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Investigation of runoff and sediment yield using N-SPECT model in Pelasjan (Eskandari), Isfahan, Iran

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Abstract

Identifying and quantifying the runoff and Sediment yield are the necessary measures in the issues of soil erosion in a watershed. Pelasjan watershed located in West of Isfahan and it is one of the sub basins of Zayanderud which is taken as the study area. In this study the amount of runoff and Sediment yield has been evaluated using the Nonpoint-Source Pollution and Erosion Comparison Tools (N-SPECT) model which is an extension to ArcGIS software. The input layer maps in the GIS environment, including land use, the rain erosion, vegetation, soil erodibility, contour map and watershed boundary map were prepared. By entering the input data and running N-SPECT model, runoff and Sediment yield raster maps of the study area were obtained. To evaluate the model and data comparing, the values obtained from the model and the actual data values of runoff and Sediment yield were converted to the eigenvalues. Special amount of runoff from the model equals 1483 m3/ha/year and the actual runoff is equivalent to 1253 m3/ha/year for 21 water years ,from 1991 to 2012. From the values obtained by the model and the actual data it can be concluded that the model is sufficiently accurate for estimating runoff since the actual runoff value and the value obtained from the model are close to each other and statistically, there is no significant difference between them during this 21 water year. In relation to a Sediment yield, the amount obtained from the model was 7.8 ton/ha/year and the average amount of Sediment yield for 21 water years is 2.1 ton/ha/year, which by comparing with the values obtained for Sediment yield it can be concluded that the model overestimates about three times from the actual amount and there is a significant difference between the real data and data obtained by model so the model has not been very successful in Sediment yield estimating. One of the advantages of this model for estimating runoff and Sediment yield is point to point estimation of runoff and Sediment yield in output maps of the region. This model is particularly recommended for harsh and difficult access regions of the watershed.

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Introduction

If the economic value of the soil and its importance in human life to be considered, it will be revealed that this precious gem is the source of all basic necessities of human nature and all living beings and human life depend on it. Inappropriate uses of lands and natural resources which takes place as a result of agricultural practices, Deforestation, overgrazing of livestock in pastures and road construction results in disrupting the natural balance of the land and causes the loss of vegetation and soil fertility, and consequently can result in the loss of soil. Studies conducted during the last century showed an unreasonably increase of human population growth and the subsequent demand for food to meet the needs of the human population. Such a situation has led to the conscious or unconscious use of natural resources by human communities to meet their needs regardless of the surrounding natural environment. The lands have been used for traditional livestock grazing or cultivation and causes pressure on existing vegetation and it leads to increased levels of soil erosion in current and future time (Javadi *et al.,* 2011). The increasing erosion of large areas that are cultivated currently, may result in lost of soil fertility in the closed future. When runoff appeared on the surface and waterways, the quantity of material transported by runoff increases, thereby causing a reduction in carrying capacity. Finally, Sediment yield occurred and at the first Sediment yield of coarse particles starts and gradually fine particles is deposited to large distances. The sediment load of the watershed output accounts for a sediment yield (Jabari and Arefi, 2003).Estimation of erosion and Sediment yield and applying appropriate management practices in a watershed, as well as any other natural phenomenon requires an understanding of the factors affecting it.Since erosion and Sediment yield is one of the most complex natural processes and many factors are involved in it, the full knowledge of the factors influencing this phenomenon is very difficult (Ahmadi *et al.,* 2005). Zahabioun *et al.,* (2010) compared the performance of Modified Pacific Southwest Inter Agency Committee (MPSIAC) and erosion potential model (EPM) model in the estimation of erosion and Sediment yield of the Saghez Chay Namin watershed. This study aimed to assess the performance of the models and results showed that the sediment production is assessed 47 ton/ha/year by MPSIAC with an accuracy of 98 percent, while the sediment production is assessed 111 ton/ha/year by EPM model with accuracy of 74 percent.

Yesuf *et al.,* (2015) was studied sediment yield in Maybar gauged watershed using SWAT. The model evaluation statistics suggested that Soil and Water Assessment Tool (SWAT) extremely under-predicted peak sediment loads in both calibration and validation periods.

Nojavan *et al.,* (2012) using two models, burea land management (BLM) and Fargas, estimate the rate of erosion in the Bandareh watershed in the Azerbaijan Gobi province. Seven factors, including surface erosion, shallow rill erosion, sedimentation of streams and development of gully erosion were investigated and the results show the agreement between two models which used for erosion estimating. Sun and Cornish (2005) conducted a study about the discharge and Sediment yield rate of a river in the headwaters of Liverpool plains of Australia using SWAT model. The results showed that compared with other models, SWAT model has good predictive ability and better performance. Pandy *et al.,* (2008) in a study used Water Erosion Prediction Project (WEPP) Model for predicting water erosion in a small catchment with hills in Karsu, India. After entering the required parameters and model analysis, it concluded that WEEP model is a good model for the region and It can easily be used in other areas.

Hongya *et al.,* (2011) conducted a research on the characteristics of the sediments in areas with low and high erosion in Guizhou Plateau in southwest China. The purpose of this study was to elicit differences in the sources of sediment and erosion. In this study, soils from regions with high and low erosion were sampled and evaluated. Differences were found in sediments in these regions and the result was that in the regions with high erosion, soil materials were removed from the surface and subsurface layers while in the regions with low erosion, only rill erosion was occured and soil materials were removed only from the surface layers and subsurface layers was undisturbed. Mahmoodabadi *et al.,* (2014) carried out a research to develop a new method for the accurate determination of sediment transport capacity, according to the stream morphology and its relation with Sediment yield. Two models, Griffith University Erosion System Template (GUEST) and WEEP, were used for this purpose. The results showed that the influence of sediment transport capacity was better predicted by GUEST model compared to the WEEP model. GUEST model in predicting sediment transport capacity is expandable. Pelasjan is one of the important Subbasin of the Zayanderood watershed, which supplies, drinking water and required water for agricultural uses and industry in Isfahan city. So providing a model for estimating runoff and sediment in the sub basins of the watershed is important. The study aimed to estimate watershed runoff and Sediment yield in Pelasjan watershed using N-SPECT model.

Materials and methods

Description of the study area

The study was conducted in Pelasjan watershed, which is located between longitudes 50 °05" to 50 °40" East and latitudes 32 °10" to 32 °42" north, with an area of about 164570 square kilometers. It has an average elevation of about 2523 meters. The average annual rainfall is estimated about 460 mm and it has a semihumid climate (Fig. 1). The area is located in the mountainous region of the Zagros mountain and it is one of the highest areas of Iran in West of Zayanderud watershed. The watershed drained by two main rivers, Savaran and Buin, Savaran currents in the north and northeast of the area and Buin originates from West Mountain and currents in the western part of the watershed. Two mentioned rivers meet each other in the south of watershed and form Pelasjan river. There is a hydrometric station in the watershed named Eskandari so the Pelasjan watershed also known by the same name.

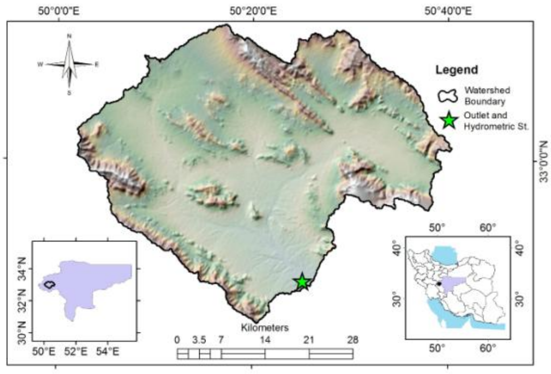

Fig. 1. Location map of the Pelasjan watershed in Isfahan, Iran.

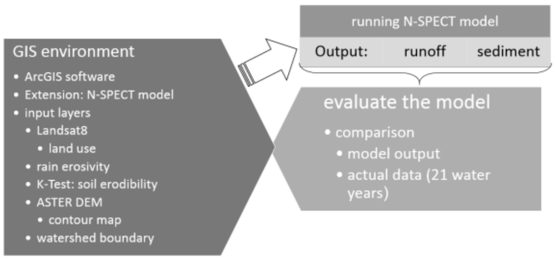

Fig. 2. Flowchart of the study.

N-SPECT model description

N-SPECT is a subset of Arc GIS software which is installed on it. This software is designed for all kinds of watersheds, but in the presence of all information needed for the software, N-SPECT is able to calculate water flow and its volume in a watershed using satellite data of area elevation. The information contained in this model is vegetation maps, elevation contours, isorain lines, hydrologic soil groups map, the coefficient k (erodibility coefficient) and the coefficient R (rainfall erosivity factor). After entering the information and running the model, two maps of the area's Sediment yield and runoff are the Output data.

methods

In order to run the model, the land use maps, Digital Elevation Model (DEM), soil erodibility factor, Hydrological groups, rain erosivity coefficient and watershed boundary maps were prepared and entered into N-SPECT software (Fig. 2).

The First step

Preparing Land use map

Land use map is one of the entries in the N-SPECT software, so the land use map was prepared in GIS environment. For land-use mapping, satellite imagery (Landsat 8, OLI: Operational Land Imager) and aerial photographs are used (Fig. 3).

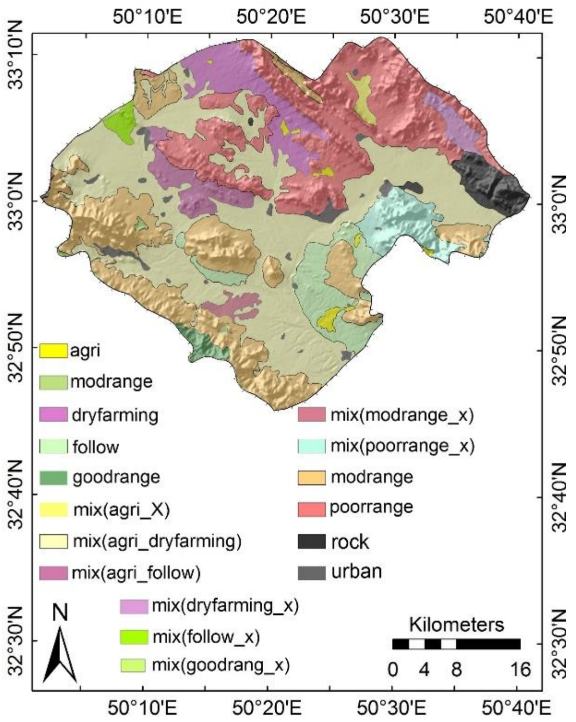

Fig. 3. Land use map of Pelasjan watershed.

The second step

isorain Map

Eskandari's precipitation statistics were provided by Isfahan regional water management and by entering precipitation information into geographic information system (GIS), the isorain map of the area was prepared (Fig. 4). Isorain map is used for calculation of annual rainfall and hydrological units through the precipitation maps. Isorain maps is achieved using contour line in the GIS environment and based on changes in rainfall with elevation (Soori, 2002).

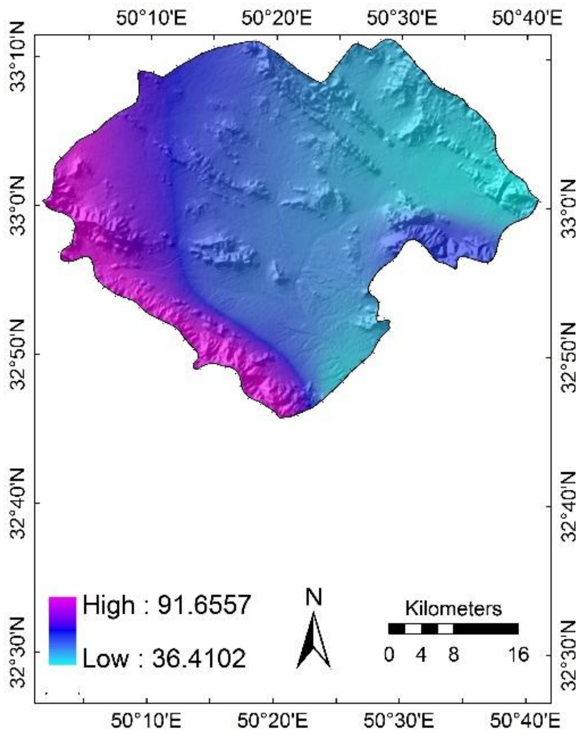

Fig. 4. Isorain raster map of Pelasjan watershed (in millimeters).

The third Step

Digital elevation model (DEM)

ASTER DEM 32 m (Advanced Spaceborne Thermal Emission and Reflection Radiometer) was defined as a digital map that contains the height of the entire covered region (Fig. 5).

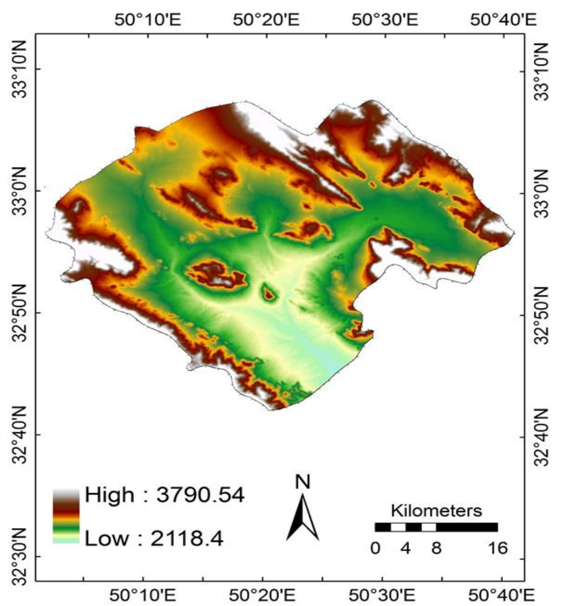

Fig. 5. Digital elevation model of Pelasjan watershed.

The forth Step

Soil map of the Pelasjan watershed

The following steps were taken to prepare the soil map: Hydrologic soil groups

The main Hydrological groups of the Pelasjan watershed were determined by the method of the soil conservation department of America. Groups are (Fig. 6):

Group A: which contains Soils having a low runoff potential when thoroughly wet.

Group B: Soils having a moderate infiltration rate and a moderate runoff potential when thoroughly wet.

Group C: Soils having a relatively high runoff potential when thoroughly wet.

Group D: Soils having a very slow infiltration rate and high runoff potential when thoroughly wet. (Mahdavi, 2007)

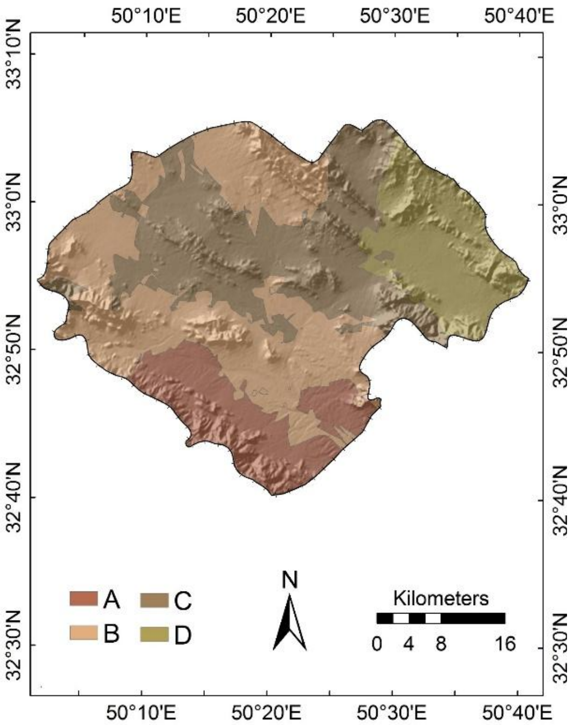

Fig. 6. Hydrologic soil groups Map of the Pelasjan watershed.

The Fifth step

Determining the soil erodibility factor

The Soil samples, collected from the watershed were transferred to the laboratory and tested. Tests were conducted on the soil texture and organic matter (Fig. 7). Soil erodibility factor, K, is used widely in studies of soil erosion and erosion risk assessment because soil erosion is in direct contact with the factor (K). In soils with a high K value which are more susceptible to erosion, to prepare soil erodibility maps, the points were interpolated by kriging method. It is a *method* of interpolation which predicts unknown values from data observed at known locations. In Kriging method in addition to the estimation of unknown values, the amount of error associated with the estimations will be calculated, therefore, we can calculate the confidence interval estimate for the estimated amount (Gzhorbani, 2012).

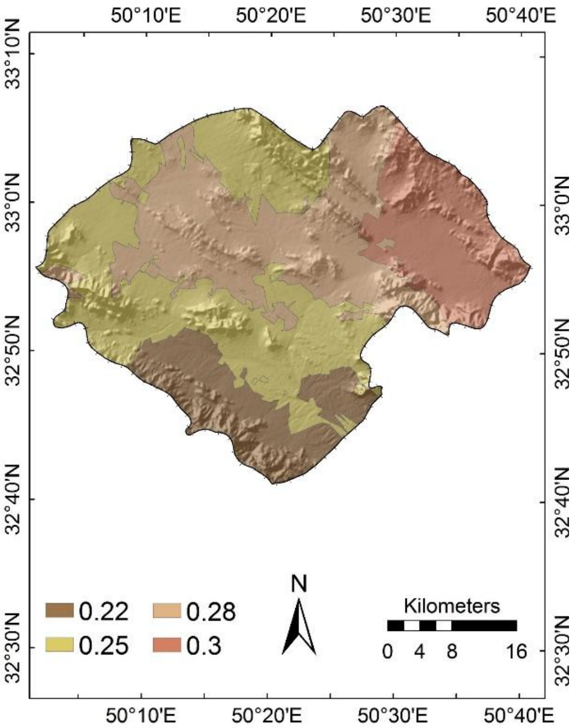

Fig. 7. erodibility factor Map of the Pelasjan watershed (t ha h MJ-1 ha-1 mm-1).

The Sixth step

Rain erosivity factor (RF) map

Rainfall and its role in erosion is demonstrated with RF or R (MJmmh-1hr-1year-1) in the erosion equation and researchers have focused on it in the past thirty years. The intensity of erosion is a function of the product of two rainfall's features: one of them is the kinetic energy of rainfall and another one is the maximum rainfall intensity in half an hour. The product of these two factors, shows the ability of each rainfall in detachment and transport soil particles (Baaybordi, 2009).

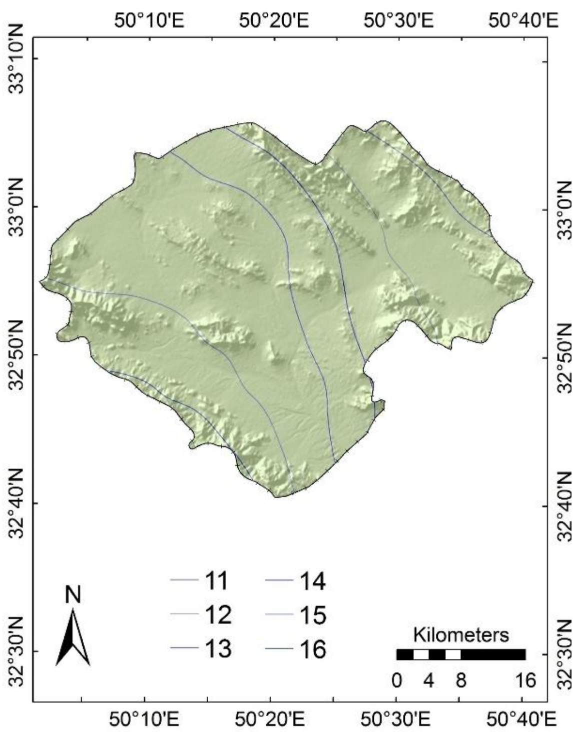

Fig. 8. Map of the rainfall erosivity factor (RF) ($MJmmh^{-1}hr^{-1}year^{-1}$).

The Seventh step

Run the Model

To run the model, the watershed boundary map and rain erosion map should be entered in the software. The first step is to determine the boundary of the watershed, and the exit point should be determined based on objective of the study. The geographical coordinates of the watershed should be specified on a topographical map. These studies can be the target point on a hydrometric station, village or town, an aqueduct, the existing dam or a proposed location for the construction of large structures, metropolitan area, industrial area or any important region. The area consists of ridges or divides that separate the area from adjacent watersheds.

Results

Model outputs

Two maps of cumulative runoff and cumulative sediment Sediment yield in a year in the Pelasjan watershed are the N-SPECT model outputs. Map values represent the cumulative amount of sediment and runoff in a year in the Pelasjan watershed. One of the advantages of this model is pixel to pixel estimation of runoff and sediment in the output maps, the amount of runoff and sediment can be found anywhere in the watershed using identify tools in the GIS environment. This model is suitable for areas of the watershed where there is no stations. For comparisons between actual and estimated amount of precipitation and runoff the obtained numbers are divided to the area of 164570 hectares so that they are comparable with each other. Special discharge volume estimated by the model was equal to 1483.2 cubic meters per hectare per year. The actual average discharge rate of the Pelasjan watershed during 21 water years from 1991 to 2012 is equal to 1253.1 cubic meters and the minimum and maximum discharge rate during 21 water years were 1241.438 and 4159.818 cubic meters, respectively.

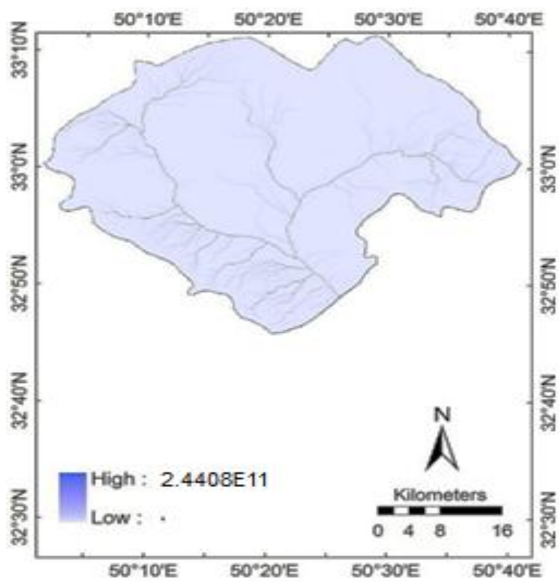

Fig. 9. Output Map of runoff obtained from N-SPECT software.

The Sediment yield rate obtained by the model was 7.8 tons per hectare per year in Pelasjan watershed and average amount of specified Sediment yield during the 1991-2012 water years are equal to 2.1 tons per hectare per year, the minimum and maximum Sediment yield rate during 21 water years were 0.008 and 27.4 tons per hectare per year, respectively.

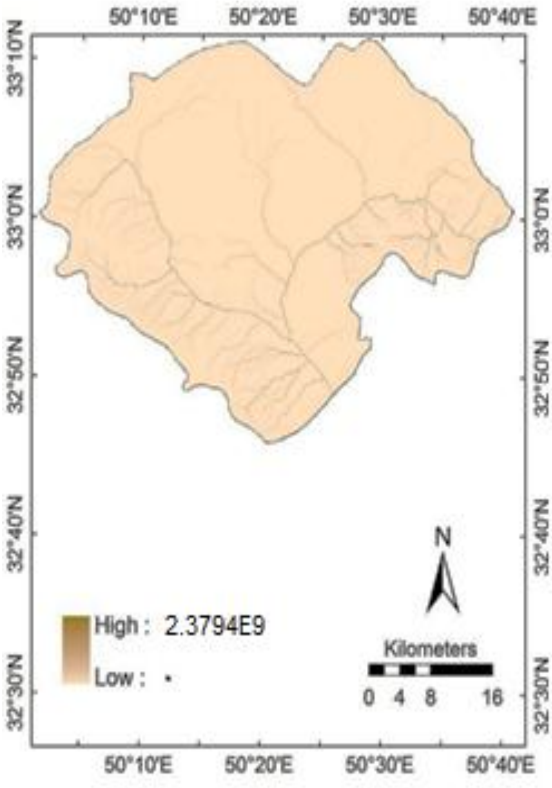

Fig. 10. Output Map of Sediment yield obtained from N-SPECT software.

Comparative points in the N-SPECT model

Using output maps of the N-SPECT and identify tool in the Arc GIS environment, runoff and Sediment yield rate of Pelasjan in some points of the output section of the watershed and also in the upstream areas were examined. This is an advantage of this model that runoff and Sediment yield can be easily analysed pixel by pixel and other models do not have such advantage. Numerical values of runoff and Sediment yield in the output map are higher than the accumulative output in Pelasjan and determine the volume of Sediment yield and runoff in all parts of the watershed.

In fact, this model serves as a hydrometric station except that the cost of building the station, station employees and also measuring difficulties will be removed and it is possible to estimate the amount of runoff and Sediment yield in a variety of land uses in a watershed without a physical presence in the region and without spending much time and money. Also the model can be used to compare and estimate the amount of Sediment yield in different geographic directions of the watershed.

Discussion and conclusions

Based on the results obtained from the N-SPECT model and also the results of the actual statistics concerning Pelasjan watershed runoff and Sediment yield it can be concluded that the calculated runoff rate resulted of the model is very close to the value calculated from actual data and has a high accuracy and this suggests that the N-SPECT estimation of runoff has not a significant difference compared to the actual data. The model is not sufficiently accurate in Sediment yield estimating and it overestimates about more than three times compared with the actual statistics. Therefore, the N-SPECT estimation has significant differences compared with the actual data.

It can be said that the application of N-SPECT model in Pelasjan watershed has better performance in runoff estimating and more accurate response is provided.

Researches have been conducted studies about the estimation of Sediment yield and runoff using various models in Iran and abroad. Nojavan *et al.*, (2012) using two models, BLM and Fargas, estimate the rate of erosion in the Bandareh watershed in the Azerbaijan Gobi province. The results show the agreement between two models which used for erosion estimating. Sun and Cornish (2005) conducted a study about the discharge and Sediment yield rate of a river in the headwaters of Liverpool plains of Australia using SWAT model. The results showed that compared with N-SPECT models, SWAT model has good predictive ability and better performance. Mahmoodabadi *et al.*, (2014) carried out a research to develop a new method for the accurate determination of sediment transport capacity, according to the stream morphology and its relation with Sediment yield. Two models, GUEST and WEEP, were used for this purpose. The results showed that the influence of sediment transport capacity was better predicted by GUEST model compared to the WEEP model. GUEST model in predicting sediment transport capacity is expandable. Performance statistics for sediment yield models could be seen as compared studies made by Setegn *et al.*, (2010), Tolson and Shoemaker (2007), and Betrie *et al.*, (2011) that sediment transport modeling has similar characteristics.

One of the advantages of this model compared to the other models which used in Iran and abroad is point to point estimation of runoff and sediment in the output maps. This model is particularly recommended for harsh and difficult access regions of the watershed.

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