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A study on the efficiency of Erosion Potential Model (EPM) using reservoir sediments

Asghar Kouhpeima[1], Seyed Ali Asghar Hashemi[2] and Sadat Feiznia[3]

[1]Islamic Azad University, Shiraz Branch, Shiraz, Iran

[2]Researchers of Agriculture and Natural Resource Research Center, Semnan, Iran

[3]Faculty of Natural Resources, Tehran University, Iran.

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ABSTRACT

Erosion and sediment yield are important factors that should be taken into account in planning renewable natural resource projects. The EPM model is extensively used to erosion and sediment yield assessments in many catchments of Iran. Because of ambiguities in the validity of the results of EPM model, the objective of this study is to evaluate the output results of this model in five small catchments, Semnan Province, Iran using sediment deposited in reservoir constructed in the outlet of these catchments. The Specific Sediment Yield (SSY) in five reservoirs was assessed by measuring the volume and mass of deposited sediment in the reservoirs and also by characterizing the reservoirs and their respective catchments. The primary data for EPM model was obtained from topographic maps, aerial photographic interpretation, earlier studies and field survey by a team with different professional backgrounds in order to score each model's factors. Model performance was evaluated by using Nash and Sutcliff's Model Efficiency (ME) and the Relative Root Mean Square Error (RRMSE). Result showed that although the amount of Model Efficiency is located in acceptable area (0.056) but no high efficiency. The Relative Root Mean Square Error (79.3) show the efficiency of model is low as well.

Introduction

Surface erosion and sediment yield are important factors that should be taken into account in planning renewable natural resource projects. (Tangestani, 2006). Soil particle transmission from farm and orchards to other areas causes the fertility of such lands decreases gradually. Moreover, sedimentation in water channels clogs the water ways; it may also transfer pollutants into farm lands and dams, which are used for irrigation and drinking purposes (Sarmadian et al., 2010). Changes in land use due to development strategies exposing erosion-sensitive geological formations consisting largely of shale and marl, and poor vegetation cover in the semi arid regions of Iran are maked a large amount of sediments available annually for erosion and transport. Several experimental models were used for predicting the erosion severity and sediment yield in a subcatchment area for which hydrometric data is not available. These models are often developed for different regions than those in which they are applied. However, more field data should be gathered for model calibration and, ultimately, a better evaluation of any method should be undertaken. (Sadeghi, 2005). The commonest models now being used are USLE (Mati et al., 2000; Erskine et al., 2002), MUSLE (Modified Universal Soil Loss Equation), WEPP (Water Erosion Prediction Project), RUSLE (Revised Universal Soil Loss Equation) (Millward and Mersey, 1999, 2001; Raghunath, 2002), PSIAC (Pacific Southwest Interagency Committee) (Heydarian, 1996;Clark, 2001), and EPM (Erosion Potential Method) (Refahi and Nematti, 1995; Tangestani, 2001). The EPM model was originally developed for Yugoslavia by Gavrilovic (1988). The method has been tested in some catchment areas in Iran, and it is found that output results are compatible with field observation (Sadeghi, 1993; Refahi and Nematti, 1995). This model is factor-based, which means that a series of factors, each quantifying one or more processes and their interactions, are combined to yield an overall estimation of soil loss. Applications of Geographic Information Systems (GIS) and remote sensing techniques in erosion and sediment yield assessment have been developed recently (Sahin and Kurum, 2002; Lin et al., 2002; Bissonnais et al., 2002; Yuliang and Yun, 2002; Martinez-Casasnovas, 2003). The EPM model is extensively used to erosion and sediment yield assessments in many catchments of Iran. Because of ambiguities in the validity of the results of EPM model, the objective of this study is to evaluate the output results of this model in five small catchments, Semnan Province, Iran using sediment deposited in reservoir constructed in the outlet of these catchments.

Materials and Methods

1- Study area

The catchments for which study included the five catchments and their reservoirs. The selected reservoirs had been created by constructing earth embankments to harvest seasonal runoff. These catchments were located in Semnan Province, one of the semi-arid central Province of Iran (Figure 1). More details of the catchments are bellow:

Amrovan catchment

Total area of the Amrovan catchment is 102.35 ha. The Altitudes range from 1795 meter at the catchment outlet to 1925 m in the upstream areas and the catchment slope average is commonly 11.4%. The mean annual precipitation is 174 mm and occurs in winter and spring months generally. The geology is dominated by Quaternary, Hezar-Dareh and Upper Red

Tele: +98-9126606591
E-mail addresses: aakouhpeima@yahoo.com

Formations. All of the catchment area is covered by bush ranges (Kouhpeima, 2009).

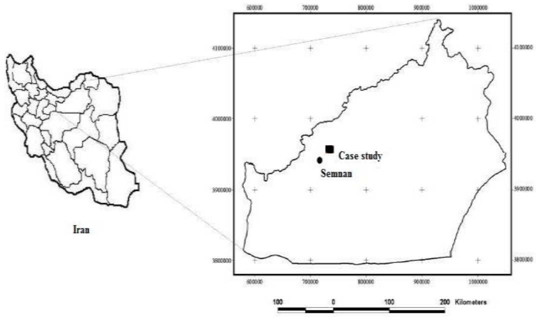


Fig1. The location map of the study areas

Atary catchment

The Atary catchment drains an area of 627.96 ha, with its moderate relief (maximum and minimum altitude 2220 and 1750 m respectively), relatively low annual precipitation (180 mm) and the catchment slope average is commonly 11.4%. Most of the rainfall occurs in winter and spring. The land use of the catchment is dominated by rangeland (100%). All of the catchment area is covered by bush ranges. The geology is dominated by Quaternary, Hezar-Dareh , Upper Red, Qum and Karag Formations. (Kouhpeima, 2009).

Ali Abad catchment

Total area of the Ali-Abad catchmen is 129.25 ha. The Altitudes range from 1775 m at the catchment outlet to 2093 m in the upstream areas and the catchment slope average is commonly 16.20%. The mean annual precipitation is 176.9 mm. Most of the rainfall occurs in winter and spring. The geology is dominated by Quaternary, Upper Red and Qum Formations. All of the catchment area is covered by bush ranges (Kouhpeima, 2009).

Ebrahim Abad catchment

The catchment has a total area of 507.81 ha. The climate annual rainfall is 183 mm. Most of the rainfall occurs in winter and spring. The Altitudes range from 1825 m at the catchment outlet to 2070 m in the upstream areas and the catchment slope average is commonly 29.31%. The eology is dominated by Quaternary, Hezar-Dareh, Karaj, Lar, Delichay and Shemshak Formations. All of the catchment area is covered by bush ranges (Kouhpeima, 2009).

Royan catchment

The catchment has a total area of 538.83 ha. The climate annual rainfall is 184 mm. Most of the rainfall occurs in winter and spring. The topography of the region mainly consists of highland parts up to 2000 meter and the catchment slope average is commonly 23.95%. The geology is dominated by Quaternary, Hezar-Dareh, Shemshak, Lar and Upper Red Formations (Kouhpeima, 2009).

Methodology

Survey of sediment deposition

Collection Sediment deposits in reservoirs were used to assess the total sediment yield from the corresponding catchment using Equation 1 proposed by werstren and poesen (2002). Here, the term total sediment yield (TSY) refers to the mass of sediment that enters the reservoir yearly. TSY =100*M/(STE*Y) (1)

Where, TSY= total sediment yield (t year_1), M= sediment mass (t), STE=sediment trap efficiency (%), Y =age of the reservoir (years), and

M =Sv*dBD (2)

Where, Sv = the measured sediment volume in the reservoir (m3), dBD = the area-weighed average dry bulk density of the sediment (g cm_3). Sediment thickness was measured by observing sediment profiles (between 0.7 to 2.8 m deep) in pits along transects, with 40 to 100 pits per reservoir depending on the size and nature of the original bottom surface of the reservoir. Sediment volume was computed by constructing a Digital Elevation Model (DEM) with a resolution of 1 m using TIN interpolation in IDRISI and taking sediment thickness as the z value (Harweayn 2005). The trapping efficiency of the reservoirs was assessed based on one year field monitoring (2008) and interviewing the local farmers about the history of the reservoir. All reservoirs are less than 10 years old and spillage has never occurred for reservoirs since their construction. Dry bulk density (dBD) was determined by the gravimetric method (Harweayn 2005).

Spatial data generation of EPM model

The primary data was obtained from topographic maps, aerial photographic interpretation, field survey and earlier studies (Agriculture and Natural Resource Research Center, Semnan, Iran). A field campaign by a team with different professional backgrounds was undertaken in each catchment in order to score each model's factors. Derivation of the factors required by the EPM model is documented in the literature (Gavrilovic, 1988). However, the recent development of GIS and remote sensing technologies permits a more accurate estimation of some of the factors. The following sections describe the techniques used to generate the data and to evaluate the erosion factors.

The coefficient of rock and soil resistance to erosion (y-factor)

Geological data were compiled by visual interpretation of 1:50,000 aerial photographs together with field observations. Rock exposures in the study area mostly consist of Upper Red, Hezar Dareh, Karaj, Shemshak formation and Quaternary deposits, with different resistance to erosion. The lithological map was manually digitized using a Calcomptable digitizer to be used as a GIS layer. Lithological units were re-classified into 10 categories based on their sensitivity to erosion. Data for estimating the coefficient of rock and soil resistance to erosion (y-factor) were obtained by examining rock and soils from 100 test sites, representative of the major rock and soil map units. The test sites were subjectively examined and evaluated based on the type of lithology, thickness of beds, degree of cementation, and density of fractures and joints. The coefficients of rock and soil resistance to erosion (y-factor) were assigned for each map class using the methodology proposed by Feyznia (1995).

Land use coefficient (Xa- factor)

To determine the 'Xa-factor' values utilized by the EPM, a land-use map was generated. The area was covered mainly by rangeland and minor dispersed garden in Royan catchment. The land use coefficient (Xa) corresponding to each land use class was estimated by the use of EPM Guide Table (Gavrilovic, 1988). This model classifies land uses into 10 categories and evaluates the coefficient 'Xa' from 0.1 (for high-density woodlands) to 1.0 (for badlands).

The coefficient of slope classes (I-factor)

Land slopes were calculated using 1:25,000 topographic maps produced by the National Cadastre Center of Iran. The original digital data in Microstation DesiGN (DGN) format were used to build up a DEM (Digital Elevation Model) of the sub-catchment area. A raster grid cell of 50*50 m was generated and was applied to produce the DEM, from which, slope steepness could be determined. The slopes were re-classified into seven categories ranging from 0–5 to >40%. The mean values of each slope class was assigned in decimal system to determine the I-factor' (Gavrilovic, 1988).

The coefficient of observed erosion processes (ψ-factor)

The coefficients of observed erosion processes (ψ-factor) required visual estimation in the field. Visual interpretation of aerial photographs at the scale 1:40,000 and field surveys were carried out to identify the erosion processes. The primary map of erosion processes generated by photo interpretation was controlled by a five-day field survey. Erosion processes are dependent mainly on the nature of the exposed rocks and soils, and the land use at the time of the survey. The tables of observed erosion process coefficient of EPM model was used to determine the 'ψfactor' (Gavrilovic, 1988). The erosion process coefficients are classified into 10 categories, ranging from 0.1 to 1.0.

EPM model

The Erosion Potential Method (EPM) is a model for qualifying the erosion severity and estimating the total annual sediment yield of a sub-catchment area, developed initially from the investigation of data in Yugoslavia by Gavrilovic (1988). This method considers six factors that depend on surface geology and soils, topographic features, climatic factors (including mean annual rainfall, and mean annual temperature), and land use. The Erosion Potential Method calculates the coefficient of erosion and sediment yield (Z-factor) of a sub-catchment area by the following equation

Z=Y Xa (ψ +I0.5) (3)

Where, Y is the coefficient of rock and soil resistance to erosion, Xa is a land use coefficient, ψ is the coefficient value for the observed erosion processes and I is the average land slope in % (Gavrilovic, 1988).

Erosion severity is classified according to values of Z. Areas with Z>1.0 have 'severe erosion' and those with Z< 0.19 have a 'very slight' erosion. Specific Erosion is estimated as

WSP =T.H.π.Z1.5 (4)

Where, Wsp is the average annual specific production of sediments ($m^3/km^2/y^{-1}$), T is a temperature coefficient, calculated as:

T= (t/10+0.1)0.5 (5)

Where t = the mean annual temperature (degrees Celsius), H the mean annual amount of precipitation (mm) and Z= the coefficient of erosion calculated from Eq. (1). Since all of the sediment productions do not enter to the reservoirs, it is necessary to determine the proportion of sediments that reach to reservoir in order to direct compare with reservoir sediments. Therefore Sediment delivery ratio (Ru) is estimated by equation 6

Ru = 4(O. D) 0.5/ (L + 10) (6)

Where, O = length of catchment border (km), D = the difference between medium altitude and catchment outlet altitude (km) Specific Sediment Yield (SSY) is estimated as

SSY = WSP. Ru (7)

Evaluation of the model

Model performance was evaluated by using Nash and Sutcliff's Model Efficiency (ME) and the Relative Root Mean Square Error (RRMSE), calculated as follows. 1- Model Efficiency (Nash and Sutcliff, 1970)

$$ME = 1 - \frac{\sum_{i=0}^{n}(\text{Qi} - \text{Pi})\text{\^{}}2}{\sum_{i=0}^{n}(\text{Qi} - \text{Qmean})\text{\^{}}2} \quad (8)$$

Where, ME is Model Efficiency, n is number of observations, Qmean is the mean observed value, Qi the observed value, Pi the predicted value. The value of ME can range from _l to 1 and represents the proportion of the initial variance accounted for by the model. The closer the value of ME approaches 1, the more efficient is the model. Negative values of ME indicate that the model produces more variation than could be observed: i.e. the model is inefficient.

2- Relative Root Mean Square Error (RRMSE) (Van Rompaey et al., 2001):

$$RRSME = \frac{\sqrt{1}/n\sum_{i=1}^{n}(Qi - Pi)\text{\^{}}2}{1/n\sum_{i=1}^{n}Qi} \quad (9)$$

Where, RRMSE=Relative Root Mean Square Error, Qi =observed value, Pi =Predicted value, n = number of observations. Values for RRMSE range from 0 to l. The closer the RRMSE approximates zero (the perfect model), the better the model performance.

Results and Discussion

Measured specific sediment yields using sediment survey

Fig 2 shows an example of topographic map to compute Sediment volume by a Digital Elevation Model using TIN interpolation in IDRISI at the Amrovan reservoir.

The results of assessment sediment survey are presented in Table 1. Sediment volume is converted to Sediment Mass using dry bulk density (dBD). In this study, the vertical variability of dBD was considered by taking average dBD values obtained from different depths in a profile, while the horizontal variation was accounted by producing a dBD map using Thiessen polygons in IDRISI software. The profile dBD analysis result from pits indicates that dBD varies spatially both within the reservoir and vertically in the profile. For instance, in the case of Atary, 10 pits were sampled and it was found that dBD varies between 1.22 gr cm^{-3} at the inlet and 1.42 gr cm^{-3} near the dam. The results seem to be reasonable because of deeper and more compressed of sediments in near the dam. For the same number of pits (n =10), analysis of vertical variation of dBD was made by analyzing dBD values from cores taken in two regions at two depths (upper and lower) in a profile pit. There exists some variation of dBD between the upper and lower zones, i.e. 1.12 gr cm^{-3} and 1.25 gr cm^{-3}, respectively. A similar trend exists in other reservoirs. There is some variation in SSY between catchments: i.e. from 3.57 t ha^{-1} $year^{-1}$ to 0.35 t ha^{-1} $year^{-1}$ (see table 1). These values are low when compared to the values reported in most semi arid regions of Iran. Several factors may explain this difference: most of the values reported obtained by river sediment statistics especially in periods of high sediment load (winter and spring) and use not the reservoir sediments. Furthermore, sediment load may increase with catchment size as channel erosion becomes dominant (e.g. Church et al., 1999).

Measured specific sediment yields using EPM model

Using the EPM model, the measured coefficients of EPM factors are shown in Table 2. The quantitative output of erosion severity (parameter Z), the average annual specific production of sediments (Wsp) and Specific Sediment Yield (SSY) was evaluated mathematically by solving Eqs. (3) to (7). Based on the amount of parameter Z the dominant erosion potential categories were moderate (rating class 3) related to Ebrahim

Abad and Royan catchments, while Amrovan and Ali Abad catchments are located to severe erosion potential with rating class 1 and 2 respectively. The Atary catchment corresponds to a slight erosion potential with rating class 4. The highest and lowest amount of EPM predicted SSY is related to Amrovan (2.255 t ha^{-1} $year^{-1}$) and Atary (0.918 t ha^{-1} $year^{-1}$) catchments respectively. Comparison of the amount of EPM predicted and observed reservoir sediment SSY indicate that model was predicted lower than observed values in one catchment (Amrovan) and higher in three other catchments but the differences are not considerable in the catchment scale. (See Tables 1 and 2). To assess the contribution of the EPM factors in explaining the variation of SSY between the catchments, linear regression and correlation analysis between observed SSY and each individual factor was undertaken across the catchments (Fig 3). Results show the coefficient of erosion and sediment yield (Z factor) is well correlated with SSY (Fig 2 E), while the coefficient of slope (I factor) shows the least influence on the variability of specific sediment yield (Fig 2. I). The low influence of slope for explaining variability in SSY is that most of the areas specially in Amrovan, Ali Abad and Atary catchments are characterized by steep upland slopes (>20%). Result showed that although the amount of Model Efficiency is located in acceptable area (0.056) but no high efficiency. The Relative Root Mean Square Error (79.3) show the efficiency of model is low as well. So far insufficient researches have been done to efficiency of empirical method such EPM for most region of Iran and most of the studies have used suspended sediment samples that affected by variation in flow of the River during the study period, and the timing of the collection of suspended sediment samples. However the reservoir sediment approach provides a more realistic estimate of the proportion of the total sediment load especially when spillage has never occurred for reservoirs since their construction (such as our reservoir). Therefore it is suggested to additional researches on the evaluation of empirical model such EPM by reservoir sediment survey to obtain more reliable sediment yield data.

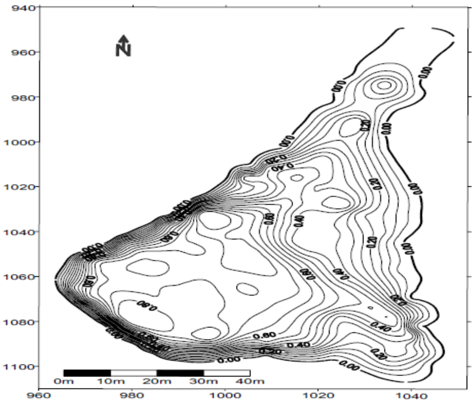
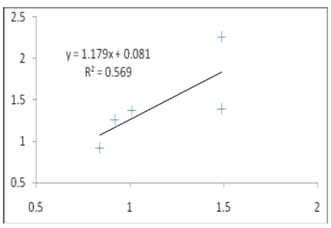
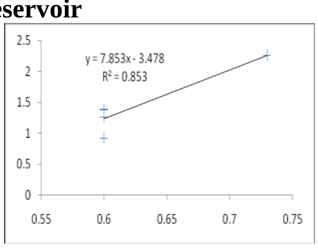


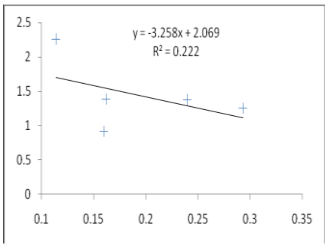
Figure 2. Topographic map to compute Sediment volume at Amrovan reservoir



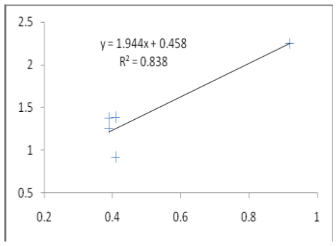
A) Y factor



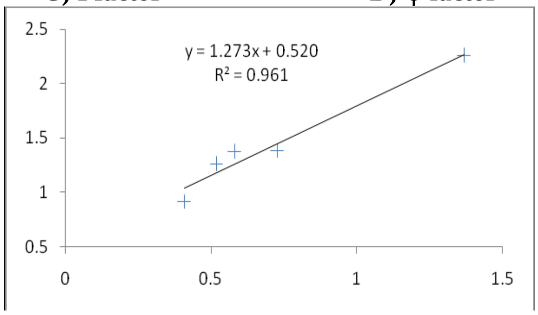
B) Xa factor



C) I factor



D) ψ factor



E) Z factor

Figure 2. Relation between each individual factor and observed SSY. Horizontal diagrams are Individual EPM factors and vertical diagrams are observed SSY (t ha-1 y-1)

Conclusion

The Erosion Potential Model (EPM) was applied to five small catchments, Semnan Province, Iran and the results were compared with sediment deposited in reservoir constructed in the outlet of these catchments. Because the coefficients of rock resistance to erosion (y) were primarily evaluated for Yugoslavia, the coefficients were modified to represent the geology of my catchment area using the methodology proposed by Feyznia (1995). The factor-classes evaluation based on this methodology showed reasonable results for model. The study provided useful data on sediment yield for catchment area, which could be used in natural resources and soil conservation projects. Although the EPM is a method for rapid and easy access to the erosion severity and sediment yield, it is completely knowledge based, and the accuracy of analyzed data primarily depends on the experience and knowledge of the experts who determine the values of erosion coefficients. However, because the EPM model considers only four factors for erosion potential assessment, it could readily be used for fast estimation of erosion potential in a sub-catchment area, for which the database layers are limited.

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Table 1. The results of assessment sediment survey

Reservoirs	TSV (m^3)	dBD ($g\ cm^{-3}$)	TSM (t)	Age (year)	TE (%)	TSY ($t\ year^{-1}$)	Area (ha)	SSY ($t\ ha^{-1}\ year^{-1}$)
Amrovan	2624.76	1.39	3651.04	10	100	365.10	102.35	3.57
Atary	2676.1	1.41	3778.65	10	100	377.87	627.96	0.6
Ali Abad	1035.89	1.35	1395.34	10	100	139.53	507.81	0.35
Ebrahim Abad	1244.4	1.43	1786.95	10	100	178.69	129.25	1.08
Royan	2363.29	1.39	3273.15	10	100	327.32	538.83	0.61

TSV: Total sediment volume; dBD: dry bulk density; TSM: Total Sediment Mass; TE: trap efficiency; TSY: Total Sediment Yield.

Table 2. The measured coefficients of EPM factors

EPM factors	Amrovan	Atary	Ebrahim Abad	Ali Abad	Royan
Y factor	49.1	84	92	49.1	10.1
Xa factor	73	6	6	6	6
I factor	114	16	293	162	240
ψ factor	92	41	39	41	39
Z factor	369.1	408	517	727	581
T factor	17.1	16.1	16.1	17.1	16.1
Wsp ($m^3/km^2/y$)	5.1027	7.171	1.248	5.401	7.296
Ru	0.16	0.39	0.37	0.25	0.34
SSY ($t\ ha^{-1} year^{-1}$)	2.255	0.918	1.258	1.386	1.374
Rating Class	1	4	3	2	3