

# The application of the Water Erosion Prediction Project (WEPP) model for the estimation of runoff and sediment on a monthly time resolution

Abolghasem Akbari<sup>1</sup> · Leila Sedaei<sup>2</sup> · Mehdi Naderi<sup>2</sup> · Azizan Abu Samah<sup>3</sup> · Nazila Sedaei<sup>4</sup>

Received: 23 April 2014 / Accepted: 30 May 2015 / Published online: 13 June 2015  
© Springer-Verlag Berlin Heidelberg 2015

**Abstract** The Water Erosion Prediction Project (WEPP) model is utilized to simulate the sediment and runoff processes. According to previous studies, WEPP model provides impressive results in watersheds of diverse climates and scales. It is also capable of modeling the sediment transportation processes and consequently predicting subsequent deposition sites. In this study, the geo-spatial interface for WEPP (GeoWEPP) was employed as a GIS framework to extract the data required from the ASTER Global Digital Elevation Model (ASTER-GDEM) dataset which was subsequently used as the model input. The case study was based on monthly data consisting of average sediment and runoff estimation from the Emameh sub-basin, in northern Iran. The model estimations were validated through field measurements. Two statistical measures of co-efficiency including the Nash–Sutcliffe Efficiency (NSE), and the coefficient of determination ( $R^2$ ) were considered to evaluate how well the model predictions could explain the variability of observations in the field. The model performed favorably as corroborated by a reasonably high NSE of 0.99 and an  $R^2$  value of 0.92 for sediment. In the case of runoff, the results were slightly

inferior, but still acceptable with an NSE of 0.76 and  $R^2$  value of 0.62.

**Keywords** ASTER-GDEM · Emameh · Runoff · Sediment · WEPP

## Introduction

From a hydrological perspective, erosion is the process whereby particles are detached from the soil surface in one place, transported by surface runoff, and deposited in another distinct location (Julien 2010). The driving forces in sediment transportation are predominantly wind, water or ice. For this motive, erosion is often classified into three corresponding categories: wind, water and ice erosion (Refahi 1996). Investigation on erosion was notably conducted by Ellison (1944) with a preliminary study of the mechanical effects of rain drops on soil particles. He demonstrated that rain drops can give rise to extensive soil erosion, which in turn can be further augmented due to lack of kinetic energy absorbing vegetation. Another noteworthy study is by Wischmeier et al. (1971), who conducted analytical studies in the United States to seek a relationship focused on erosion of farmland and construction sites. In the same year many further studies were carried out but at a regional level and the results were not applicable for large areas. Ella (2005) used the WEPP model to simulate erosion and sediment on hill slope environments located in small upland watersheds. His investigation was orientated towards establishing a relationship between vegetation cover and erosion in this specific terrain. He demonstrated that vegetation cover gives rise to the reduction of runoff and soil erosion. Flanagan and Nearing (1995) undertook a research on the Piracicaba River, Brazil, and evaluated the

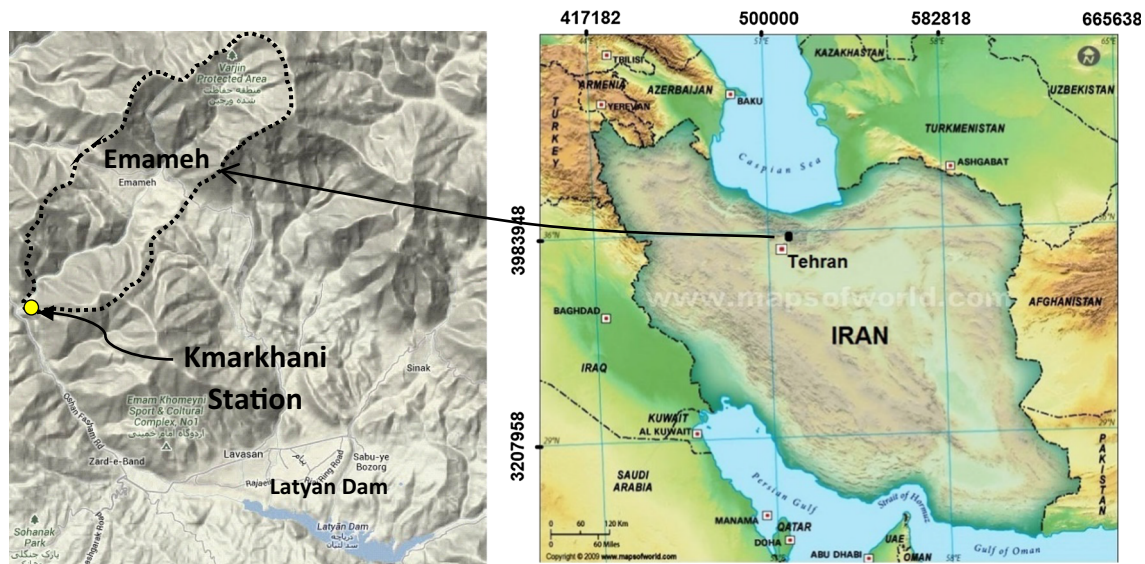
✉ Abolghasem Akbari  
akbariinbox@yahoo.com; akbari@ump.edu.my

<sup>1</sup> Faculty of Civil engineering and Earth Resources, University Malaysia Pahang, Gambang, Kuantan, Malaysia

<sup>2</sup> Faculty of Natural Resources, Shahrekord University, Shahrekord, Iran

<sup>3</sup> NARC and IOES, University Malaya, Kuala Lumpur, Malaysia

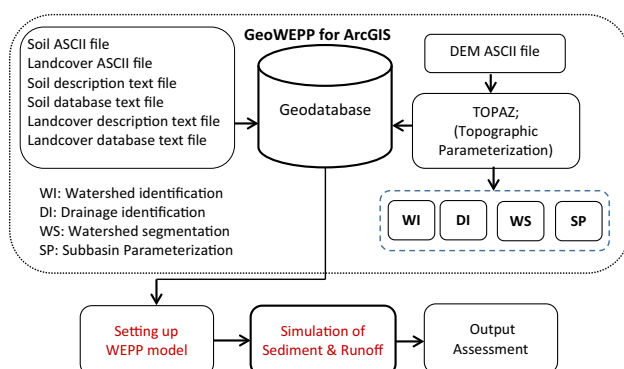
<sup>4</sup> Faculty of Natural Resources, Sari Agricultural Sciences and Natural Resources University, Sari, Iran



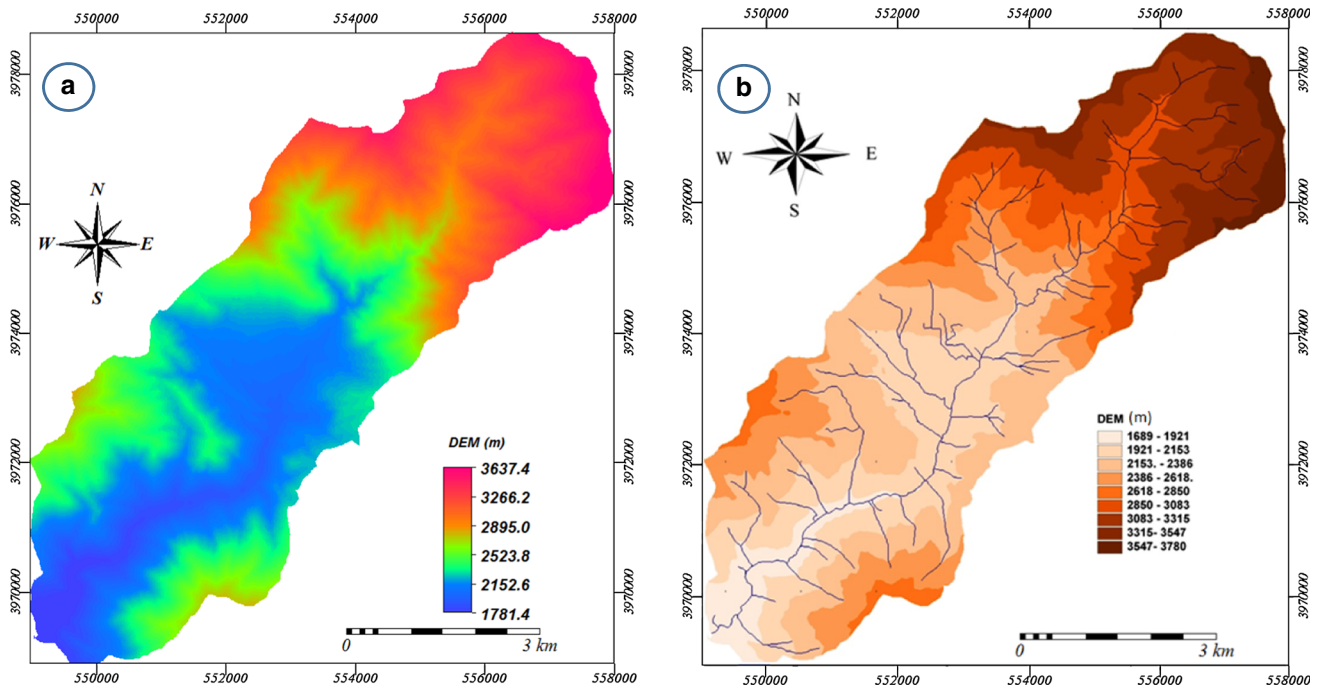
**Fig. 1** Layout of the study area, Emameh watershed in North-West of Tehran, Iran

estimation of three methods including Cs, Universal Soil Loss Equation (USLE), and WEPP by contrasting results with observed field data. That study was specifically undertaken to evaluate the amount of erosion and the temporal distribution of sediment, apart from investigating the influence of soil characteristics on soil erosion estimation using the aforementioned methods. The results show that these methods are mutually exclusive. Although these three methods are not accurate in the estimation of soil erosion, one had the highest correlation with soil characteristics. This can be attributed to the empirical parameter used (Sparovek et al. 2000). Stolpe (2005) evaluated three erosion methods including the Revised Universal Soil Loss Equation (RUSLE), the Environmental Policy Integrated Climate (EPIC) model and the WEPP model in the Mediterranean climate of Chile. He found that USLE and WEPP models provide the same accuracy in the estimation of erosion. Recently, RUSLE has been applied on landslide prevention in Greece (Rozos et al. 2013a, b).

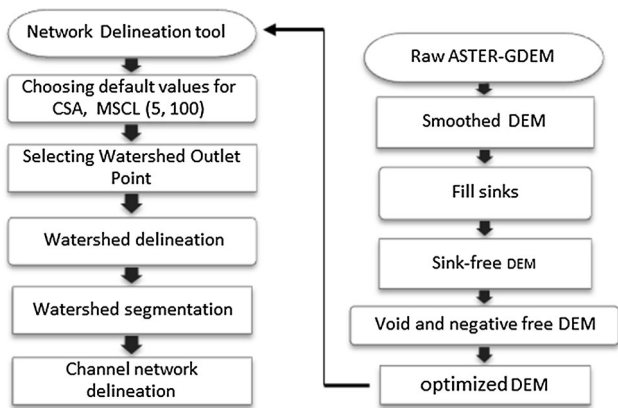
Amore et al. (2004) compared the output from WEPP and USLE in three Sicilian sub-basins at distinct spatial scales. They demonstrated that WEPP can estimate the amount of sediment similar to the measured deposited sediment in reservoirs. In addition, they confirmed that using two different scales do not have any significant effect on the estimation. In another case study, Bhuyan et al. (2002) employed three erosion models including EPIC, WEPP and the Areal Nonpoint Source Watershed Environment Response Simulation model (ANSWERS) in a 1-year period for small plots with tillage. Each model was calibrated with the most sensitive parameters using measured data. This research show that in the row and second tillage systems the ANSWERS and WEPP models are more reliable than the EPIC model. In the case of a non-tillage system, WEPP and EPIC had a superior prediction as compared to that from ANSWERS. Bhuyan et al. (2002) concluded that a more precise and realistic prediction can be achieved for soil loss using the WEPP model when compared to the two other models. In a further study, Baigorria and Romero (2007) developed erosion risk and runoff model in Peru by integrating the geospatial information system (GIS) tools into the WEPP model and named it as GEospatial Modeling of Soil Erosion (GEMSE). Later, Defersha et al. (2012) tested two physical models including WEPP and Erosion 3D, to predict sediment and runoff responses at a watershed scale. Results of this study indicated that both the WEPP and Erosion 3D models are useful tools for watershed scale application in the estimation of runoff and sediment yield. However, in another study by Defersha et al. (2012), they conclude that both models perform well in the estimation of runoff. Nevertheless, the WEPP model performs better than



**Fig. 2** Conceptual representation of research work



**Fig. 3** a The ASTER-GDEM of study area. b Stream network delineated by TOPAZ



**Fig. 4** Workflow of DEM optimization and channel network delineation

Erosion 3D in the estimation of soil erosion. More recently, Mahmoodabadi and Cerdà (2013) compared WEPP results with observation data at a plot scale for arid and semi-arid terrain. They conclude that the model tends to overestimate the lower, but underestimate the higher erosion rates. Singh et al. (2011) compared the WEPP result with field data and found that WEPP underestimates the erosion rates, especially when subjected to rill erosion on steep slopes.

Execution of the WEPP model was also contrasted with ANSWERS and EPIC (Bhuyan et al. 2002), SWAT (Shen et al. 2009) and Erosion 3D (Defersha and Melesse 2012). They found that the performance of the WEPP model is similar to ANSWERS and Erosion 3D, and notably superior

to EPIC and SWAT in sediment yield estimation. Pandey et al. (2008) used WEPP in Indian semi-tropical conditions by calibrating and validating with historical hydrologic data in a small agricultural watershed with medium slope conditions and annual precipitation of the order of 1300 mm. Sediment yield is highly dependent on the soil erodibility. Geospatial comparison of the soil erodibility has been addressed by Adhikary et al. (2014) using four different models in a semi-arid region of Central India. The geomorphological aspect of the soil is another important aspect in soil erosion and sediment yield (Magliulo 2012). The related studies on geomorphological aspects of watershed, GIS application in soil erosion and mass movement can be found in the studies carried out by Mhangara et al. (2012), Bathrellos et al. (2012) and Chousianitis et al. (2014). The objective of this study is to estimate runoff and soil erosion in the Emameh sub-basin in northern Iran using WEPP coupled with the ArcGIS platform.

## Methodology

### Study area

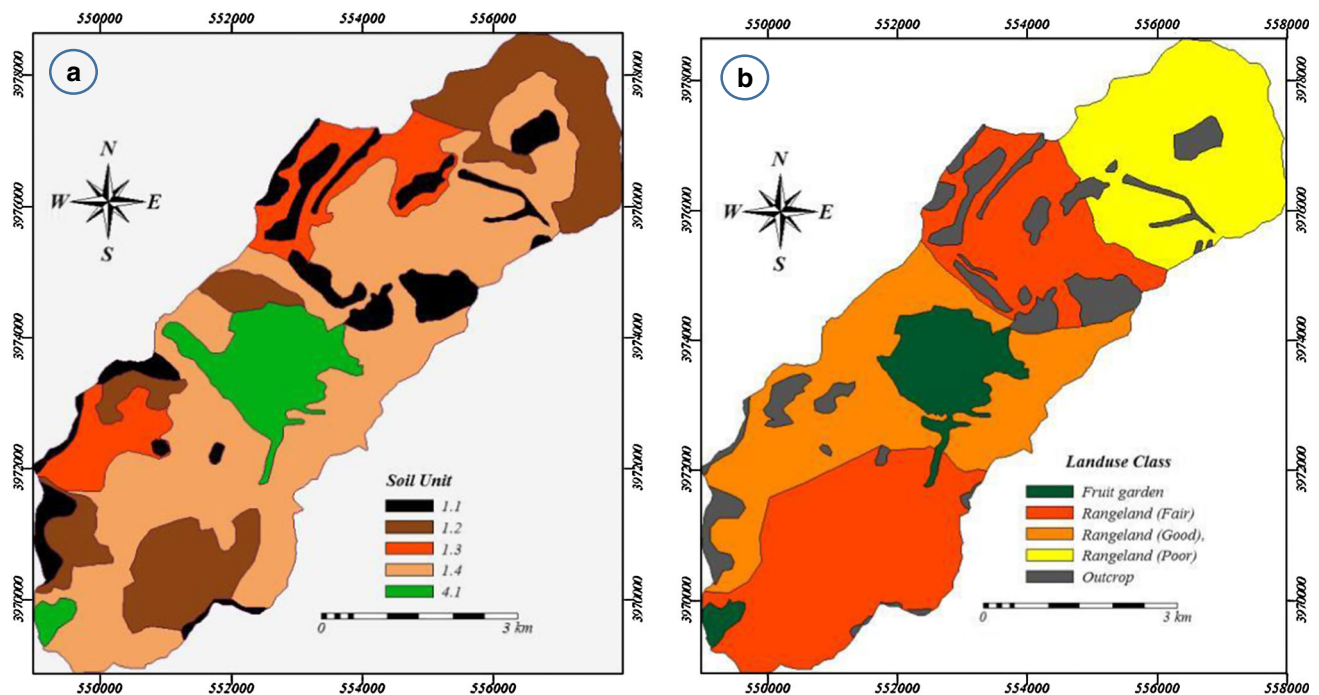
Emameh is a representative sub-basin for the Latyan Dam watershed located between 35°57'05"–35°49'10"N and 51°38'40"–51°31'30"E in northern Iran. (see Fig. 1). The watershed area is about 37.2 km<sup>2</sup> at a junction to the Jajroud River. Elevation ranges from 1781 m at the outlet to

**Table 1** Climatological data from the Emameh watershed

Parameters	Jun	Feb	Mar	Apr	May	Jan	Jul	Aug	Sep	Oct	Nov	Dec
$P$ (W/W) <sup>a</sup>	0.41	0.41	0.50	0.53	0.35	0.38	0.53	0.45	0.00	0.63	0.52	0.48
$P$ (W/D) <sup>b</sup>	0.08	0.21	0.21	0.23	0.25	0.38	0.05	0.04	0.01	0.08	0.13	0.25
Mean rainfall in wet days (mm)	3.56	11.18	13.21	16.00	7.37	0.25	6.35	8.38	1.78	8.64	10.92	9.65
Mean rainfall (mm)	10.67	78.23	118.87	144.00	58.93	9.40	12.70	16.76	0.00	43.18	65.53	96.52
Number of wet days	3.00	7.00	9.00	9.00	8.00	75.18	2.00	2.00	0.00	5.00	6.00	10.00
Std (rainfall)	0.09	0.37	0.52	0.63	0.22	8.00	0.22	0.18	0.01	0.23	0.42	0.32
Mean min temperature (°C)	13.91	-6.78	-0.97	3.65	8.78	-10.16	17.24	15.91	11.03	7.13	-1.18	-7.14
Std ( $T_{\min}$ )	4.89	5.86	6.75	6.13	5.56	8.03	4.73	3.53	5.45	4.54	8.91	7.06
Mean max temperature (°C)	27.89	6.52	10.47	15.29	20.89	4.36	3.59	29.26	25.59	20.05	10.56	5.57
Std ( $T_{\max}$ )	5.91	6.50	7.59	9.01	6.48	6.52	5.12	4.50	6.34	6.81	7.66	8.10
Dew-point temperature (°C)	16.70	-4.12	2.32	5.98	11.20	-7.26	19.92	18.58	13.94	9.71	1.17	-4.59
Solar radiation (Langley/day)	729.0	399.0	516.0	628.0	7.1	291.0	648.0	603.0	556.0	439.0	334.0	271.0

<sup>a</sup> Probability of one wet day after wet day

<sup>b</sup> Probability of one dry day after wet day



**Fig. 5** **a** Soil units (*Unit 1.1* represent mountain with steep slope, *Unit 1.2* sandy loam with moderate depth and steep slope, *Unit 1.3* sandy clay loam with deep soil and moderate slope, *Unit 1.4* Clay

loam with very deep soil and gentle slope, *Unit 4.1* silty clay and gentle slope) and **b** landuse class of Emameh watershed

3870 m at the headwaters (reference to the international datum WGS84). The main channel length is about 13 km, displaying a mean slope of 9.2 % (Nahvi 1994). The Kamarkhani streamflow station is situated at the mouth of the Emameh sub-basin.

For better consideration of the methodology involved in this study, a short description of the data set and workflow is provided as follows.

Firstly, Geodatabase including Soli, Landcover and Digital Elevation Model (DEM) derivations are generated using ArcGIS10.1 platform. Watershed delineation and parametrization was performed based on high-resolution satellite-based DEM data and GIS tools and techniques. DEM optimization process is then carried out to generate agree-DEM which robust automated watershed delineation process. The WEPP model is then set up based on the field

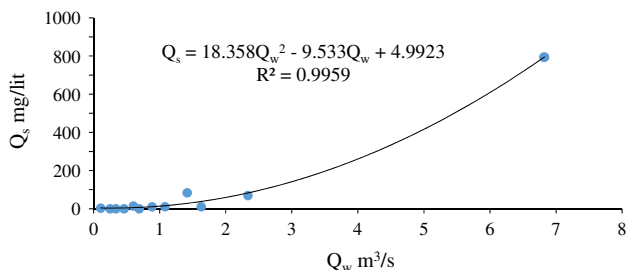
measurements and estimated parameters to simulate sediment and runoff simulation in Emameh watershed. Conceptual representation of undertaking study in Emameh watershed is shown in Fig. 2. Further details of the workflow are provided in the following.

**GeoWEPP**

GeoWEPP is the geospatial interface for WEP. It is a collaborative project conducted by the Agriculture Research Service at Purdue University, and the USDA National Soil Erosion Research Laboratory (Minkowski and Renschler 2012). GeoWEPP uses GIS data to delineate watersheds used in WEPP. GeoWEPP was developed to run using ESRI’s ArcGIS, and for this motive ArcGIS and the associated Spatial Analyst extension are required to delineate basins. To predict sediment yield and runoff at watershed scale, GeoWEPP integrates the WEPP model and Topography Parameterization (TOPAZ) software within the ArcGIS environment. In GeoWEPP, the requisite input files include land cover, landuse, slope, climate, soil, and land management data. In TOPAZ the channel networks are generated based on two key factors, namely the minimum source channel length (MSCL) and the critical source area (CSA). Both of these parameters are dependent on the resolution of the DEM. According to Minkowski and Renschler (2012), the default value for CSA is 5 ha, and 100 m for MSCL. Referring to Zhang et al. (2009) and Yüksel et al. (2008), and considering the DEM resolution which is 30 m in this case, the MSCL was selected to be 100 m and the CSA was set at 5 ha. The lower these values, the greater the time required to run the process, with the added disadvantage of larger output files. Nevertheless, in areas of slight relief, or urban areas, higher resolutions are desirable to minimize errors.

**Theoretical background of WEPP**

The WEPP model uses the continuity equation in a steady state for the estimation of sediment load. The erosion modeling of hillslopes using the WEPP model has been



**Fig. 6** Sediment rating curve of Kamarkhani station

**Table 2** Monthly observed and predicted sediment yield and runoff in Emameh sub-basin (1998–2008)

Month	Sediment yield (kg/ha)		Runoff (m³)	
	Observed	Predicted	Observed	Predicted
Jun	83.79	38.03	3,728,700	728,700
Feb	19.91	0.17	2,718,516	2,018,516
Mar	312.47	365.62	7,132,000	4,158,700
Apr	0.64	0.05	312,600	523,490
May	0.39	0.10	312,190	299,870
Jan	0.01	0.00	190,400	280,380
Jul	0.02	0.00	65,380	125,980
Aug	0.11	0.02	275,500	537,890
Sep	0.15	0.04	138,530	466,523
Oct	0.06	0.00	439,690	379,373
Nov	0.47	0.10	542,106	109,035
Dec	63.13	23.77	1,015,345	1,865,345
Annual	481.14	427.90	16,870,957	11,493,802

**Table 3** Statistical measures utilized in Emameh watershed

Statistical measure	R²	NSE
Sediment yield	0.99	0.92
Runoff	0.76	0.62

presented by Foster and Lane (1987). According to Flanagan et al. (2007), the daily sediment yield is computed using the instantaneous concentration and flow values as follows:

$$L = 0.0864 C Q, \tag{1}$$

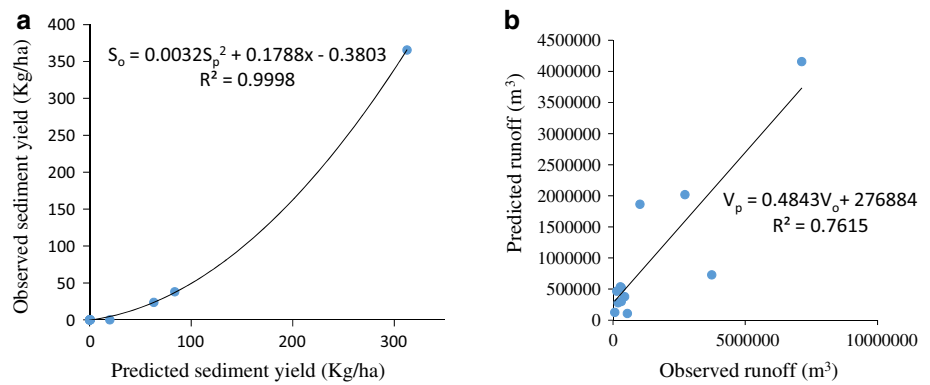
where  $L$  is the load in tonnes/day;  $C$  instantaneous concentration, in  $\text{mg l}^{-1}$ ; and  $Q$  instantaneous discharge, in  $\text{m}^3 \text{s}^{-1}$ . The 0.0864 constant is an empirical conversion factor for the transformation of sediment yield values from seconds to days and from milligrams to tonnes.

The annual and monthly sediment yield and runoff outputs from GeoWEPP are calculated to compare with the observed sediment yield and runoff. GeoWEPP uses the steady-state sediment continuity equation (Eq. 2) to estimate net detachment in hill slopes as follows:

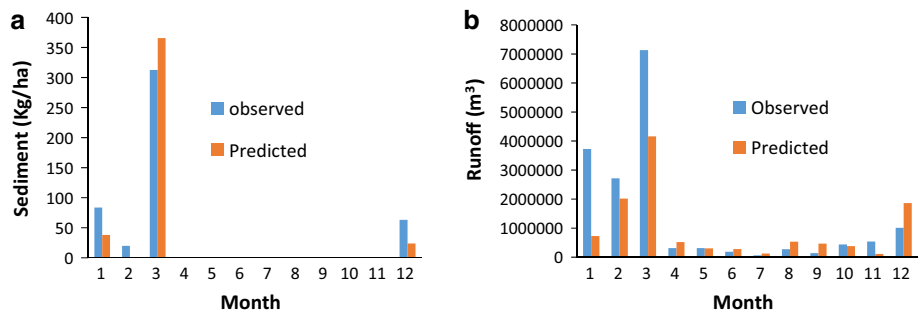
$$\frac{\partial G}{\partial x} = D_i + D_f, \tag{2}$$

where  $G$  is sediment load ( $\text{kg/m}^2/\text{s}$ ) at distance  $x$  from the origin of hill slope,  $x$  is distance down slope ( $m$ ),  $D_i$  is inter-rill sediment delivery rate to rill ( $\text{kg/m}^2/\text{s}$ ), and  $D_f$  is rill detachment rate ( $\text{kg/m}^2/\text{s}$ ),  $D_i$  is calculated based on Eq. 3.

**Fig. 7** The relation between estimated and observed sediment (a) and runoff (b)



**Fig. 8** Comparison between estimated and observed sediment (a) and runoff (b)



$$D_i = K_i I_e \sigma_{ir} SDR_{RR} F_{nozzle} \left[ \frac{R_s}{W} \right], \quad (3)$$

where  $K_i$  is adjusted inter-rill erodibility ( $\text{kg s/m}^4$ ),  $I_e$  is effective rainfall intensity ( $\text{mm/h}$ ),  $\sigma_{ir}$  is inter-rill runoff rate ( $\text{mm/h}$ ),  $SDR_{RR}$  is inter-rill sediment delivery ratio,  $F_{nozzle}$  is an adjustment factor for sprinkler irrigation nozzle impact energy variation,  $R_s$  is rill spacing ( $\text{m}$ ), and  $W$  is width of rill ( $\text{m}$ ). Rill detachment rate  $D_f$  is calculated using Eq. 4:

$$D_f = K_r (\tau_f - \tau_c) \left( 1 - \frac{G}{T_c} \right), \quad (4)$$

where  $K_r$  is an adjusted soil erodibility parameter ( $\text{s/m}$ ),  $\tau_f$  is flow shear stress ( $\text{kg/m/s}^2$ ),  $\tau_c$  is adjusted critical shear stress of the rill surface ( $\text{kg/m/s}^2$ ), and  $T_c$  is sediment transport capacity of the rill flow ( $\text{kg/m/s}$ ).  $T_c$  is defined by Eq. 5:

$$T_c = K_{tr} q_w s, \quad (5)$$

where  $K_{tr}$  is constant parameter,  $q_w$  is flow discharge per unit width ( $\text{m}^2/\text{s}$ ), and  $s$  is the slope in percent (%). Finally, the rill detachment rate is calculated using Eq. 6:

$$\frac{\partial G}{\partial x} = D_f = \frac{\beta_r V_f}{q} (T_c - G) + D_i, \quad (6)$$

where  $V_f$  is the effective fall velocity of the sediment ( $\text{m/s}$ ) and  $\beta_r$  is the raindrop induced turbulence coefficient which has a range from 0 to 1.

## Dem digital elevation

The Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) known as Global Digital Elevation Model (ASTER-GDEM) (JSS 2012) is the best freely available elevation data set which are suitable for hydrological and geo-hazards studies (Akbi et al. 2012). In this study, ASTER-GDEM version 2 provided by NASA was used to generate the slope profile and other physical factors (see Fig. 2a). ASTER-GDEM v2 has a spatial resolution of 28 m per pixel. This data is in public domain and free of charge which was released by NASA (<http://reverb.echo.nasa.gov>) in October 2011. Raw DEM for the study area is shown in Fig. 3a and stream network delineated by TOPAZ in Fig. 3b.

The GeoWEPP model functions as a distributed model, i.e., the amount of sediment and runoff is calculated for each pixel individually. The model outputs are obtained in grid and text file format. The workflow for DEM optimization and channel identification is presented in Fig. 4.

## WEPP inputs

To process hillslope geometry, meteorological characteristics, soil properties, and land cover, the WEPP model employs four input files that include slope, climate, soil, and management files.

### Slope profile editing window

The slope file is generated based on the necessary hillslope parameters such as slope gradient, shape, width and orientation along its length. GeoWEPP employs TOPAZ for watershed parameterization. The sub-watersheds and channels were derived from 28 m resolution of ASTER-GDEM version 2.

### Climate data

The WEPP model uses CLIGEN (Climate Generator), which is a stochastic weather generation model (Min et al. 2011) to produce climate data files containing daily rainfall, temperature, solar radiation, and wind speed obtained from synoptic stations. To generate climate data, “Rock: Clime”, the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database is used which estimates rainfall and temperature based on orographic effects (Daly et al. 1994). In “Rock: Clime”, the inputs of monthly mean rainfall and temperature values can be adjusted. For this investigation, the climatological dataset including maximum and minimum air temperature, relative humidity, rainfall, solar radiation, and wind speed listed in Table 1, were obtained from Iranian Water Resources Management Company.

### Soil map and landuse

Soil properties of the study area do not exist in WEPP template tables. Therefore, it has to be keyed in by the user. Accurate representation of soil properties in WEPP is essential for estimating sediment yield and runoff. Critical parameters in the soil file are: soil texture, albedo, saturation level, hydraulic conductivity, rill erodibility, inter-rill erodibility, and critical shear (Yüksel et al. 2008). These parameters are obtained from field data collection or calculated by the WEPP model. In this study, soil parameters were measured based on a soil map and previous soil sampling reports from the Emameh basin. Land units were delineated using existing soil map generated by Research Institute for Soil and Water. Required soil information for the WEPP was obtained by soil sampling in the field by taking five samples from each land unit. Figure 5 shows the soil sampling for measuring bulk density of soil in Emameh basin.

The values of the other properties such as rill and inter-rill erodibility, critical shear, and hydraulic conductivity were calculated by WEPP model. The Green-Ampt effective hydraulic conductivity equation is used to estimate hydraulic conductivity based on rainfall amount, surface cover, and runoff. Rill and inter-rill erodibility values can be determined depending on the sediment delivery

equation in WEPP v2008.5. The soil unit map is obtained from the Research Institute for Soil and Water, Iran (See Fig. 5a). The landuse for the study were generated using Land Sat TM and aerial photo and field checking using handheld GPS.

Soil file for the WEPP models were generated based on five soil samples taken from each land units (see Appendix, Table 4). The sample was analyzed in soil laboratory and the necessary parameters were obtained.

### Management file

The landuse is indicated in the management file and based on growth and mortality parameters. In this study, the necessary management file data (i.e., the amount of vegetation, tuff, litter, and woody debris) were obtained by field measurements and then entered into WEPP. The management file was generated for different landuse types (i.e., rangeland and rock), for each sub-watershed, and for every year of simulation. Based on the grass cover density, rangelands were assigned in 3 classes including poor, fair and good. Poor indicates grass density <25 %, fair indicates grass density greater than 25 % and less than 75 % and good indicate grass density greater than 75 %. Classified landuse map was obtained from the Natural Resources and Watershed Management Organization, Tehran (see Fig. 5b).

## Results and discussion

Generally, the erosion assessment and the hazards assessment are useful tools for urban and regional planning (Bathrellos et al. 2012, 2013; Papadopoulou-Vrynioti et al. 2013; Chousianitis et al. 2014). In this research the WEPP model coupled with the GeoWEPP were used to estimate sediment yield and runoff discharge in the Emameh sub-basin. Predicted sediment and runoff were compared with observed data. Sediment load of rivers including suspended sediment and bed load are produced by erosion, physical destruction and chemical weathering of stones, etc. The most important factors of sediment load in the Emameh watershed are heavy precipitation, the high erodibility of river beds and banks, steep slopes, poor vegetation cover, and geological formations. Bed load sediment estimation (tonne/day) was made based on the relationship between the available rating curve of discharge ( $\text{m}^3/\text{s}$ ) and suspended sediment concentration  $\text{mg l}^{-1}$  (see Fig. 6).

Monthly simulation of sediment yield and runoff was successfully performed in the Emameh watershed and then compared with observed data (see Table 2). By considering the monthly average sediment yield (74 kg ha) and the area

of the Emameh sub-basin (3720 ha), the total annual sediment yield is estimated at 3303.36 tonnes.

Statistical measures are employed to assess the practical use of WEPP model. Based on two statistical measures, Table 3 illustrates the strength of the prediction power of the WEPP model for the monthly simulation of sediment and runoff at Kamarkhani hydrometric station.

### Statistical measures

The accuracy of the model was assessed based on two statistical indices; the Nash–Sutcliffe Efficiency (NSE) (Nash and Sutcliffe 1970), and R-squared coefficient under the essential assumption that distribution of used data follows a normal distribution. The NS Efficiency coefficient is defined by Eq. 7. NSE varies from negative infinity to unity. Value closer to unity shows closer agreement between the estimated and observed data.

$$\text{NSE} = 1 - \left( \frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \right), \quad (7)$$

where  $P_i$  is the predicted sediment yield and run off for each month,  $O_i$  the observed sediment yield and runoff in each month,  $\bar{O}$  the mean observed sediment yield and runoff in each month.

The second statistical measure is the coefficient of determination denoted  $R^2$ . It indicates how well data points fit a statistical model. It is a statistic indicator which is frequently used in the context of statistical models whose main purpose is either the prediction of future outcomes or the testing of hypotheses, on the basis of other related information. It provides a measure of how well observed outcomes are replicated by the model, as the proportion of total variation of outcomes explained by the model (Steel and Torrie 1960). The coefficient of determination ranges from 0 to 1. The  $R^2$  is defined by Eq. 8.

$$R^2 = \left( \frac{n \sum P_i O_i - \sum O_i \sum P_i}{\sqrt{n \sum O_i^2 - (\sum O_i)^2} \times \sqrt{n \sum P_i^2 - (\sum P_i)^2}} \right)^2 \quad (8)$$

According to the Eqs. 7 and 8 capability of WEPP in runoff and sediment yield prediction were assessed based on the observed data.

$R^2$  shows a dispersal rate between the estimated and observed data. If they were equal, this factor would be 1. The results demonstrate a strong correlation between the

estimates. The NSE, which shows the relative difference between predicted and observed data, was positive. This indicator also shows a significant agreement between the predicted and observed sediment yield in the watershed; however, some discrepancy is observed for runoff which may be associated with the numerous springs located in the upstream on the watershed that drains into the main river. The relation between the estimated and observed data is shown in Figs. 7 and 8.

### Conclusion

Results from the WEPP model shows that significant correlation exists between the estimated and observed sediment yield based on the R-squared value (0.99) and the NSE (0.92) in Emameh watershed. However, runoff shows relatively low correlations of 0.76 and 0.62 for  $R^2$  and NSE, respectively. The low correlation is highly due to the contribution from the numerous springs in the basin that drains into the principal channel, thereby somewhat undermining the runoff estimation. In general, it is clear that the GeoWEPP model can assist watershed-related management institutions to generate quality predictions rapidly and quickly for sediment yield and runoff in textual or graphical format based on the digital database of the watershed. Moreover, the model provides information about the areas that have a high potential sediment delivery. As such, watershed management and conservation projects can be well oriented to minimize sediment yield and flood runoff.

The WEPP model is also capable of evaluating the strategies of vegetation residuals, pedogenesis system, border places and grazing management under potential water erosion.

As a result of this study and considering other referenced works, the WEPP model is found to have high degree of adaptability within diverse climatic conditions and distinct morphologies.

**Acknowledgments** The authors acknowledge and thank Dr Jonathan Peter Cox and Mr See Hai Ooi for valuable help in editing and improving the English of manuscript. We also wish to thank University Malaysia Pahang for supporting this work through the grant number RDU14359.

### Appendix

See Appendix Tables 4, 5, 6, and 7



**Table 4** Soil parameters obtained by soil sampling from the field required for the WEPP model

Profile no.	Soil horizon	Depth (mm)	SSG <sup>b</sup> (%)	CEC <sup>a</sup> (mq/100 g)	Organic matter (%)	Clay (%)	Sand (%)
1	A	100	45	40	2.5	18.8	62
2	A	250	30	35	1.5	13.6	64.4
	C	350	35	30	0.75	10	70
3	A	160	33	50	3.69	10.8	52
	B	260	39	45	2.5	20.8	60
	C	380	42	1.5	1	22.8	36
4	A	400	4.5	69	0.95	35	29
	B	550	5.5	73	0.8	36	36
	C	750	12	55	0.75	36	40
5	A	250	18	45	2.1	20	45
	B	650	15	35	1.9	14	67
	C	750	22	20	1.5	12	50

<sup>a</sup> Cation exchange capacity

<sup>b</sup> Soil surface gravel

**Table 5** Channel summary (watershed method, off-site assessment) for the first 20 records

Channels			Discharge volume (m <sup>3</sup> /year)	Soil loss (tonne/year)	Sediment Yield (tonne/year)	Length (m)	Length (cells)
NUM	WEPP	TOPAZ					
1	45	1014	58,300	n.a.	0.8	367.3	11
2	44	1024	75,150	n.a.	1.7	789.4	23
3	47	994	63,900	n.a.	1.8	332.1	9
4	41	1054	78,100	n.a.	2.4	422.1	12
5	50	964	61,850	n.a.	1.5	664.3	18
6	40	1064	85,650	n.a.	1.7	392.1	11
7	39	1074	80,550	n.a.	1.6	187.3	5
8	36	1104	90,750	n.a.	2.2	349.7	10
9	77	694	52,600	n.a.	2.3	454.3	11
10	53	934	148,500	n.a.	3.3	669.4	19
11	34	1124	43,700	n.a.	0.6	247.3	7
12	78	684	27,500	n.a.	0.2	252.4	8
13	73	734	72,450	n.a.	1.4	289.7	8
14	33	1134	84,650	n.a.	1.6	434.6	12
15	80	664	117,150	n.a.	3.2	289.7	8
16	72	744	43,200	n.a.	1	187.3	5
17	75	714	39,000	n.a.	0.8	174.9	5
18	32	1144	134,100	n.a.	3.4	1211.5	35
19	63	834	193,950	n.a.	8.6	1017	31
20	82	644	45,700	n.a.	0.6	204.9	6

**Table 6** Flowpath summary (flowpath method, on-site assessment) for the first 20 records

Hillslopes		Runoff volume (m <sup>3</sup> /year)	Soil loss (tonne/year)	Sediment yield (tonne/year)	Area (ha)	Soil loss (tonne/ha/year)	Sediment yield (tonne/ha/year)
WEPP	TOPAZ						
1	22	51,850	2	n.a.	8.9	0.22	n.a.
2	23	75,950	4	n.a.	8.5	0.47	n.a.
3	32	53,650	2	n.a.	11	0.18	n.a.
4	33	145,900	15	n.a.	20.2	0.74	n.a.
5	42	138,600	9	n.a.	23.9	0.38	n.a.
6	43	102,950	15	n.a.	11.5	1.3	n.a.
7	52	64,700	10	n.a.	7.4	1.35	n.a.
8	53	57,550	9	n.a.	4.3	2.09	n.a.
9	61	54,500	7	n.a.	12.7	0.55	n.a.
10	63	30,400	8	n.a.	3.7	2.16	n.a.
11	62	69,200	9	n.a.	8.8	1.02	n.a.
12	73	145,600	16	n.a.	12.3	1.3	n.a.
13	72	222,500	27	n.a.	23.4	1.15	n.a.
14	81	66,200	4	n.a.	14	0.29	n.a.
15	83	39,100	4	n.a.	2.7	1.48	n.a.
16	82	21,050	1	n.a.	3.6	0.28	n.a.
17	91	65,200	5	n.a.	11.2	0.45	n.a.
18	92	15,200	1	n.a.	0.9	1.11	n.a.
19	93	14,000	1	n.a.	1.1	0.91	n.a.
20	102	159,450	22	n.a.	22	1	n.a.

**Table 7** WEPP watershed simulation for representative hillslopes and channels for the first 20 records

Hillslopes		Runoff volume (m <sup>3</sup> )	Soil loss (kg)	Sediment yield (kg)
Hill	1	45,115	469.78	469.78
Hill	2	44,920	189.06	189.06
Hill	3	38,600	822.15	822.11
Hill	4	0	0	0
Hill	5	0	0	0
Hill	6	48,925	3089.95	3089.88
Hill	7	28,150	418.12	418.12
Hill	8	32,095	575.3	575.31
Hill	9	0	0	0
Hill	10	41,940	550.15	550.15
Hill	11	30,300	1011.1	1011.07
Hill	12	83,860	807.95	807.96
Hill	13	107,315	5922.5	5922.46
Hill	14	0	0	0
Hill	15	19,735	339	339
Hill	16	20,505	220.74	220.73
Hill	17	0	0	0
Hill	18	26,585	107.36	107.36
Hill	19	23,525	139.8	139.8
Hill	20	0	0	0

## References

- Adhikary PP, Tiwari S, Mandal D, Lakaria BL, Madhu M (2014) Geospatial comparison of four models to predict soil erodibility in a semi-arid region of Central India. *Environ Earth Sci* 72:5049–5062
- Akbari A, Abu Samah A, Othman F (2012) Integration of SRTM and TRMM data into the GIS-based hydrological model for the purpose of flood modelling. *Hydrol Earth Syst Sci Discuss* 9:4747–4775
- Amore E, Modica C, Nearing MA, Santoro VC (2004) Scale effect in USLE and WEPP application for soil erosion computation from three Sicilian basins. *J Hydrol* 293:100–114
- Baigorria GA, Romero CC (2007) Assessment of erosion hotspots in a watershed: integrating the WEPP model and GIS in a case study in the Peruvian Andes. *Environ Model Softw* 22:1175–1183
- Bathrellos GD, Gaki-Papanastassiou K, Skilodimou HD, Papanastassiou D, Chousianitis KG (2012) Potential suitability for urban planning and industry development by using natural hazard maps and geological–geomorphological parameters. *Environ Earth Sci* 66(2):537–548
- Bathrellos GD, Gaki-Papanastassiou K, Skilodimou HD, Skianis GA, Chousianitis KG (2013) Assessment of rural community and agricultural development using geomorphological–geological factors and GIS in the Trikala prefecture (Central Greece). *Stoch Environ Res Risk Assess* 27(2):573–588
- Bhuyan SJ, Kalita PK, Janssen KA, Barnes PL (2002) Soil loss predictions with three erosion simulation models. *Environ Model Softw* 17:135–144
- Chousianitis K, Del Gaudio V, Kalogeras I, Ganas A (2014) Predictive model of Arias intensity and New mark displacement for regional scale evaluation of earthquake-induced landslide hazard in Greece. *Soil Dyn Earthq Eng* 65:11–29
- Daly C, Neilson RP, Phillips DL (1994) A statistical topographic model for mapping climatological precipitation over mountainous terrain. *J Appl Meteorol* 33:140–158
- Defersha MB, Melesse AM (2012) Field-scale investigation of the effect of landuse on sediment yield and runoff using runoff plot data and models in the Mara River basin, Kenya. *Catena* 89:54–64
- Defersha MB, Melesse AM, McClain ME (2012) Watershed scale application of WEPP and EROSION 3D models for assessment of potential sediment source areas and runoff flux in the Mara River Basin, Kenya. *Catena* 95:63–72
- Ella VB (2005) Simulating soil erosion and sediment yield in small upland watersheds using the WEPP model. In: Coxhead I, Shively GE (eds) *Landuse change in tropical watersheds: evidence, causes and remedies*. CABI Publishing, CAB International, Oxfordshire
- Ellison WD (1944) Studies of raindrop erosion. *Agric Eng* 25:131–136
- Flanagan D, Nearing M (1995) USDA-water erosion prediction project: hillslope profile and watershed model documentation. NSERL Report No. 10. USDA-ARS National Erosion Research Laboratory, Indiana
- Flanagan DC, Gilley JE, Franti TG (2007) Water Erosion Prediction Project (WEPP): development history, model capabilities, and future enhancements. *Trans ASABE* 50(5):1603–1612
- Foster GR, Lane LJ (1987) User requirements: USDA Water Erosion Prediction Project (WEPP). NSERL Laboratory, USDA-ARS National Soil Erosion Research, West Lafayette
- JSS (2012) ASTER GDEM Version 2 (Online). <http://gdem.ersdac.jp/spaceystems.or.jp/>. Accessed May 2012
- Julien PY (2010) *Erosion and sedimentation*. Cambridge University Press, UK
- Magliulo P (2012) Assessing the susceptibility to water-induced soil erosion using a geomorphological, bivariate statistics-based approach. *Environ Earth Sci* 67:1801–1820
- Mahmoodabadi M, Cerdà A (2013) WEPP calibration for improved predictions of interrill erosion in semi-arid to arid environments. *Geoderma* 204:75–83
- Mhangara P, Kakembo V, Lim KJ (2012) Soil erosion risk assessment of the Keiskamma catchment, South Africa using GIS and remote sensing. *Environ Earth Sci* 65(7):2087–2102
- Min Y-M, Kryjov VN, An K-H, Hameed SN, Sohn S-J, Lee W-J, Oh J-H (2011) Evaluation of the weather generator CLIGEN with daily precipitation characteristics in Korea. *Asia-Pac J Atmospheric Sci* 47:255–263
- Minkowski M, Renschler C (2012) *GeoWEPP for ArcGIS 9.x Full Version Manual*. Department of Geography State University of New York at Buffalo
- Nahvi H (1994) Estimation of CN in Emmameh Watershed. Master Degree, University Of Tehran
- Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part I—a discussion of principles. *J Hydrol* 10:282–290
- Pandey A, Chowdary V, Mal B, Billib M (2008) Runoff and sediment yield modeling from a small agricultural watershed in India using the WEPP model. *J Hydrol* 348:305–319
- Papadopoulou-Vrynioti K, Bathrellos GD, Skilodimou HD, Kaviris G, Makropoulos K (2013) Karst collapse susceptibility mapping considering peak ground acceleration in a rapidly growing urban area. *Eng Geol* 158:77–88
- Refahi H (1996) *Water erosion and control*. University of Tehran, Tehran
- Rozos D, Bathrellos G, Skilodimou H (2013a) Comparison of the implementation of rock engineering system and analytic hierarchy process methods, upon landslide susceptibility mapping, using GIS: a case study from the Eastern Achaia County of Peloponnesus, Greece. *Environ Earth Sci* 63:49–63
- Rozos D, Skilodimou HD, Loupasakis C, Bathrellos GD (2013b) Application of the revised universal soil loss equation model on landslide prevention. An example from N. Euboea (Evia) Island, Greece. *Environ Earth Sci* 70(7):3255–3266
- Shen Z, Gong Y, Li Y, Hong Q, Xu L, Liu R (2009) A comparison of WEPP and SWAT for modeling soil erosion of the Zhangjia-chong Watershed in the Three Gorges Reservoir Area. *Agric Water Manag* 96:1435–1442
- Singh R, Panda R, Satapathy K, Ngachan S (2011) Simulation of runoff and sediment yield from a hilly watershed in the eastern Himalaya, India using the WEPP model. *J Hydrol* 405:261–276
- Sparovek G, Bacchi O, Schnug E, de Ranieri S, Maria I (2000) Comparison of three water erosion prediction methods (137Cs, WEPP, USLE) in south-east Brazilian sugarcane production. *J Agric Tropics Subtropics* 101:107–118
- Steel RGD, Torrie JH (1960) *Principles and procedures of statistics with special reference to the biological sciences*. McGraw Hill, New York
- Stolpe NB (2005) A comparison of the RUSLE, EPIC and WEPP erosion models as calibrated to climate and soil of south-central Chile. *Acta Agric Scandinavica Sect B-Soil Plant Sci* 55:2–8
- Wischmeier WH, Johnson CB, Cross BV (1971) A soil erodibility nomograph for farmland and construction sites. *J Soil Water Conserv* 26:189–193
- Yüksel A, Akay AE, Gundogan R, Cetiner MR (2008) Application of GeoWEPP for determining sediment yield and runoff in the Orcan creek watershed in Kahramanmaraş, Turkey. *Sensors* 8:1222–1236
- Zhang JX, Wu JQ, Chang K, Elliot WJ, Dun S (2009) Effects of DEM source and resolution on WEPP hydrologic and erosion simulation: a case study of two forest watersheds in northern Idaho. *Transac ASABE* 52:447–457