An investigation on the effect of land use land cover changes on surface water quantity
Mahsa Mirhosseini, Parvin Farshchi, Ali Akbar Noroozi, Mahmood Shariat and Ali Asghar Aalesheikh

ABSTRACT

The present study is an attempt to show how changes in land use and land cover would change the quantity of surface water resources in a river basin in northwestern Iran. In order to detect the changing trend of surface water quantity in the river basin, the long-term statistic data of sediment load and river discharge were gathered over the period between 1987 and 2013. For land use change detection of the river basin, the land use land cover maps of the study area in the years of 1987, 1998, 2002, 2009, and 2013 were prepared from Landsat satellite images using supervised classification method. The changing trend of river discharge showed a significant and positive relationship with rain-fed agriculture ($R^2 = 0.8152$), poor rangeland ($R^2 = 0.7978$), and urban areas ($R^2 = 0.8377$). There was also a strong negative correlation between water discharge and irrigated agriculture ($R^2 = 0.7286$) and good rangeland ($R^2 = 0.8548$). In conclusion, increasing the area of rain-fed agriculture, good rangeland (type IV), and urban land uses, due to their effects on increasing the runoff, have caused an increase in the water flow of Zanjanroud River.

Key words | change detection, flow rate, land use/land cover map, river basin, surface water quantity

INTRODUCTION

An undeniable fact is that the world’s freshwater resources are very limited and include only 2.5–2.7% of the total water content of the Earth. Of this, approximately 1.75–2% is almost inaccessible as polar ice, and just less than 0.01% is available as lakes and rivers for direct use by humans (Shiklomanov 1993; USGS 2016). The bitter truth is that this low rate of fresh water is not distributed equally worldwide, thus 29% of freshwater lakes are found in Africa, 20% in Russia, 21% in North America, and 14% in the remaining parts of the world (USGS 2012). In the meantime, countries in the hot and arid belt of the earth, such as Iran, have a far worse situation. In a report by the World Resources Institute in 2013, Iran was ranked the 24th most water-stressed country dealing with an extremely high risk of water crisis in future (Chini et al. 2013). These are all strong reasons for countries, especially those who are faced with the problem of water shortage, to preserve perfectly their existing resources. In this context, attempts have been made to initially find the causative agents of deterioration of water resources, and then, based on these agents, appropriate control and preventive measures have been recommended. One of the influential factors on water quality and quantity is land use and land cover changes. However, there are limited studies providing empirical data on the relationship between land use land cover changes and the quantity of surface water and sediment load, particularly outside the developed world. Conversion of natural land types, such as water bodies,
forest areas, and rangelands can definitely affect the availability, quantity, and quality of water resources (Adnan Rajib et al. 2016; Battaglin et al. 2016; Jiang et al. 2016; Sample et al. 2016). In spite of the apparent effect of land use changes on water resources, there can be found only limited research on the issue, which may be due to spatiotemporal complexities of these types of studies. In a research by Fernandes Cunha et al. (2016), the influence of different land use types on the quality of raw surface water for potable water supply was investigated in more than 50 river/stream sites with industrial/urban, agricultural, and forest land uses. According to their findings, the quality of water was significantly better ($p < 0.01$, ANCOVA) in forested watersheds. Sun et al. (2016) studied the effect of land use change on water balance, in northwest China. They concluded that reduced area of farmlands will be an influential factor to overcome water shortage in the region. This involves balancing the relationship among various stakeholders to secure water transformation from the agricultural sector to industrial and service sectors. Xu et al. (2016) analyzed the net effects of climate change, water management policies, and land use changes in the spatial pattern of water bodies and concluded that land use change had a far greater effect on the changing area of water bodies than the other two factors. Zope et al. (2016) used topographic maps and satellite images of the years 1966, 2001, and 2009 to detect the effect of land use land cover changes and urbanization on flooding of Oshiwara River, India. They concluded that over the study period, peak runoff and runoff volume varied by 3.0% and 4.45% as built-up area increased by 74.84%. Waqas Liaqat & Choi (2016) studied the effect of land use/land cover changes on water stress in the Korean peninsula. They reported the highest mean water stress of 0.74 in evergreen forestland under poor vegetation condition and maximum mean water stress of 0.56 from cropland regions.

According to the above, conservation of freshwater resources is an issue of global concern and has been the focus of many researchers from different countries. In this regard, this study, as the first research of this type and this scale was conducted to determine the relationship between water quantity and its changes with changes in different land use types in a river basin in northwestern Iran. The research attempted to find the net effect of changes in each land use type on variation of river flow rate in different periods, between 1987 and 2013. It was supposed that the quantity of surface water (runoff) has been increased due to the expansion of impervious surfaces as a result of conversion of natural land uses to built-up areas. Attempts were made to show how changes in land use over time could affect the quality of surface water and specifically what type of land uses have a greater role in this case.

**MATERIAL AND METHODS**

**Study area**

The study area is located in Zanjanroud River Basin in Zanjan Province, northwestern Iran, between the geographic coordinates of 47°47’23’’–49°04’55’’ eastern longitudes and 36°17’41’’–37°13’27’’ northern latitudes. There are three climate types in the river basin, dry to extra dry in the downstream, dry in central parts, and semi-arid in the highlands of the northern and southern parts as well as downstream areas (Qoddousi 2005). The average annual rainfall in the above-mentioned climate zones varies between 150 and 515 mm per year. There can be found different geomorphological land types of mountains, foothills, alluvial terraces, and piedmont plains, whose lithological units belong to Precambrian and Cenozoic eras. The maximum and minimum heights of the basin are approximately 2,917 and 1,110 m above sea level. The average slope in the study area is 3.82%, which plays a fundamental role in the erosion, runoff, water infiltration in soil, and intensity of floods in the river basin. Figure 1 demonstrates the situation of the study area in Iran.

**Land use/land cover maps**

In the present study, for generation of the land use land cover maps of the study area, Landsat satellite images of the years 1987, 1998, 2002, 2009, and 2013 were prepared from Geographic Organization of Iran. For this, a data set of the satellite images was formed, which included the Landsat-5 TM images, acquired on 10/6/1987, 08/6/1998, and 06/6/2009, Landsat-7 ETM images, acquired on 29/7/2002, and Landsat-8 OLI-TIRS image, acquired on 17/6/
2013. The TM images include a total number of six bands with a spatial resolution of 30 m and the ETM images consist of eight bands with a spatial resolution of 30 m. There is also a 15 m spatial resolution panchromatic band. The OLI-TIRS images comprise nine spectral bands with a spatial resolution of 30 m (bands 1 to 7 and 9), a panchromatic band (8th band) with a spatial resolution of 15 m, and two thermal bands (10th and 11th bands), with a spatial resolution of 100 m.

Once the data set of the research was completed, the images were corrected geometrically. This was done using topographic maps of the study area at the scale of 1:250,000, prepared from the Geographical Survey Organization of Iran. The situation of roads and rivers on the topographic maps was intersected on the satellite images. The projection system of the images was set as Universal Transverse Mercator (UTM), zone 39, North WGS 84 and they were geo-referenced by Affine Function and used 50 ground control points already specified on the topographic maps in a way to create good distribution over the study area. For this purpose, nearest neighbor algorithm was used to re-sample the images. The root mean square error (RMSE) of the 1987, 1998, 2002, 2009, and 2013 images were 1.1, 1.0, 0.9, and 0.7, which fall within the acceptable range of 0–0.5 pixels. Band rating was used to remove the intruding effect of shadow and Optimum Index Factor (OIF) was applied to improve the contrast between the features on the images and to select the best color composite.

Figure 1 | Situation of Zanjanroud River Basin in Zanjan Province and in Iran.
After preprocessing of the images, they were classified by supervised classification procedure and maximum likelihood method. According to this, for each land use land cover type, a signature is introduced to the software, then, the entire pixels on the images are classified based on their similarity to the spectral reflectance set as signature. Maximum likelihood method was introduced and developed by Ronald Fisher over the years 1912 to 1922 (Pfanzagl et al. 1994). Maximum likelihood method, by estimating probability thresholds of each land use type (different features on the Earth), classifies the pixels of the same probability threshold, in the same feature class based on their highest probability. The pixels of small probability will remain unclassified or allocated to the other land use types with similar probability threshold. The discriminant function of the maximum likelihood method is as follows:

$$g(x) = \ln p(\omega_i) - \frac{1}{2} \ln |\Sigma| - \frac{1}{2} (x - m_i)^T \Sigma^{-1} (x - m_i) \tag{1}$$

where $l$ = land use type, $x$ = n-dimensional data, $n$ = number of bands, $p(\omega_i)$ = probability for the occurrence of $\omega_i$ land use class in the image, $|\Sigma|$ = determinant of the covariance matrix of the data in $\omega_i$ land use class, $\Sigma^{-1}$ = inverse matrix, and $m_i$ = mean vector value.

Accordingly, the preprocessed satellite images were classified into various land use types, including D.F (dry farming), I.A (irrigated agriculture), O.D (orchards), urban (U), and four rangeland types of RL4 (highly capable rangelands), RL3 (averagely capable rangelands), RL2 (poor rangelands), and RL1 (very poor rangelands).

The accuracy of the classifications was finally checked by kappa coefficient, which was obtained from error matrix, in accordance with Equation (2). It is an indicator for the assessment of the accuracy of classifications compared to the random classifications:

$$k = \frac{N \sum_{i=1}^{R} x_{ii} - \sum_{i=1}^{R} \sum_{j=1}^{N} (x_{ij} \cdot x_{ij})}{N^2 - \sum_{i=1}^{R} \sum_{j=1}^{N} (x_{ij} \cdot x_{ij})} \tag{2}$$

in which $N$ = total number of sites in the matrix, $R$ = number of rows in the matrix, $x_{ii}$ = value in the $i$th row and $i$th column, $x_{i+}$ = total value of the $i$th row, and $x_{+i}$ = total value of the $i$th column.

The $K$ value of 0.80 indicates full agreement, the values between 0.40 and 0.80 show a moderate agreement, and the value of less than 0.40 reflects poor agreement between the reality and the result of classifications. It is worth mentioning that, in this research, the value of overall accuracy and kappa coefficient were respectively equal to 72% and 0.69, which is an indication for the accuracy of the classifications.

Change detection

At the end of the previous step, the land use/land cover maps of the study area in the time intervals of 1987, 1998, 2002, 2009, and 2013 were prepared. In the next step, in order to detect spatiotemporal pattern of land use changes, these maps were cross-tabulated by crosstab module in the IDRISI software.

Sediment and runoff data set

As mentioned earlier, the primary goal of this research was to highlight the role of land use/land cover changes on the fluctuation of river flow rate in Zanjanroud River Basin. In order to detect changes in the flow rate and sediment load of the river, the statistical data of the river over the years 1987 and 2013 were collected from five synoptic stations along the Zanjanroud River (Figure 2). The average annual flow rate and sedimentary load of the river was then calculated to detect any upward and downward trends over the study period. At the end, using correlation analysis, the relationship between land use/land cover classes and sediment loads, as well as between land use/land cover classes, and river flow rate was studied in different time intervals.

The use of SPSS software can be helpful in showing the presence or absence of a relationship between different land uses and also displays the type of relationships between land uses as independent data and the amount of water in streams and sediment load as dependent data. A simple type of relationship between different types of variables is shown by points that are scattered around a straight line. Little scatter around the line is a sign of a strong relationship, while great dispersion of points shows a weak linkage between the variables. By obtaining the $p$-values, it can be concluded whether or not the correlation coefficients...
are significant at the levels of $\alpha = 0.01$ or $\alpha = 0.05$. Then, using linear regression relationship, a simple linear model can be fitted to the data. In the linear regression equation, the fitted line is drawn so as to reach the minimum possible sum of the squares of the vertical deviations from each data point to the line, which is called the best-fitting line.

### RESULTS

**Change detection results**

Figure 3 demonstrates land use land cover maps of Zanjanroud River Basin over the time intervals of 1987, 1998, 2002, 2009, and 2013. Table 1 shows the changing trends of different land use classes in different time intervals in Zanjanroud River Basin. At first glance, in the year 1987, capable rangelands and rain-fed agriculture were the two land uses that occupied the greatest areas, respectively 27.75% (1,291.63 km²) and 24.65% (1,146.64 km²) of the entire river basin in the study area. Orchards and urban areas, with a share of 0.68% (31.76 km²) and 0.08% (3.8 km²) accounted for the smallest land use types in the study area. Over the study period, irrigated land use had the largest extent in the year 1987, when urban areas only occupied a small proportion of 0.08 in the whole river basin. A decade later, in the year 1998, signs of degradation and human manipulation in nature could be observed in the region, so that the area of rain-fed agriculture, orchards, and urban areas was expanded as the area of highly capable and
moderately capable rangelands decreased. This shows that parts of rangelands were converted into built-up areas and farmlands. Degradation of rangeland continued in the subsequent years, so that in the year of 2002 the area of highly capable rangelands decreased to half their original value in 1987, from 14.43% (671.86 km²) in 1987 to 7.04% (327.92 km²) in 2002. Overall pattern of land use changes from 1987 to 2013 showed that the area of rain-fed farming has kept an upward trend (almost twice the area of the base year) in the study period. Likewise, the changing trend of orchards was upward, and doubled from 0.68% (31.76 km²) in 1987 to 1.41% (65.73 km²) in 2013. Changes
in the area of agricultural land have been wavy but the general trend is decreasing, from 7.5% (349.04 km²) in 1987 to 5.22% (243.22 km²) in 2013. According to the results, as the area of rain-fed farming has been added to, poor rangelands have experienced an increase of 3.5%. Urban areas were developed considerably by 8.2% from 0.08% (3.8 km²) in 1987 to 2.05% (959.55 km²) in 2013.

Sediment and river flow analysis

Table 2 gives average flow rate and sediment yield of Zanjanroud River over the years 1987 to 2013. The statistical data were gathered from synoptic stations along the river course. As the table suggests, sediment load and flow rate follow an upward trend over the study period, so that the flow rate has doubled from 3.92 m³/s in 1987 to 8.1 m³/s in 2013. The increasing trend of sediment load has been slightly slower than the flow rate over the study period, from 7.03 g/L in 1987 to 8.9 g/L in 2013.

Regression analysis

According to the results, there was a positive linear relationship found between rain-fed farming and inflow rate of Zanjanroud River at the confidence level of 95%. This shows that the inflow rate has increased as the area of rain-fed fields has been expanded over time. In addition, correlation analysis of the flow rate and the area of irrigated agriculture showed a negative linear relationship between these two parameters at the confidence level of 99%. This means that establishment of new irrigated farmlands in the area has had a negative effect on the increase of water

<table>
<thead>
<tr>
<th>Land use type</th>
<th>OD</th>
<th>RL1</th>
<th>RL2</th>
<th>RL3</th>
<th>RL4</th>
<th>U</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Km²</td>
<td>%</td>
<td>Km²</td>
<td>%</td>
<td>Km²</td>
<td>%</td>
<td>Km²</td>
<td>%</td>
</tr>
<tr>
<td>1987</td>
<td>1.146</td>
<td>24.65</td>
<td>349.04</td>
<td>7.5</td>
<td>27.75</td>
<td>1,101.63</td>
<td>2.03</td>
</tr>
<tr>
<td>1998</td>
<td>1.291</td>
<td>27.35</td>
<td>309.42</td>
<td>6.64</td>
<td>7.24</td>
<td>1,511.73</td>
<td>1.55</td>
</tr>
<tr>
<td>2002</td>
<td>1.567</td>
<td>28.44</td>
<td>208.64</td>
<td>4.48</td>
<td>5.74</td>
<td>2,142.06</td>
<td>1.23</td>
</tr>
<tr>
<td>2009</td>
<td>1.933</td>
<td>31.85</td>
<td>288.47</td>
<td>6.2</td>
<td>6.77</td>
<td>2,524.01</td>
<td>1.12</td>
</tr>
<tr>
<td>2013</td>
<td>2.080</td>
<td>34.62</td>
<td>243.12</td>
<td>5.22</td>
<td>6.52</td>
<td>2,673.94</td>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years</th>
<th>Sediment (g/L)</th>
<th>Flow rate (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>7.03</td>
<td>3.92</td>
</tr>
<tr>
<td>1998</td>
<td>7.9</td>
<td>5.46</td>
</tr>
<tr>
<td>2002</td>
<td>8.5</td>
<td>7.71</td>
</tr>
<tr>
<td>2009</td>
<td>8.4</td>
<td>7.63</td>
</tr>
<tr>
<td>2013</td>
<td>8.9</td>
<td>8.1</td>
</tr>
</tbody>
</table>
quantity in the study area. In fact, the irrigated lands are surfaces covered with vegetation cover with high permeability. This would be the main reason behind the negative relationship between the flow rate and the area of irrigated agriculture. No significant relationship was found between orchards and flow rate of the river (p-value = 0.06). Very poor rangeland land use positively correlated with flow rate of the river at the confidence level of 95% (p-value = 0.03). There was also a negative significant relationship reported between poor rangelands and inflow rate of the river at the confidence level of 95% (p-value = 0.05). In other words, conversion of natural grasslands in the study area into the poor rangelands over time has increased the inflow rate. This means that poor rangelands are not rich enough in vegetation cover to prevent generation of more runoffs. Moderately capable rangelands correlated poorly with the flow rate of the river. Although the relationship was significant, the confidence level was not reliable (p-value = 0.25). The relationship between highly capable rangelands and inflow rate of the river was strong, significant, and negative (p-value = 0.009). This indicated that the inflow rate has adversely been affected by the expansion of highly capable rangelands with high permeability capacity. Accordingly, more capable rangelands can absorb more water and reduce less runoff.

Urban areas and flow rate were correlated strongly and positively (p-value = 0.009). Expansion of urban areas increases the area of impervious surfaces and, consequently, much of the rainwater cannot penetrate into the soil and get out of reach in the form of runoff and eventually release into the river. Table 3 gives linear regression equations to show possible correlation between the amount of inflow rate and different types of land uses in the study area.

Table 3 | Linear regression equations to show possible correlation between the amount of inflow rate and different types of land uses in the study area

<table>
<thead>
<tr>
<th>Regression equation</th>
<th>(R²) R square</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate = 0.1919 DF + 0.1971</td>
<td>R² = 0.8152</td>
<td>0.03</td>
</tr>
<tr>
<td>Flow rate = -14.477 IA + 1.3171</td>
<td>R² = 0.7486</td>
<td>0.01</td>
</tr>
<tr>
<td>Flow rate = 6.3384OD + 0.185</td>
<td>R² = 0.004</td>
<td>0.06</td>
</tr>
<tr>
<td>Flow rate = 3.7594 RL1 + 0.9553</td>
<td>R² = 0.7486</td>
<td>0.03</td>
</tr>
<tr>
<td>Flow rate = -10.867 RL2 + 0.1666</td>
<td>R² = 0.3029</td>
<td>0.06</td>
</tr>
<tr>
<td>Flow rate = 11.676 RL3 + 0.2446</td>
<td>R² = 0.1111</td>
<td>0.25</td>
</tr>
<tr>
<td>Flow rate = -9.4552 RL4 + 0.3711</td>
<td>R² = 0.9239</td>
<td>0.009</td>
</tr>
<tr>
<td>Flow rate = 4.1226 U + 2.9079</td>
<td>R² = 0.8377</td>
<td>0.009</td>
</tr>
</tbody>
</table>

(d) Irrigated agriculture with a correlation coefficient of 0.7486 (α = 0.01)
(e) Poor rangelands with a correlation coefficient of 0.3029 (α = 0.01).

The changing area of orchards and moderately capable rangelands, due to being partial and heterogenous, had no significant effect on the flow rate of the river. In other words, the changing pattern of rain-fed farming, very poor rangelands, highly capable rangelands, and urban areas on river flow had been more effective than the changes in irrigated farming and poor rangelands. Figure 4 depicts the relationship between the changing pattern of different land uses and fluctuation of river flow.

Correlation analysis between the changes of sediment load and different land uses revealed a linear and positive relationship between sediment load and the area of rain-fed agriculture at the confidence level of 99% (p-value = 0.007). Rain-fed farming at steep slopes, which is usually established by converting poor rangelands into farm fields, causes loss of natural land cover in the study area. With the loss of natural vegetation and plowing the land, the topsoil is loosened and, in the first rainfall, the generated runoff washes out and carries a large amount of sediment into the river. The relationship between irrigated cultivated areas and sediment load was also significant but negative, at the confidence level of 99% (p-value = 0.009). Irrigated farming is usually carried out in flat and fertile fields with high permeability capability. This causes much of the irrigation water and rainfall to be absorbed by the land and less released as runoff. Thus, development of agricultural
Figure 4  Relationship between the changing pattern of different land uses and fluctuation of river flow.
land could be considered as an agent of sediment control. No significant relationship was found between the changing pattern of orchards and sediment load (p-value = 0.204).

However, very poor rangelands and sediment load showed a significant and positive relationship at the confidence level of 99%. Very poor rangelands are not rich enough in vegetation cover to absorb rainwater, thus the topsoil is washed at slopes and transported as sediment load by the runoff (p-value = 0.001). The relationship between sediment load and poor rangelands was insignificant (p-value = 0.1). There was also found to be no significant relationship between sediment loads and the changing trends of moderately capable rangelands (p-value = 0.32). Capable rangelands strongly and adversely correlated with the sediment loads at the confidence level of 99% (p-value = 0.000). This indicated that the sediment load is decreased with the expansion of highly capable rangelands with high permeability capacity. Much of the rainwater can be absorbed by the dense vegetation cover of highly capable rangelands, so less runoff is produced and, consequently, less topsoil will be washed and transported as sediment load. As well, the relationship between the urban areas and river sediment loads was positive and significant at the confidence level of 99% (p-value = 0.000). Urban areas with impervious surfaces cause an increase in total runoff and sediment load. Table 4 shows linear regression equations to show possible correlation between the amount of sediment load and different types of land uses in the study area.

Table 4 | Linear regression equations to show possible correlation between the amount of sediment load and different types of land uses in the study area

<table>
<thead>
<tr>
<th>Regression equations</th>
<th>R² R square</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment = 5.588 DF + 0.0741</td>
<td>R² = 0.6669</td>
<td>0.007</td>
</tr>
<tr>
<td>Sediment = -11.255 IA + 0.5174</td>
<td>R² = 0.7286</td>
<td>0.002</td>
</tr>
<tr>
<td>Sediment = 7.8123 OD + 0.1238</td>
<td>R² = 0.01666</td>
<td>0.204</td>
</tr>
<tr>
<td>Sediment = 7.0714 RL1 + 0.3653</td>
<td>R² = 0.6931</td>
<td>0.001</td>
</tr>
<tr>
<td>Sediment = -8.8084 RL2 + 0.0316</td>
<td>R² = 0.0863</td>
<td>0.1</td>
</tr>
<tr>
<td>Sediment = -9.7747 RL3 + 0.08444</td>
<td>R² = 0.0858</td>
<td>0.32</td>
</tr>
<tr>
<td>Sediment = -9.1753RL4 + 0.1366</td>
<td>R² = 0.8548</td>
<td>0.000</td>
</tr>
<tr>
<td>Sediment = 7.2442 U + 1.0082</td>
<td>R² = 0.749</td>
<td>0.000</td>
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</tbody>
</table>

In other words, the changing trend of sedimentation in Zanjaniroud River was influenced by the changing pattern of these land use types. The sediment yield showed a decrease with increasing the area of highly capable rangelands and irrigated farming. The changes in the area of orchards, poor rangelands, and moderately capable rangelands, due to being slight, could not cause a noticeable change in the sedimentation load of the river during the five time intervals. As the regression and correlation analyses showed, the effect of each land use type on sediment yield of the river basin is different from the other types. This is investigated through the Pearson correlation coefficients presented in the following:

(a) Highly capable rangelands with a correlation coefficient of 0.8410 (α = 0.01)
(b) Urban land use with a correlation coefficient of 0.749 (α = 0.01)
(c) Rain-fed farming with a correlation coefficient of 0.6186 (α = 0.01)
(d) Irrigated agriculture with a correlation coefficient of 0.5271 (α = 0.01)
(e) Very poor rangelands with a correlation coefficient of 0.4955 (α = 0.01).

The changing pattern of the orchards, poor and highly capable rangelands on sediment yield of the river basin, due to being partial, was insignificant during the five time intervals. As the correlation coefficients show, the effect of changing area of highly capable rangelands, urban land
use, and rain-fed farming on sediment yield of the river basin was more than that of irrigated agriculture and very poor rangelands. Figure 5 illustrates the relationship between the changing pattern of different land uses in the river basin and fluctuation of sediment loads.

DISCUSSION AND CONCLUSION

This paper, as the first paper of this type and this scale, is an attempt to showcase the different roles of various land use land types on the variations of inflow rate of a river basin in northwestern Iran. The findings revealed what type of land use classes have played a more important role on the changes in the sedimentation and inflow rate of the river.

According to the research findings, a positive and linear relationship was found between the flow rate of the river and the changing pattern of rain-fed farming, very poor rangeland, and urbanization. In addition, the relationship between the flow rate and the changing trends of irrigated agriculture, poor rangelands, and highly capable rangelands was evaluated to be significant and negative. In addition, no significant relationship was found between the changes of orchards and moderately capable rangelands in the flow rate of the river. In conclusion, the effect of each of the land use types on flow rate of the river was different. In this regard, the effect of changing pattern of rain-fed farming, very poor rangelands, highly capable rangelands, and urban areas on river flow have been more effective than those of irrigated farming and poor rangelands.

Land use and land cover changes can also affect the sediment load of rivers. As the results of this paper show, the effect of changes in sediment load and the area of rain-fed agriculture, very poor rangelands, and urban areas on sedimentation were positive and linear. In addition, the changing pattern of irrigated cultivated areas, and capable rangelands were correlated adversely with the fluctuation of sediment loads in the river basin. The changes of orchards, poor rangelands, and moderately capable rangelands could not produce any significant effect on the variation of the sediment load over the study period.

According to the findings, the changing trend of sedimentation in Zanjarnourd River was influenced by the changing pattern of highly capable rangelands and irrigated farming. The changes in the area of orchards, poor rangelands, and moderately capable rangelands, due to being slight, could not cause a noticeable change in the sedimentation load of the river during the study period. The effect of changing area of highly capable rangelands, urban land use, and rain-fed farming on sediment yield of the river basin was more than that of irrigated agriculture and very poor rangelands. This is in contrast with the findings by Sajikumar & Remya (2015) on the effect of land cover and land use change on runoff characteristics of Kerala, India. They could not find any relationship between the changes of land use and land cover and runoff in the region. Dunjó et al. (2004) concluded that land use and land cover could greatly influence the runoff in a catchment area. Yang et al. (2012) conducted a study in Shalamulun River Basin in China and reported that, in the growing months of April to September, spatiotemporal variation of runoff was affected by the land use changes in the region.

Generally, and logically, it is expected that the land uses, which increase the quantity of water entering the river, also increase the sediment loads. The findings of this paper confirm this result. In the study area, those land uses (e.g. rain-fed agriculture and urban areas) that have increased the inflow rate of the river, also caused an increase in the sediment load of the river over time. On the contrary, some types of land uses, such as irrigated agriculture and highly capable rangelands, showed a negative relationship with the inflow rate of the river and caused a reduction in the sediment load. The findings also showed that the increase in the area of urban areas (due to expansion of impervious surfaces), rain-fed farming (due to cultivation of annual and non-resistant plants), and very poor rangelands (because of the lack of suitable vegetation cover) has caused an increase in runoff and sediment load entering the river bed. This, in many cases, has resulted in the removal of topsoil and in water erosion. Regression analysis in this study indicated that very poor rangelands (because of dense vegetation cover) and irrigated agriculture (because of plowing the land surface and increasing the permeability capacity of topsoil) reduce runoff so less sediment enters the river. It can be concluded that highly capable rangelands and irrigated agriculture cause a reduction in the volume of runoff and recharge the ground water, so less soil wash and water erosion occurs. Huang et al. (2017) introduced human
Figure 5 | Relationship between the changing pattern of different land uses and fluctuation of sediment yield of Zanjanroud River Basin.
activities responsible for non-stationarity in the relation between runoff and sediment load in the Wei River Basin, China. In a study by Zuo et al. (2016), variations in the annual water and sediment yields of Huangfuchuan River Basin in the Loess Plateau were attributed to the land use land cover change. Gagnon et al. (2017) found that loss of land cover, as a result of land leveling, significantly decreased total runoff volume in a farm field in Québec, Canada. Elledge & Thornton (2016) studied the effect of land use change in a region in Australia from woodland into unfertilized farmland or conservatively grazed pasture. They reported that fluctuations of water quality in the study area were due to the presence of native legumes, poor land cover, tillage practices, and pasture rundown. Yuan et al. (2015) investigated the effect of land use change on surface runoff and sediment yield in Taihang Mountains and concluded that when land use was changed to 93.89% of cropland, mixed crop/forest land, mixed crop/shrub land, and mixed crop/grass land, the total runoff and sediment yield were increased due to loss of forest and shrub land cover. The effect of land use change on runoff and sediment yield is also confirmed by other researchers worldwide, including but not limited to, Maalim et al. (2015), Defersha & Melesse (2012), and Sajikumar & Remya (2015). Their results on the effect of land use change on sediment load and water quantity were in line with the findings of this research. Flow rate of the rivers, as an influential factor in water supply of river basins, depends on a variety of parameters such as rainfalls, upstream dams and reservoirs, water withdrawals, climatic conditions, etc. For better management of water resources, it is very important to accurately identify and detect the causative agents of water flow fluctuations. One of the influential factors in fluctuation of river flow is changes in land use/land cover of river basins. Any changes in the land use of river basins can increase the area of impervious surfaces and, as a result, the volume of river inflow and sedimentation. Thus, the use of land should be based on land use planning approaches and in line with the goals of sustainable development. According to the research findings, very poor rangelands and expansion of urban areas are two main land uses responsible for variations of water quantity and sediment load in the study area. Although the findings of the research confirm the influential role of land use/land cover changes on water quantity, further research is required to apportion the effect of other variables on the increasing water quantity in the river basin. For better control of sediment entering the river and water level fluctuations, it is recommended to avoid conversion of natural land cover into these two types of land uses. It is also strongly recommended to restore the degraded rangelands and abandon rain-fed agricultural fields at steep slopes.

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