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SWAT MODELLING FOR SEDIMENT YIELD: A CASE STUDY OF UJJANI RESERVOIR IN MAHARASHTRA, INDIA

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ABSTRACT

This study is related to the use of SWAT model for the prediction of sediment yield from the rainwater runoff in the Upper Bhima Basin (UBB) which is the source of water for the terminal reservoir called Ujjani Reservoir, in Solapur district, Maharashtra State, in India. SWAT-model configuration was developed, using data pertaining to 27 sub-basins in the catchment area of the UBB. Extensive use of satellite images has been done, for a period of 2 years and 7 months (January 2012 to July 2014). Digital Elevation Model (DEM), Land Use and Soil data were included, in addition to climatic data applicable to the area. The annual average sediment yield in the various reaches of sub-basins was estimated to vary from 1342.0 tons/year to 888010.0 tons/year, during the study period.

The trend of results the SWAT model applied to Ujjani Reservoir will serve as a clue to similar studies in major reservoirs in India, in estimating the sediment yield from the rainwater surface runoff. These estimates have relevance to soil conservation schemes envisioned in the catchment areas, and for ensuring adequate water storage needed for meeting the requirements of the various human uses. Also, the sediments yielded to Ujjani Reservoir could be thought of as a resource for sand, a building material which is very much in demand, as reported by Bhamre,P.R., et.al (2014), if the sediments could be harvested, annually, by suitable de-silting/dredging operations.

Keywords: SWAT-model, Upper Bhima Basin, Ujjani reservoir, Rainwater runoff, Sediment yield.

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1. INTRODUCTION

The importance of sedimentation studies cannot be overlooked. Dandy *et. al* (1973) studied some 1100 dam-reservoirs in the USA, and reported that a great majority of small lakes were becoming completely silted in periods less than 30 years. Radoane and Radoane (2004) analyzed 138 reservoirs, in Romania, whose storage capacities varied from 1.0 million cubic metres to 1230.0 million cubic metres, and identified 30 reservoirs which would lose 30% of their storage capacities in periods between 2 years and 10 years. In the State of Maharashtra in India, Swami and Kulkarni (2016) predicted the sediment yield in Kaneri watershed (near Kohlapur), in Maharashtra, India, using SWAT-model, and reported that the predicted sediment yield was 124.61 tons/ha, against an observed sediment yield of 118.26 tons/ha. Thakkar *et. al* (2007) reported that, on an average, India is experiencing the loss of about 1.3 billion cubic metres (BCM) of storage capacity every year, citing the reports of the Government of India's National Commission of Integrated Water Resources Department.

Shendge and Chockalingam (2016) reiterated the fact that estimation of sedimentation rate in reservoirs forms an integral part of water resource planning exercise, which would include the periodic measurement of sedimentation rate, deposition pattern and the consequent increase in the storage capacity of live-storage in the case of a reservoir/dam.

The annual loss of capacity in Ujjani Reservoir was in order of 0.44% in the year 1977, thereby deserving an alarming state of sedimentation rate, as the rate was higher than 0.30% (Kalvit and Kulkarni, 2010). The sedimentation was reported as 0.612% (between 1977 and 1991), and 0.529% (between 1991 and 2004) as reported by Roman Uday, C., et.al (2010). Narayan and Ram Babu (1983) reported that the estimated loss of storage capacities in reservoirs of India was in the range of 1.0% to 2.0 %

McGully *et. al* (1996) reported that sediment-yield to the reservoirs of the power-generating dams directly reduces the storage capacity, apart from posing some technical problems to the dam-operators, in the sense that the sediments cause aberrations in the turbine-blades, and other dam-components. The erosion caused by the water-borne sand and silt in the moving parts of the machinery could warrant the frequent replacement of the parts.

In the case of Ujjani Reservoir, there is a need to apply the best model for estimating the quantum of sediments which would accumulate in the Ujjani Reservoir, due to the rainwater runoff of from the upper catchment area (called the upper Bhima river catchment). It has been reported that about 29000.0 hectares of land gets submerged in the backwaters of Ujjani reservoir, and that the sand content in the sediment yielded to the Ujjani reservoir was about 21.3% (Bhamre *et. al,* 2014). The inference is that the annual desilting operations could prove to be a cost-effective scheme. The quantum of sediments reaching the reservoir during the rainwater runoff process occurring in the catchment area can be predicted, using the SWAT model, for the purpose of facilitating remedial and corrective measures.

2. STUDY AREA

The Upper Bhima Basin was chosen as study-area, as it is the source of water draining into the Ujjani Reservoir site located in Solapur District in the State of Maharashtra, India, as shown in Figure-1, sub-divided into 27 sub-basins. The basin is located in the western region of Maharashtra State between 17°53´ North Latitude and 19°24´ North Latitude, and 70°20´ East Longitude and 75°18´ East Longitude, covering a drainage area of 14858.0 Sq.Km.

The location of Ujjani Dam corresponds to the geological coordinates of 18° 04' min 23" sec North Latitude, and 75 ° 07 ' 15 " East Longitude.

3. METHODOLOGY

Soil and Water Assessment Tool (SWAT) was employed in the study. SWAT is a watershed hydrological transport model used to quantify the impact of land management practices in large and complex watersheds. The first step was to delineate the watershed of the basin, into 27 sub-basins. The second step was the generation of HRUs (Hydrological Response Units). The river network for the reservoir catchment area was extracted from the digital elevation model (DEM) from SRTM (Shuttle Radar Topographic Mission) data, using standard techniques contained in the ArcSWAT GIS Interface. A 90.0m x 90.0m resolution was achieved in the grid. Totally, 27 sub-basins were defined, and the 199 HRUs were generated in the model, based on unique combinations of land-use, soil and slope overlay of the sub-basin, adopting a threshold area of 100,000 sq.m (10.0 hectares). This data was projected to UTM 43 Q on spheroid of WGS84. It was in raster format to fit into the model requirement. The water-balance equation used by Neitsch *et. al* (2005) was employed.

The SCS Curve Number Method (SCS-CN) was used for estimating the surface runoff in all the 27 sub-basins. The Curve Number could vary from 0.0 to 100.0, depending on aspects such as, (*i*) infiltration characteristics of the soils prevalent in the catchment area, (*ii*) land use pattern/ land cover, and (*iii*) the antecedent moisture conditions of the soil, which could be dry (wilting point), or average moisture condition, or the lowest moisture condition for the day. The Curve Numbers for moisture conditions 2 and 3 were computed by using specific equations spelled out in USDA-SCS 1972 document.

3.1. Estimation of sediment yield

For the prediction of sediment yield, the MUSLE (Modified Universal Soil Loss Equation) was used. The main factor considered for the analysis is runoff factor in MUSLE. The runoff factor is calculated using the runoff and peak runoff rates which could be measured at the outlet of the watershed. Each HRU was unique in characteristic nature, in terms of specific combination of parameters.

3.2. Land use/Land cover

In this study, global land use and land cover map of the basin was used. The Food and Agriculture Organisation (FAO)-Soil Map was obtained and reclassified into soil textural classification grid. Daily rainfall grid map of 0.5 degree x 0.5 degree resolution developed by IMD (Indian Meteorological Department) was used for this study for the period of 2 years and 7 months. All the rainfall grids obtained from IMD were in binary '*grd'* format and they were converted into ERDAS '*img'* format. IMD developed daily temperature data of 1.0 degree x 1.0 degree resolution for the entire India. All the temperature grids obtained from IMD were in binary 'grd' format, and they were converted into ERDAS 'img' format. The daily minimum and maximum air temperatures for the study area were then extracted from the image.

3.3. Salient features of the catchment

(*i*) Weighted mean annual rainfall in the basin varies from 461.0 mm (in Daund area) to 4320.0 mm (in Lonavala area); whereas the annual mean rainfall is around 500.0 mm near the Dam-site. (*ii*) Hydrological soil group is classified under C and D groups in the study area. Texture names are: Clayey Loam, Loam, Sandy clay Loam, Clay Loam, and Clay. (*iii*) Landuse varied in percentages in the entire catchment, in the various categories of FAO-classification, namely, (*a*) Dry land, Crop Land and Pasture (CRDY) as 23.16%; (*b*) Irrigated Crop Land and Pasture (CRIR) as 30.20%; (*c*) Cropland/Grassland Mosaic (CRGR) as 11.77%; (*d*) Cropland/Woodland Mosaic (CRWO) as 0.11%; (*e*) Grass Land (GRAS) as

0.44%; (*f*) Shrub Land (SHRB) as 34.38%; (*g*) Savanna (SAVA) as 3.72%; (*h*) Ever Green Broad Leaf Forest (FOEB) as 0.13%; (*i*) Evergreen Needle Leaf Forest (FOEN) as 1.28%; (*j*) Water (WATR) as 3.93%; and (*k*) Residential Medium Intensity (URMD) as 0.78%.

3.4. Flow routing phase

Two options are available to route the flow in the channel network, the Variable Storage Method and Muskingum Routing Method. The Variable Storage Method uses a simple continuity equation in routing the storage volume, whereas the Muskingum Routing Method models the storage volume in a channel length as a combination of wedge and prism storages. In this study Muskingum Routing Method was adopted.

4. MODEL INPUT DATA COLLECTION AND ANALYSIS

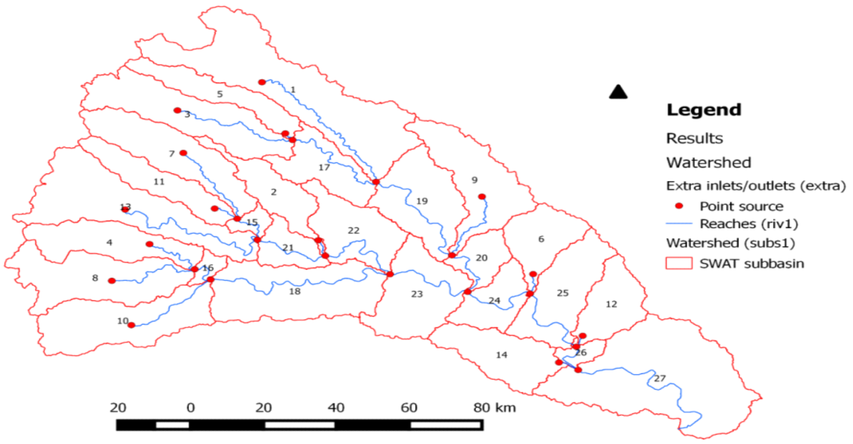

Figure 1 SWAT Sub-basins of the Ujjani watershed

SWAT is highly data intensive model that requires specific information about the watershed such as topography, land use and land cover, soil properties, weather data, and other land management practices. The climatic data such as rainfall, minimum and maximum air temperatures, humidity, wind speed, and solar radiation were used.

4.1. Water balance of the watersheds

The water balance details describing the general principles of the Annual Water Balance of the Basin, with proportionate values expressed in millimeters were estimated.

4.2. Annual means Potential Evapotranspiration (PET)

The spatial variations of Annual Mean Potential Evapotranspiration (PET) at each of the 27-sub-basins, in different ranges were estimated. Spatial variations of Annual Mean Evapotranspiration (ET) at sub-basins of UBB were computed.

4.3. Annual mean groundwater

The spatial variations of annual mean ground water table (levels) in each sub-basin of the UBB were computed.

4.4. Annual mean percolation

The spatial variation of annual mean percolation rates occurring in different ranges, were computed.

4.5. Annual means flow/Discharge

The annual mean flow (discharge), in terms of cubic meters per second was computed. The differences among the sub-basins were brought out clearly with regard to quantitative aspects. Annual mean flow rate variations, in various sub-basins were predicted to occur, in 5 slabs, namely, 8.0 to 122.0 cum/sec, 122.0 to 304.0 cum/sec, 304.0 to 475.0 cum/sec, 475.0 to 1243.0 cum/sec, and 1243.0 cum to 2498 cum/sec.

4.6. Annual mean sediment yield

The sediment-yield, in terms of annual mean values, were computed, and are given for the 27 sub-basins of Ujjani Watershed in Figure-3.

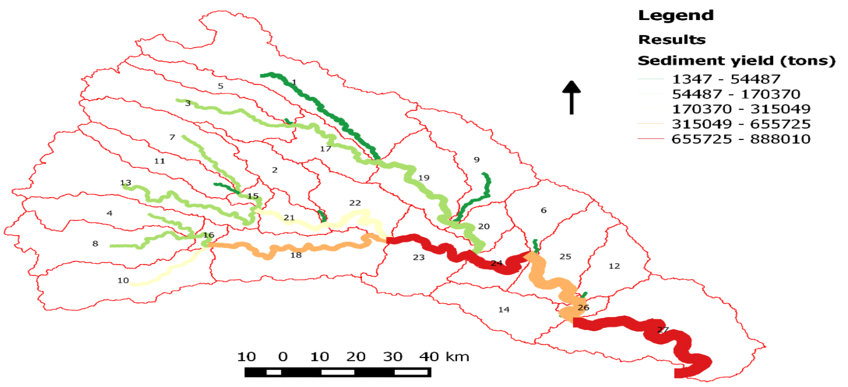

Figure 2 Sediment yield (annual mean in tons) in the reaches of the sub-basins of Ujjani watershed

4.7. Variation of monthly sedimentation yield at watershed outlet

The sedimentation rate as predicted as monthly variations at the outlet of the watershed are presented in Table 1 and Figure 3.

Table 1 Annual average of sediment yield

Date	Sediment out (tons)
2012/1	1090.0
2012/2	26.8
2012/3	1.0
2012/4	0.0
2012/5	0.0
2012/6	24700.0
2012/7	203000.0
2012/8	169000.0
2012/9	231000.0
2012/10	238000.0
2012/11	23900.0
2012/12	7130.0
2013/1	798.0
2013/2	23.0
2013/3	0.0
2013/4	0.0

2013/5	0.0
2013/6	75600.0
2013/7	260000.0
2013/8	173000.0
2013/9	482000.0
2013/10	116000.0
2013/11	50400.0
2013/12	17200.0
2014/1	3330.0
2014/2	149.0
2014/3	28.0
2014/4	0.0
2014/5	0.0
2014/6	172.0
2014/7	336000.0

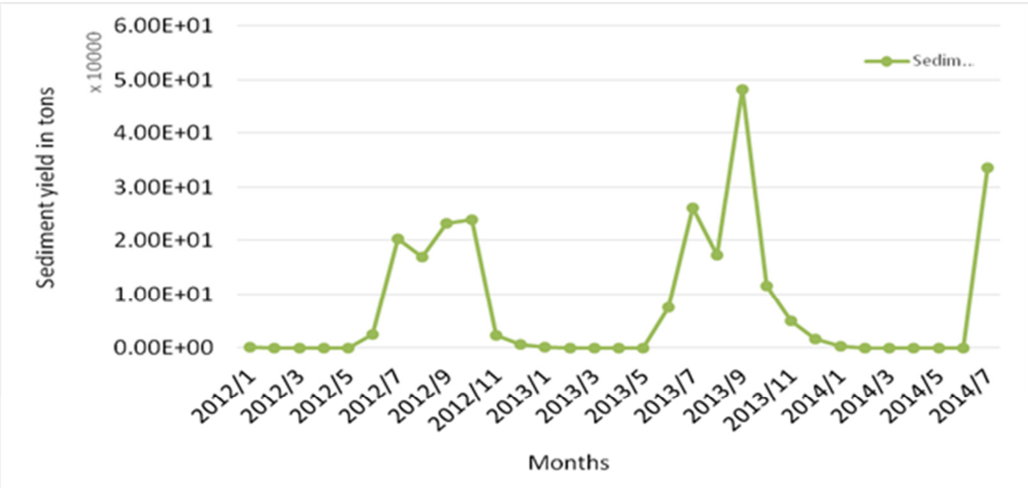

Figure 3 Variation of monthly Sediment yield during the Study period

5. RESULTS

The SWAT-model carried out in the catchment area of Ujjani reservoir, using the relevant data pertaining to a total period of 2 years and 7 months (January 2012 to July 2014) predicts that the sediment yield varied as detailed below, and presented in Figure-3 and Table-1:

1. During the monsoon period from June 2012 to November 2012, the predicted average monthly sedimentation rate was 148266.0 tons, with a minimum of 23900.0 tons to a maximum of 238000/0 tons.
2. During the monsoon period from June 2013 to October 2013, the predicted average monthly sedimentation rate was 167742.0 tons, with a minimum of 17200.0 tons to a maximum of 482000.0 tons.
3. As presented in Figure-2, the annual yields of sediments predicted in various sub-basins, indicate the following trend of variation in various sub-basins: (*i*) Sediment yield varies from 1347.0 tons/year to 54487.0 tons/year in sub-basins 8, 4, 13, 7, 3, 17 and 19. (*ii*) Sediment yield from 54487.0 tons/year to 170370.0 tons/year, in sub-basins 11, 1, 9, 6 and 12. (*iii*) Sediment yield from 170370.0 tons/year to 315049.0 tons/year, in sub-basin 18. (*iv*) Sediment yield from 315049.0 tons/year to 655725.0

tons/year in sub-basins 25 and 26. (*v*) Sediment yield from 655725.0 tons/year to 888010.0 tons/year in sub-basins 23, 24 and 27. No or meager yield of sediment is predicted from sub-basins 10 and 14.

However, the rates of siltation reported in this study are to be treated as the most probable values which need to be checked with the actual field data.

6. DISCUSSION

The sediment yield has to be compared with the data gathered in the field, for the purpose of validation. Many investigators have show that the SWAT-modeling produces a good and satisfactory correlation with the field-data, Banking upon their views, it is believed that the trend of sedimentation rates estimated in this study would offer sufficient guidelines in seeking remedial measures to manage the loss of storage resulting from excessive sedimentation, by resorting to improved methods of de-silting / dredging operations. Mandwar, S.R., et.al (2013) reiterated on the importance of conducting siltation studies due to its importance with relevance to the dead storage of any reservoir. Kalvit, S.K., et.al (2010) studied the sedimentation rate in the reservoirs in Maharashtra State, employing Remote Sensing Techniques and reported the probable storage annual loss of storage due to sedimentation in Ujjani Reservoir as 0.44%. The data available with the Central Water Commission (2015) reports the average rate of siltation in Bhima Reservoir as 0.815 Th.Cum/Sq.Km/year.

The sedimention process becomes the precursor for the subsequent Eutrophication (growth of excessive aquatic vegetation) which includes the growth of aquatic weeds in the submerged lands in the peripheral zones of the reservoir, paving the way for mosquito breeding, or often interfering with the growth of fish. The soil erosion phenomenon carries nutrients such as sulphates, phosphates, nitrates, and other minerals from the agricultural lands in the catchment area. The corrective measures would, therefore, warrant the scientific contributions from multi-disciplinary teams of experts, in agriculture, forestry and engineers, in addition to the involvement of local authorities and the State Government of Maharashtra, and more especially, the involvement of people in the efforts.

7. CONCLUSION

The sediment yield in each sub-basin varied considerably, depending upon the soil surface characteristics, quantum of surface runoff flow, and other relevant factors. This needs to be checked through studies conducted in each sub-basin. Appropriate measures can be suitably planned for controlling/reducing the sediment transport. The benefits can be categorized as follows: (*i*) Based on the results obtained in the study, suitable remedial measures will be identified and recommended, for water and soil conservation in the catchment area, ii) Prevention and control of silt transport in the catchment area will eventually reduce the eutrophication problem faced in the reservoir, and (i*ii*) This result will be adequately useful for a long term planning of annual schemes of desilting/dredging operations in the Ujjani Reservoir, which may deserve the attention of the stake holders, especially the Government of Maharashtra.

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