% of higher sediment yield obtained from N-SPECT model studies. Figure 9 clearly shows that in the western part of the Karha basin has indications of yielding more sediment load. The remaining part of the basin shows almost yielding a very low sediment load.

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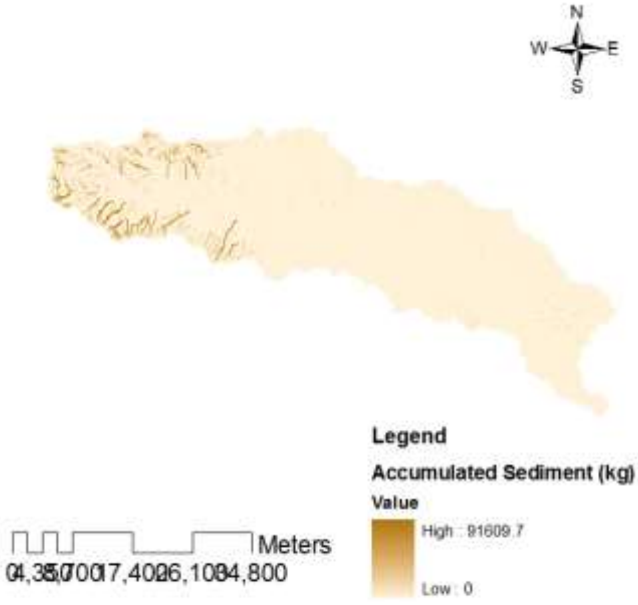

Fig 9: Accumulated sediment map of N-SPECT

CONCLUSIONS

This study has been conducted to evaluate accumulated sediment yield of Karha basin with a hydrological interface model of 'Non Point Source Pollution and Erosion Comparison Tool' with identical physical parameters and equations with two different GIS softwares of Map Window GIS (OpenNSPECT) and Ac Map (N-SPECT). The sediment deposited in Karha basin is 86253.4 kg from OpenNSPECT model and 91609.3 kg from N-SPECT model. Though both the models are designed based on the same scientific approach and physical parameters, N-SPECT model depicts higher sediment yield to OpenNSPECT. One of the common lacuna in both the model is that the support practice factor 'P' is not embedded in the models. It is evident from the above discussion that the spatial and non-spatial data integrated with GIS technology can be successfully utilized for developing the accumulated sediment yield map of any watershed with minimum data requirement. From the above hypothetical case study it can be concluded that although the rainfall erosivity in the selected watershed was high, the corresponding dense land use has played a major role in controlling the resultant soil loss and corresponding sediment load from the watershed. It is evident from the above discussion that the OpenNSPECT and N-SPECT allows users to perform basic scenario analysis. However, the government agencies such as district assemblies and municipal assemblies are more concerned about the rate of soil erosion in their region.

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