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List B of Scientific Journals, Poland,
Directory of Research Journals

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ISSN 0974-5904, Volume 08, No. 02

International Journal of Earth Sciences and Engineering

April 2015, P.P.497-501

Simulation of Sediment Yield over Ungauged Stations Using Musle (Case Study Meghadrigedda Reservoir)

P SUNDARA KUMAR[1], T V PRAVEEN[2], M ANJANEYA PRASAD[1], L MOUNIKA[1], T SANTHI[1] AND T BHARAT KUMAR[1]

[1]Department of Civil Engineering, KL University, Vaddeswaram, Guntur Dist., Andhra Pradesh, India
[2]Department of Civil Engineering, Andhra University, Visakhapatnam, A.P
***Email:** psundarkumar@kluniversity.in*

Abstract: Land and water are the two most vital natural resources of the world and these resources must be conserved carefully to protect environment and maintain ecological balance. Estimation of runoff and sediment yield is one of the prerequisites for conservation and management of water resources and also for many hydrologic applications. The present study has been taken up to predict runoff and sediment yield for a reservoir basin viz. Meghadrigedda Reservoir situated in Visakhapatnam District, Andhra Pradesh, India having a drainage area of 363 Sq.km. Modified Universal Soil Loss Equation (MUSLE) has been used to estimate the sediment yield. The runoff factors of MUSLE were computed using the measured values of runoff and peak rate of runoff at outlet of the reservoir. Topographic factor (LS) and crop management factor(C) are determined using geographic information system (GIS) and field-based survey of land use/land cover. The conservation practice factor (P) is obtained from the literature. Sediment yield at the outlet of the study reservoir is simulated for fifteen storm events spread over the period of 2012-2013 and is validated with the measured values. The resulted coefficient of determination value of 0.77 for the study area indicates that MUSLE model is working satisfactory for the selected basin

***Keywords:** SCS-CN, Land use/land cover, MUSLE, Soil erosion, Sediment yield, Storm event.*

1. Introduction

Soil erosion is an important item of consideration in the planning of watershed development works. It reduces not only the storage capacity of the downstream reservoirs but also deteriorates the productivity of the watershed. Erosion involves the detachment, transport and deposition of soil particles and aggregates. Sediment yield is defined as the total amount of eroded material to be delivered from its source to a downstream control point (Gottschalk, 1964). Thus, sediment yield rates are directly dependent upon both soil loss rates and the transport phenomenon of surface runoff and channel flow. Accurate estimation of sediment-transport rates, in general, depends on an accurate prior estimation of overland flows. Thus, any errors in the estimation of overland flows would be magnified through grossly inaccurate erosion estimations . Globally, more than 50% of pasturelands and about 80% of agricultural lands suffer from soil erosion (Pimentel et al. 1995). It is reported (Dudal 1981) that, worldwide, about 6,000,000 ha of fertile land is being lost every year due to soil erosion and related factors. At this rate, it is estimated that currently about 1,964.4 Mha of total land area has already been degraded (UNEP 1997). Of this, about 1,903 M ha and 548.3 Mha are affected with water and wind erosion problems, respectively. Land degradation by soil erosion is a serious problem in India and with an estimated land degradation of 120.4 million hectare (Mha). Around 93 Mha land is affected due to water erosion. This widespread problem threatens the sustainability of watershed which is the main surface source of drinking water and irrigation. Water and soil losses are the main reasons for sediment entering the reservoir, and these processes potentially reduce water quality. Therefore, it became necessary to quantify soil erosion more extensively, with the aim of providing a tool for planning soil conservation strategies on watershed basis. The formulation of proper watershed management programs forsustainable development requires information on watershed sediment yield. Sediment yield is a complex phenomenon and the variables involved in erosion modelling makes it difficult to measure and also to predict the sediment yield in a precise manner. Among available soil erosion and sediment yield models, the universal soil loss equation (USLE), the revised version of it (RUSLE), and its modified version (MUSLE) are widely used in hydrology and environmental engineering for computing the potential soil erosion and sediment yield. The USLE (Wischmeier and Smith 1978) was developed for estimation of the annual soil loss from small plots of an average length of 22 m and its application for individual storm events and large areas leads to large errors. It is reported that its accuracy increases if it is coupled with a hydrological rainfall excess model. In the USLE model, there is no direct consideration of runoff, although erosion depends on sediment that is being discharged with flow and varies with runoff and sediment concentration (Kinnell 2005). It has been observed that delivery ratios to determine sediment yield from soil loss equation can be predicted accurately with considerable variation. The reason for variation may be due to the change in rainfall distribution over time from year to year. Williams and Berndt (1977) proposed MUSLE with the replacement of the rainfall factor with a runoff factor to consider variability of delivery ratio.

The proposed model is intended to estimate the sediment yield on a single storm basis for the outlet of the watershed based on runoff characteristics. It is reported that it is the best indicator for sediment yield prediction (ASCE 1970; Williams 1975a, b; Hrissanthou 2005). MUSLE increases sediment yield prediction accuracy and as well as it eliminates the need for delivery ratios. The MUSLE equation has been used previously by many researchers (Tripathi et al. 2001;) and, in some cases, the equation was subjected to different modifications. The sediment yield model like MUSLE is easier to apply because the output data for this model can be determined at the watershed outlet (Pandey et al. 2009). Hikaru et al. (2000) demonstrated by successful application of USLE to mountainous forests in Japan. Tripathi et al. (2001) estimated sediment yield from a small watershed of India using MUSLE and GIS, and the estimated values were very close to the observed values. Based on the reported advantages and applicability of method, the present investigation has been taken up to assess the applicability of the MUSLE for the Meghadrigeddawatershed of Visakhapatnam, Andhra Pradesh, India; where there is difficulty in identifying suitable models for estimation of soil erosion and sediment yield at the watershed. The basin also has problems of irregular and discontinuous runoff and sediment data availability.

2. Objectives

To develop a methodology and establish a procedure to predict the sediment yield with greater reliability in watersheds with deficiency of record in sediment data.To validate sediment yield model by comparing predicted values and observed values.

3. Study Area

The geographic location of the Meghadrigedda reservoir catchment is located in the north eastern part of Visakhapatnam district of Andhra Pradesh State and lies between latitudes of 17.43’N-17.57’N and longitudes 83.02’E-83.17’E. The geographical area of the Meghadrigedda reservoir catchment has 363 Sq. Km. The Reservoir is spread about 6.9 sq.km. Major streams/rivers feeding the reservoir are Meghadrigedda, NarvaGedda and Borrammagedda. Meghdrigedda is flowing from north-west to south-east direction about 17 km , Borrammagedda is flowing from west to east for about 7 km and Narvagedda is flowing from south west to north east for about 6.5 km. Physiographic characteristics of the catchment: Catchment area is consists of Hilly area , undulating terrain and plains. Hill portion is located in the north west and north east and south-west, undulating areas is located at the foot hill portions and plain areas are located in north and central portions. Major portion of the catchment area is covered by agriculture land which consists of nearly about 51% of the total area, Hill area is covering about 17% and water bodies are consists of 11% in the total area.

4. Materials and Methods

In the present study, MUSLE equation is used to estimate sediment yield for the Meghadrigedda watershed. Runoff factor is a major input into the MUSLE model. It is computed using the runoff and peak runoff rates measured at the outlet of the study area using SCS-CN method. The sediment yields estimated by MUSLE for different events during the year 2013 are compared with the observed sediment yield data collected from the stream ungauged station located at the outlet of the watershed. The model performance is evaluated on the basis of test criteria recommended by the ASCE Task Committee (1993) and graphical performances criteria suggested by Haan et al. (1982).

4.1. SCS-CN Method of Estimating Runoff Volume

SCS-CN method developed by Soil Conservation Services (SCS) of USA in 1969 is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. It relies on only one parameter, CN. Currently it is a well-established method and widely accepted for in USA

Table.1: *Land use/Land cover statistics are presented in the table below*

S no	LU/LC Type	Area in Sq.km	Percentage
1	Agriculture Land	186.13	51.28
2	Built-up Land	13.32	3.67
3	Hill	61.65	16.98
4	Plantation	30.28	8.34
5	Waste Land	31.32	8.63
6	Water Bodies	40.30	11.10
Total		**363.00**	**100.00**

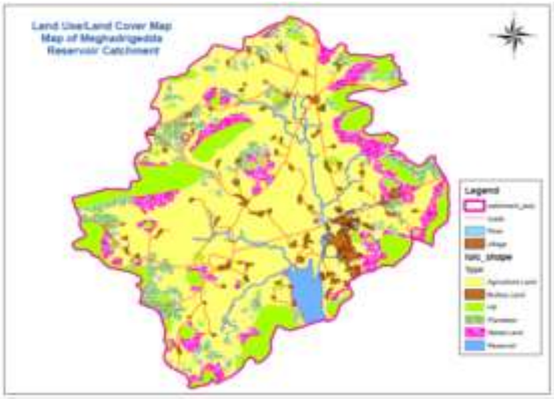

Figure 1 *Land use/land cover map of study area*

SCS-CN method developed by Soil Conservation Services (SCS) of USA in 1969 is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. It relies on only one parameter, CN. Currently, it is a well-established method and is widely accepted for in USA and many other countries. The details of the method are described in the section. The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the amount of direct surface runoff Q to the total rainfall P (or maximum potential surface to the runoff) with the ratio of the amount of infiltration Fc amount of the potential maximum retention S. The second to the potential hypothesis relates the initial abstraction Iamaximum retention. Thus, the SCS-CN method consisted of the following equations

(a) Water balance equation:

Proportional equality $P = Ia + Fc + Q$ (1)

Hypothesis $Q/(P - Ia) = Fc/S$ (2)

Hypothesis: $Ia = \lambda S$ (3)

Where, P is the total rainfall, Ia the initial abstraction, Fc the cumulative infiltration excluding Ia, Q the direct runoff, S the potential maximum retention or infiltration and λ the regional parameter dependent on geologic and climatic factors ($0.1<\lambda<0.3$).

Solving equation (2)

$$Q = (P - Ia)^2 /(P - Ia + S) \quad (4)$$

$$Q = (P - \lambda S)^2 /(P - (\lambda - 1)S) \quad (5)$$

The relation between Ia and S was developed by analyzing the rainfall and runoff data from experimental small watersheds and is expressed as $Ia=0.2S$. Combining the water balance equation and proportional equality hypothesis, the SCS-CN method is represented as

$$Q = (P - 0.2S)^2 /(P + 0.8S) \quad (6)$$

The potential maximum retention storage S of watershed is related to a CN, which is a function of land use, land treatments, soil type and antecedent moisture condition of watershed. The CN is dimensionless and its value varies from 0 to 100.The S-value in mm can be obtained from CN by using the relationship

$$S = (25400 /CN) - 254 \quad (7)$$

4.2. Estimation of sediment yield using MUSLE

The original USLE is based on soil loss by rainfall energy with slope angle and slope length, which are used as a proxy for the flow detachment process. The MUSLE model (Williams, 1975) improved USLE model (Wischmeier and Smith, 1965) by adding a runoff factor to the driving force. There is usually no provision for deposition in this model. Therefore, MUSLE is a sediment yield prediction model, for estimating sediment yield from a specified land in a specified cropping and management system. The MUSLE equation (8) is applicable to the point where overland flow enters the streams and all those point are summed up to give the total amount of sediment delivered to the stream network within watershed. It computes the sediment yield for a given site, as a product of seven major variables (William 2005;).

MUSLE computes sediment yield from a single storm event.

$$S_y = \frac{11.8}{A} . (V_Q . Q_P)^{0.56} . K . LS . C . P \quad (8)$$

Where, Sy= sediment yield in tones
A is Area (ha):
V_Q is Runoff volume (m^3)

MUSLE method uses, by the replacement of the rainfall factor with a runoff factor for Sediment computation. Particularly, this model is intended to estimate the sediment yield on a single storm basis for the outlet of the watershed based on runoff characteristics, as the best indicator for sediment yield prediction (ASCE 1970; Williams 1975a, b; Hrissanthou 2005). 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). MUSLE method has improved accuracy of soil erosion prediction over USLE and RUSLE (Williams 1975a, b; Williams and Berndt 1977;

Q_p is Peak flow rate (m^3/sec)
K is the soil erodibilty factor

Runoff volume means the draining or flowing off of excess precipitation from the catchment area through surface channel. This portion of the runoff is called overland flow. Flows from several small channels join bigger channels and flows from these in turn combine to form a larger stream, and so on, till the flow reaches the catchment outlet. Many researchers in the past have developed empirical runoff estimation formulae. However, these formulae are applicable only to the region in which they are derived. The SCS-CN method, developed by Soil Conservation Service (SCS) of USA in 1969, is a simple, predictable, and stable conceptual method of direct runoff depth based on rainfall depth. It is well-established method, having been widely accepted for use in USA and many other countries.

4.2.1. *Runoff volume (V_Q)*

Peak flow rate (Q_p) may be estimated by using a simplified model of a triangular hydrograph suggested by Soil Conservation Service (SCS). (Hrissanthou, 2005)

$$Qp = (0.278 \times A \times D) / Tp \qquad (9)$$

Where

Qp is Peak flow rate (m3/sec)
A is Area (km2)
D is Runoff Depth (mm)
Tp is Rise time of the hydrograph (h),
Tp = 0.67Tc
Tc is Time of concentration (h)

4.2.2. *Time of concentration (T_c)*

The time required for a drop of water falling on the most remote point of the drainage basin to reach the basin outlet is termed as a time of concentration. Kirpich (1940) has given a formula relating the time of concentration of the length of travel and slope of the catchment as:

$$T_c = 0.01947\, L^{0.77}\, S^{-0.385} \qquad (10)$$

T_c is Time of concentration (Minute)
S is Slope of watershed or catchment (ΔH/L)

ΔH is difference between elevation of the most remote point and outlet of the watershed

L is Maximum length of watershed (meter)

5. Results and Discussions

The discharge and sediment yield data from Meghadrigedda watershed were collected for storm events occurring from January 2013 to August 2013. All the required information for the application of the MUSLE model such as L=17000m, Tp=4.843hrs, S=0.0015 and area of the Meghadrigedda basin were extracted with the help of GIS database. Comparison of predicted and estimated values has been carried out and is reported in table: 3.The good coefficient of determination value (0.77) indicates that good relation exists between observed and estimated values as shown in fig.2. The percentage deviation of the storm in estimated yield from the observed values varied in the range of 1.20% to 68.46%. The average value of the estimated error for the studied storm was estimated 13.38% for the MUSLE model. The average value of estimated error is within 20%. Hence the value can be considered as the acceptable with level of accuracy for the simulation as per the recommendation of Bingner et al(1989). In other words the model is acceptable for the model process considering the natural phenomena Das (2000).

Table2: *Estimated values of peak flow and runoff volume (2013)*

S.no	Strom date	Peak flow m^3/se	Runoff volume, m^3
1	09-Jan	16.86	871991.3
2	19-Mar	2.63	136248.64
3	19-Apr	13.30	688055.63
4	20-Apr	12.51	647181.04
5	21-Apr	10.27	531369.7
6	23-Apr	21.60	1117238.8
7	13-May	11.59	599494.02
8	07-Jun	21.73	1124051.3
9	20-Jun	24.37	1260299.9
10	24-Jun	7.51	388308.62
11	04-Jul	22.13	1144488.6
12	07-Jul	27.00	1396548.6
13	13-Jul	8.56	442808.08
14	14-jul	9.88	510932.4
15	8-Agust	4.61	238435.12

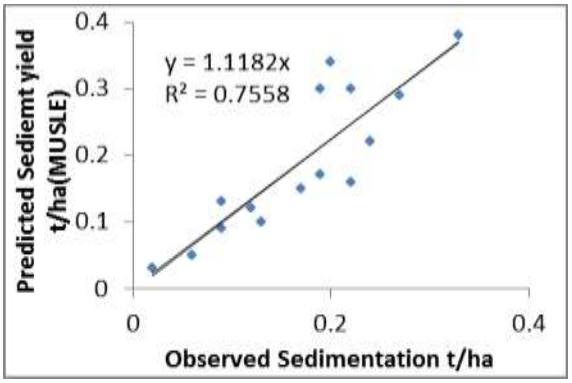

Figure2 *graph showing coefficient of determination*

Table 3: *Comparison of Predicted and Observed Sediment Yield values (2013)*

Strom date	Predicted sediment yield t/ha	Observed Sediment yield, t/ha	Percentage of error
09-Jan	0.22	0.24	-5.01
19-Mar	0.03	0.02	64.83
19-Apr	0.17	0.19	-12.00
20-Apr	0.16	0.22	-27.44

21-Apr	0.13	0.09	36.96
23-Apr	0.29	0.27	9.99
13-May	0.15	0.17	-16.03
07-Jun	0.30	0.22	32.93
20-Jun	0.34	0.20	68.46
24-Jun	0.09	0.09	1.20
04-Jul	0.30	0.19	62.88
07-Jul	0.38	0.33	15.00
13-Jul	0.10	0.13	-22.34
14-Jul	0.12	0.12	2.40
8-Agust	0.05	0.06	-11.17
Average		13.38	

6. Conclusions

MUSLE model has been successfully used for the estimation of storm-wise sediment yield in the Meghadrigedda Basin with good coefficient of determination (0.77) which indicates accurate simulation of sediment yield from the MUSLE model. The average value of estimated is 13.38% between the sediment yield measurement and observations. However, the present results can also be used in erosion-based watershed prioritization in the study area. To regionalize the results of the study area, greater numbers of storms events as well as case studies are needed. Hence researchers should consider this aspect. In addition, other simple soil erosion and sediment yield models must be considered with reasonably accurate estimation of system response at the watershed scales, when scarce information exists.

References

[1] ASCE (American Society of Civil Engineers) (1970) Sediment sources and sediment yields. *J HydraulDiv* ASCE 96 (HY6):1283–1329

[2] ASCE Task Committee (1993) Criteria for evaluation of watershed models. *J Irrig Drain Eng ASCE* 119(3):429–442

[3] Bingner RL, Murphee CE, Mutchler CK (1989) Comparison of sediment yield models on various watersheds in Mississipi. *TransASAE* 32(2):529–534

[4] Das G (2000) Hydrology and soil conservation engineering. *Prentice- Hall*, India

[5] Dudal R (1981) An evaluation of conservation needs. In: Morgan RPC, Soil conservation: problems and prospects. *Wiley, New York*

[6] FAO/UNEP (1994) Land degradation in south Asia: its severity causes and effects upon the people. *FAO, UNEP and UNEP project, Rome*

[7] Haan CT, Johnson HP, Brakensiek DL (1982) Hydrological modelling of small watersheds. *American Society of Agricultural Engineers*, Michigan

[8] Gottschalk, L.C. (1964) Reservoir Sedimentation. Chapter 17-1. In: V.T. Chow, éd., Handbook of Applied Hydrology, *McGraw-Hill Book* Co., New York, NY. USA

[9] Hikaru K, Yoichi O, Toshiaki S, Kawanami A (2000) Application of Universal Soil Loss Equation (USLE) to mountainous forests in Japan. *J For Res* 5(4):156–162

[10] Hrissanthou V (2005) Estimate of sediment yield in a basin without sediment data. *Catena* 64:333–347 Kinnell and Risse 1998;

[11] Pandey A, Chowdary VM, Mal BC (2009) Sediment yield modelling of an agricultural watershed using MUSLE, *remote sensing and GIS*. J Paddy Water Environ (Springer) 7(2):105–113

[12] Kirpich, Z. P. (1940). Time of concentration of small agricultural watersheds. Civil Engineering 10 (6), 362.*The original source for the Kirpich equation.*

[13] Tripathi MP, Panda RK, Pradhan S, Das RK (2001) Estimation of Sediment yield form a small watershed using MUSLE and GIS. *J InstEng* I 82:40-45

[14] UNEP (1997) World Atlas of desertification, 2nd edn. Arnold, London, p 77

[15] Walling DE, Webb BW (1982) Sediment availability and the prediction of storm-period sediment yields. In: *Proceedings of the Exeter Symposium*, 327–337. IAHS Publ. 137. IAHS Press, Wallingford, UK

[16] Williams JR (1975a) Sediment routing for agricultural watersheds. *Water Resour Bull* 11:965–975

[17] Williams JR (1975b) Sediment yield prediction with Universal Equation using runoff energy factor. In: Present and prospective Technology for predicting sediment yields and sources, 244–252, *Agricultural Research Service, US Department of Agriculture*

[18] Williams JR, Berndt HD (1977) Sediment yield prediction based on watershed hydrology. *Trans Am SocAgricEng* 20(6):1100–1104

[19] Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses. *USDA Agricultural Research Services Handbook 537.* USDA, Washington, p 57.