

# Assessment of land cover changes & water quality changes in the Zayandehroud River Basin between 1997–2008

Fatemeh Bateni · Sima Fakheran · Alireza Soffianian

Received: 20 December 2012 / Accepted: 10 July 2013 / Published online: 28 July 2013  
© Springer Science+Business Media Dordrecht 2013

**Abstract** Water quality of rivers is strongly influenced by landscape characteristics of their watershed, including land use /cover types, and their spatial configuration. This research evaluates the effects of land cover changes on the water quality of the Zayandehroud River, which is the most important river in the center of Iran. The main goal of this study was to quantify the change in rangelands, forests, and bare lands in the Zayandehroud river basin, which suffered intense human interference, in a period of 11 years (1997–2008), and to evaluate how landscape patterns (including the number of patches, edge density, percentage of rangelands, forests, and bare lands) influence on the 14 water quality indices (including BOD<sub>5</sub>, EC, NO<sub>3</sub>, P, and TDS) measured in 10 stations along the river. Results showed that from 1997 to 2008, bare lands increased from 5.8 to 20 %, while rangelands decreased from 70 to 55 % in the whole basin. The results indicated that water quality was significantly correlated with both the proportions and configuration of rangeland and bare land areas. The total edge (TE) of rangeland area had positive effects on water quality, especially on BOD<sub>5</sub> and EC. Percentage of landscape (PLAND) and largest patch index (LPI) metrics of rangeland had positive effect on decreasing nutrient

(NO<sub>3</sub>, PO<sub>4</sub>). The results showed that water quality was more likely degraded when there was high edge density (ED) of bare lands. Results of this study also revealed that degradation of rangeland lead to the degradation of water quality. Finding of this study highlights the importance of rangeland conservation in water quality management at landscape scale.

**Keywords** Land cover change · Rangeland · Bare land · Landscape metrics · Water quality · Zayandeh Roud Basin

## Introduction

The quality of water in many regions of the world is threatened by overuse, misuse, and pollution, and it is increasingly recognized that water quality of rivers, streams, and wetlands is strongly influenced by human actions at landscape scale (Allan 2004; Strayer et al. 2003; Wu and Hobbs 2002). The global transition from undisturbed to human-dominated landscapes has impacted ecosystems worldwide and directly or indirectly has influences on many hydrological processes (Changnon and Demissie 1996; Tong and Chen 2002; Smith et al. 2003; Allan 2004). One of the major direct environmental impacts of development and land use/cover change is the degradation of water resources and water quality (USEPA 2001). Therefore, quantification of land use/land cover change is a valuable indicator of the state of the ecosystems (Meyer and Turner 1994), and the relationship between land

For more information about the river Zayandehroud River, visit <http://en.wikipedia.org/wiki/Zayanderud>

F. Bateni (✉) · S. Fakheran · A. Soffianian  
Department of Natural Resources,  
Isfahan University of Technology,  
Isfahan 84156-83111, Iran  
e-mail: fa\_bateni@yahoo.com

use/cover and water quality is one of the most important issues of today's hydrological research (Yuan 2008).

It is increasingly recognized that water quality of rivers, streams, and wetlands is strongly influenced by landscape characteristics of the watersheds including landscape composition (i.e., land use/land cover types and their fractions) in uplands and the spatial configuration of these land use/land cover types. Many studies have shown that composition and spatial arrangement of landscapes within watersheds can account for the variability of water quality parameters and their concentration in streams (Lenat and Crawford 1994; Johnson et al. 1997; Basnyat et al. 2000; Tong and Chen 2002; Cretaz and Barten 2007; Lee et al. 2009; Alberti et al. 2007). Most of these studies conclude that agricultural land use strongly influence stream water nitrogen (Howarth et al. 2000), phosphorus (Hill 1981), and sediments (Johnson et al. 1997).

Using landscape metrics for quantitative analysis of landscape pattern structure and its change have been widely adopted by landscape ecology researchers. Reviewed studies have demonstrated that land use and land cover have a strong impact on water quality, and significant correlations exist between water quality parameters and landscape composition (Sliva and Williams 2001; Mehaffey et al. 2005; Amiri and Nakane 2008; Lee et al. 2009; Tu 2011). The landscape pattern metrics have been used in related research projects for quantifying land use configuration, land use spatial pattern, and integration of the landscape pattern and the hydro-geomorphic structure, while for the assessment of surface water quality, different indices have been used including hydro-chemical ions (Schoonover et al. 2005), common water quality variables such as BOD<sub>5</sub>, COD, TDS, and nutrients (Cretaz and Barten 2007; Lee et al. 2009), heavy metals (Callender and Rice 2000), organic pollutants (Schoonover et al. 2005), sediment loads, and aquatic organisms (Iserendino et al. 2011).

Though there have been many studies linking land use/cover and landscape configuration to water quality of rivers, we know of none that has been done in the Zayandehroud basin and other watersheds in Iran. Therefore, quantifying landscape pattern changes, its effects on water quality, and further results of landscape-scale studies in Iran are urgently required. Planners need to know about land cover change and their spatial patterns to analyze their relationships to

surface water pollutions. The main goal of this study was to quantify the change in rangelands, forest, and bare land areas in the Zayandehroud river basin in Isfahan province, Iran, in a period of 11 years (1997–2008) and to evaluate how landscape patterns influence on the Zayandehroud river water quality. Human activities such as urban development and intensification of agriculture and residential area played an important role in the drastic change of rangeland and forest areas in recent decades, particularly in semi-arid areas in Iran. The rapid increase of water demand and water pollution due to population growth and industrial and agricultural development around Zayandehroud River has caused the Zayanderoud water quality to severely downgrade over the past decades. Therefore, monitoring of the Zayandehroud water quality is a critical issue, especially due to the concern that freshwater is a scarce resource in this region of Iran. In this study, we examined (1) what are the land cover changes in the Zayandehroud basin between 1997 and 2008, (2) whether there is a significant relationship between land cover changes and surface water quality in the Zayandehroud basin, (3) whether landscape metrics are good indicators for predicting impacts of landscape structure on surface water quality, and (4) which of the metrics can be more accountable in predicting water quality in the study area.

## Material and methods

### Study area

The Zayandehroud river is the most important river in central Iran which stretches over a length of 400 km, originating from the Zardkough Mountain and ending in the Gavkhooni swamp after passing through the city of Isfahan and runs in a roughly west–east direction. Isfahan metropolitan area is the second most populous metropolitan area in Iran after Tehran. Urban expansion, population growth in addition to industrial development, has resulted in degrading environmental quality in Isfahan (Murray et al. 2000).

The Zayandehroud river basin has an area of 41,500 km<sup>2</sup>, with an altitude ranging from 1,466 to 3,974 m above sea level, and an average rainfall of 130 ml. There are 2,700 km<sup>2</sup> of irrigated land in the Zayandehroud river basin, with water derived from the nine main hydraulic units of the

Zayandehroud river, wells, qanat and springs in lateral valleys. Also, there have been a number of tunnel projects (Koohrang) to redirect water from the Karun river (Iran’s largest river that also originates from the Zagros Mountains), to the Zayandeh Roud. The Zayandeh Roud River flow regime depends not only on climatic conditions but also on the hydroelectric power generation, as well as irrigation needs through the Chadegan Dam (Murray et al. 2000; Salemi 2004). The main source of pollution in Zayandeh Roud River is agrochemical materials from agricultural drains, and in terms of organic pollutants, phosphorus and heavy metals from municipal and industrial sewages (Pour moghadas et al. 2001). The location of the study area is shown in Fig. 1.

Data collection and preparation

Water quality data (including 14 water quality parameters for 10 sampling stations along the Zayanderour river in Ghaleshahrokh, Tanzimi Dam, Zamankhan bridge, Kalle bridge, Dizicheh, lenj, Mousiyan, Choum bridge, Ziyar bridge, and Varzaneh between 1997 and 2008 were retrieved from the Isfahan regional water authority and Department of Environment, Isfahan Provincial Directorate. Grab methods were used for sampling of the river water. Various water quality indices in these databases including electrical conductivity (in ms/cm at 25 1 C), biological oxygen demand (BOD5), NO<sub>3</sub>, P, total dissolved solid (TDS), chemical oxygen demand (COD), dissolved oxygen

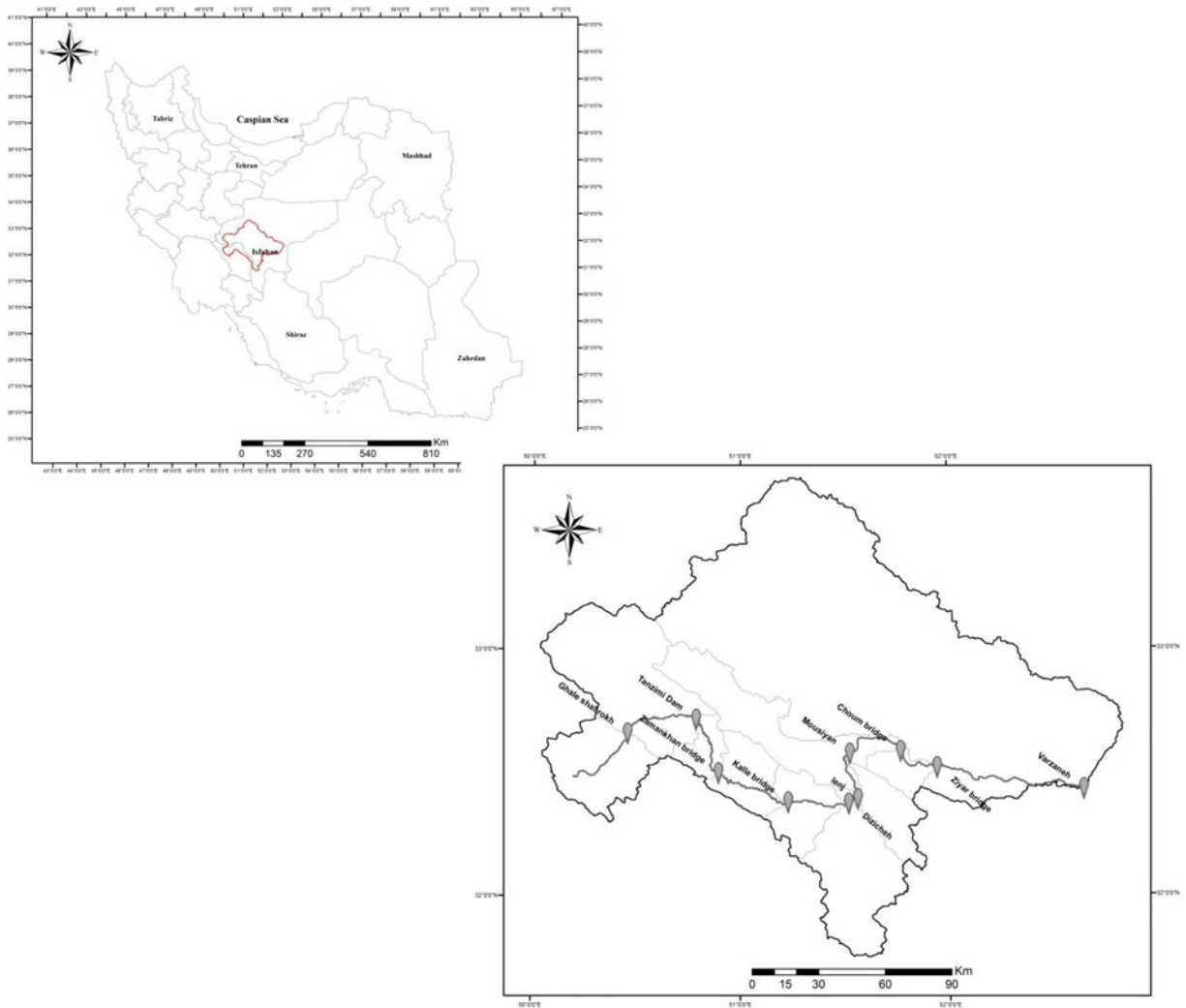


Fig. 1 Location of Zayandehroud Basin in Iran

(DO), pH, Na, K, Ca, Cl, SO<sub>4</sub>, and HCO<sub>3</sub> were selected as water quality indicators for the analysis.

In order to determine land use/land cover for the study area, maps were prepared using hybrid classification of multi-temporal Landsat5 (ETM) images taken in September 1997 and 2008. The five land use/land cover types were determined including (1) water (2) bare land (covering fallow field and rock quarries, transitional), (3) forest (covering forest, secondary forest, and planting forest), (4) range land, and (5) other land uses. The accuracy of the results was evaluated by comparison with aerial photographs and ground data through Kappa coefficient calculation (Jensen et al. 1997). The Kappa coefficient for estimating the accuracy was 87 %.

#### Sub basins delineation

Detection and quantification of non-point-source pollutions in a large basin such as Zayanderoud is challenging. Therefore, the Zayanderoud basin was divided into 10 distinct sub basins based on elevation and available hydrographical data, using Arc-SWAT extension in ArcGIS 9.3. Defining water and land use linkages, stream hydrology has been linked to land coverage. A continuous drainage network flow was created by applying 30 m digital elevation data and each of the 10 selected water sample sites, using the point coordinates as the stream outlet (Royappan 2001; Rothenberger et al. 2009).

#### Quantifying landscape pattern changes

Changes of landscape pattern can be detected and measured by landscape metrics, specified as a measure, model, or index, which can quantify and categorize complex landscapes in to identifiable patterns (Gustafson 1998; Mehaffey et al. 2005). For quantifying landscape patterns or characteristics, many landscape metrics have been proposed and utilized (McGarigal 1995). For this study, to quantify the landscape pattern changes in 1997–2008, we used proportion indices of four land use/land cover types: range land, forest, bare land area, and water area. We chose six class level metrics including PLAND, number of patches (NP), LPI, ED, TE, and landscape shape index (LSI), for quantifying the landscape pattern in the study area in 1997 and 2008.

The two images of Landsat Thematic Mapper (TM) taken in 1997 and 2008 were used to investigate the

changes of landscape patterns. The images were classified using the hybrid classification method. Spatial pattern analysis software FRAGSTATS 3.3 (McGarigal 1995) was applied to calculate landscape metrics of each class type and total landscape.

#### Statistical analysis

Pearson correlation test and regression analysis was applied to assess the relationship between landscape metrics and water quality parameters. Statistical analyses were conducted in R 2.7.12 (R Development Core Team 2007; Olsen 2009). The normality of water quality and landscape metrics data was examined in the initial phase. In some cases, log transformed data was applied to normalize the distribution, and linearize the relationship with landscape metrics (Madansky 1988; Jones et al. 2001). Pearson correlations were computed to assess pair-wise relations between water quality variables and landscape variables (i.e., landscape metrics). Regression analyses were then performed. The log-transformed water quality indicators were treated as response (or dependent) variables, and the landscape metrics were used as predictor (or independent) variables.

## Results and discussion

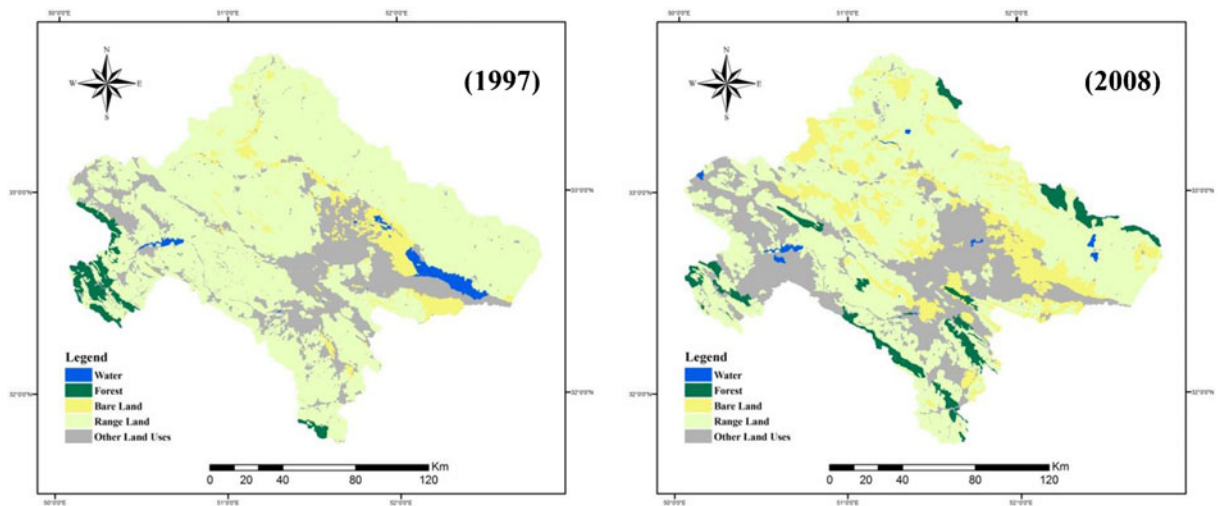
#### Land cover change

Land-cover classification maps for 1997 and 2008 are displayed in Fig. 2, which demonstrates that the bare land expansions had occurred in the study area from 1997 to 2008. Bare lands increased from 5.8 to 20 %, while rangelands decreased from 70 to 55 % in whole basin.

Range land has decreased in area (by 15 %); on the other hand, bare land has increased by 14.2 % (Table 1), which could be caused by recent drought in Iran.

The 10 sub basins, which have been set for the study area is shown by the name of their outlets (sampling site stations). The largest sub basin was Varzaneh and the smallest was Ziyar.

In particular, bare land expansion had occurred in Varzaneh (13.5 %), Choum (12.7 %), and Ziyar (12 %) sub basins. Bare land increases were traced to the conversion from rangeland. Zaman Khan (33.3 %) and Mousiyan Bridge (36.1 %) basins have shown the most dramatic decrease in range land in the 11-year span (Table 2).



**Fig. 2** Land cover of Zayandehroud Basin in (a) 1997 and (b) 2008

Therefore, the increase of bare land and decrease of rangeland accounted for the most obvious transformation in the study area. The most land cover changes occurred in the Mousiyan sub basin, which experienced significant changes in all types of land cover, except water bodies. Besides the major change, from rangeland to bare land, the other type of conversion was also identified in Fig. 2. The decreasing of natural forests which were located in the upper sub basins such as Ghaleshahrokh and Tanzimi Dam had occurred. However, in total, forests increased by 1.4 %, due to increasing planted forests.

Landscape pattern changes

Landscape metrics for each sub basin in class level were calculated. The change in landscape pattern in

11 years is shown in Table 3. There was a significant difference between the PLAND of bare land and rangeland in 1997 and 2008 ( $p < 0.05$ ). LPI changed particularly in Pol Kalleh Bridge, Zamankhan Bridge, and Tanzimi dam. The results showed that the ED of bare land has been increased from 1997 to 2008; however, the edge density of range land has been significantly decreased (Fig. 3).

Water quality

Results show that there is a clear trend for water quality variables (including BOD, COD, EC,  $\text{NO}_3$ , P, Na, Do, K, Ca, Cl,  $\text{SO}_4$ ,  $\text{HCO}_3$ , pH, and TDS) from upstream to downstream, which was linked to fluctuations of drainage discharge and changes in land use pattern. The water quality in the 11 years has declined, and there

**Table 1** Land cover changes between 1997 and 2008 in the Zayandehroud river basin, Iran

Land cover classes	1997 (ha)	(%)	2008 (ha)	(%)	Changes (ha)	(%)
Water	142,428	3.45	112,680	2.7	-29,748	-0.75
Forest	72,909	1.75	165,908	4	92,999	2.25
Bare land	370,134	8.9	824,382	19.8	454,248	10.9
Rangeland	2,977,955	71.6	2,286,622	55	-691,333	-16.6
Other land uses	593,660	14.3	767,494	18.5	173,834	4.2

**Table 2** Land cover and land use changes between 1997 and 2008 in Zayandehroud river basin, Iran

	Water		Bare land		Forest		Rangeland		Other land uses	
	1997	2008	1997	2008	1997	2008	1997	2008	1997	2008
Ghale shahrokh		5.12	0.45		35.6	12.965	50.59	47.7	13.326	34.203
Tanzimi Dam	1.52	14.59	0.341	2.2577	4.34	0.0352	62.955	41.072	30.8424	42.031
Zamankhan Bridge			0.204				84.966	51.66	14.831	48.336
Kalle Bridge			0.179	2.58		10.87	84.71	63.89	15.1133	22.664
Dizicheh	0.12	0.12	0.066	9.04		10.52	58.29	49.981	41.527	30.339
Lenj			3.215	7.304	2.87	10.73	70.875	54.34	23.043	27.635
Mousiyan			1.016	12.7		24.67	60.878	24.74	38.1092	37.889
Choum Bridge	0.0098	1.31	2.785	15.51		4.35	64.26	43.02	32.943	35.808
Ziyar Bridge	0.046		4.791	16.83		6.02	44.88113	22.95	49.38264	54.2
Varzaneh	2.154	1.69	9.2	22.75		2.79	74.626	58.65	14.0188	14.111
Whole Basin	1.371	4.38	5.759	19.91	2.642	3.99	70.04	55.07	20.196	16.658

was significant increase in BOD5, NO<sub>3</sub>, P, K, Ca, HCO<sub>3</sub>, NO<sub>3</sub>, and P concentrations ( $p < 0.05$ ) (See Tables 4). A significant difference of water quality among the sub basins was also revealed ( $p < 0.05$ ).

#### Relationship between landscape pattern and water quality

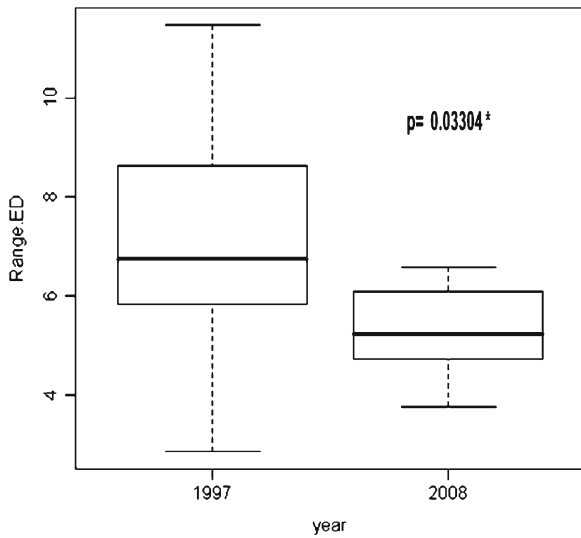
The results from the statistical analyses revealed that there was a significant relationship between land cover and in-stream water quality (See table 5). The results indicated that water quality was significantly correlated with both the proportions and configuration of rangeland areas. However, there was no significant correlation between water quality variables and proportion of forest in the Zayandehroud basin. Total edge of rangeland area had positive effects on water quality, especially on BOD5 and EC ( $p < 0.01$ ). In particular,

concentrations of BOD5 and EC were more likely to be high when rangeland areas in basins were fragmented into smaller patches. These results suggest that non-fragmented large rangelands in watersheds might reduce the concentrations of BOD5 and EC in the river. Lee et al. (2009) also found a similar result about the effect of rangeland ED on water quality. PLAND and LPI metrics of rangeland also had a positive effect on the decreasing nutrients (NO<sub>3</sub>, PO<sub>4</sub>) of water in this river ( $p < 0.05$ ). It was shown that degradation of rangeland led to the degradation of water quality which indicated the importance of rangeland conservation (Tong and Chen 2002; Lee et al. 2009). Thus, human land uses might degrade water quality not only by transforming natural areas into urban or agricultural areas generating pollutants and nutrients, but also by degrading the quality of remnant rangeland patches in basins with fragmented and isolated rangeland patches.

**Table 3** Landscape metric changes between 1997 and 2008 in Zayandehroud river basin

Land cover classes	ED		NP		LSI		PLAND		TE ( $\times 10^6$ m)		LPI	
	1997	2008	1997	2008	1997	2008	1997	2008	1997	2008	1997	2008
Range	4.19	4.01	68	47	20.07	27.54	70.04	55.07	108	167	63.08	46.47
Bare land	1.36	2.39	396	195	22.69	27.36	5.76	19.91	3.5	9.96	1.91	3.68
Forest	0.36	0.49	12	27	8.95	12.51	2.64	3.99	0.932	2.04	1.26	0.49
Water	0.17	0.56	13	47	5.64	13.59	1.37	4.38	0.424	2.32	1.12	2.13

PLAND percentage of landscape, NP number of patches, LPI largest patch index, ED edge density, TE total edge, LSI landscape shape index



**Fig. 3** Rangeland edge density (ED) in 1997 and 2008. *Bold horizontal lines* indicate the median, *boxes* indicate the interquartile range, and the *whiskers* indicate the maximum and minimum values

The results indicate that water quality of Zayandehroud River is closely associated with both the proportions of land cover and the configurations of bare land. Water quality is more likely to be degraded when there is high edge density of bare land. However, there was no significant correlation between water quality variables and proportion of forest in the Zayandehroud

**Table 4** Water quality changes between years 1997 and 2008 in the Zayandeh Roud River in Isfahan, Iran

Changes (%)	Year		Unit	Water quality indices
	2008	1997		
39.2	14.2	10.2	mg/L	BOD
-15.6	5.4	6.4	mg/L	Do
83.7	14.24	7.75	mg/L	K
1.1	1.84	1.82	mg/L	Cl
1000	0.77	0.07	mg/L	P
755.7	11.98	1.4	mg/L	NO <sub>3</sub>
15.9	74.8	86.7	mg/L	so4
14.8	86.45	75.3	mg/L	Ca
14.7	622.66	542.7	mg/L	Na
11.4	190.77	171.2	mg/L	HCO <sub>3</sub>
654.7	101257.9	13416	mg/L	TDS
20.7	2.3	2.3	us/cm	EC
-1.28	7.6	7.7	-	pH

**Table 5** Statistical relationship between landscape pattern and water quality in Zayandehroud river basin in Isfahan, Iran

	BOD	COD	Na	Do	K	Ca	Cl	so4	HCO <sub>3</sub>	Ec	pH	TDS	P	NO <sub>3</sub>
Bareland-ED	.625**	.555*	.632**	-.915**	.634**	.604**	.570*	.512*	.802**	.227		.663**	.503*	.716**
Bareland-LPI	.915**	.925**	.947**	-.687**	.913**	.945**	.941**	.937**	.565*	.919**			.601**	.723**
Bareland-LSI	.741**	.783**	.880**	-.598**	.752**	.834**	.878**	.944**	.775**	.938**	.488*			
Bareland-NP	.745**	.684**	.658**	-.859**	.769**	.692**	.629**	.555*	.584*	.500*			.631**	.921**
Bareland-PLAND	.952**	.984**	.962**	-.531*	.957**	.960**	.947**	.907**	.706**	.918**				.568*
Bareland-TE														
Forest-NP														
Range-ED	-.609**	-.571**	-.590**	.645**	-.610**	-.615**	-.600**	-.583**	-.693**	-.531*				-.533*
Range-LSI	.738**	.576**	.518*		.557*	.505*	.475*	.456*	.289	.496*				
Range-NP	.541*									.332				
Range-TE	.905**	.910**	.895**	-.354	.866**	.873**	.865**	.850**	.571**	.879**				
Range-PLAND														
Water-NP	.871**	.909**	.825**		.881**	.846**	.806**	.727*		.753*				.781**

\* Correlation is significant at the 0.05 level (2-tailed)  
 \*\* Correlation is significant at the 0.01 level (2-tailed)

basin except the number of patches for forest land cover that was negatively related to EC. It means that by increasing the number of forest patches in sub basins, electrical conductivity has been decreased. The total edge of rangeland area had positive effects on water quality, especially on BOD5 and EC ( $p < 0.01$ ).

## Conclusions

This study evaluated general land cover patterns, and environmental impacts of land cover change in the Zayandehroud basin in 1997–2008. Many studies have reported that forest and vegetation cover like rangeland and forests play primary roles in protecting water quality in adjacent aquatic systems (Tong and Chen 2002; White and Greer 2006; Lee et al. 2009). Results of this study also revealed that the degradation of rangeland led to the degradation of water quality which highlighted the importance of rangeland conservation in water quality management at landscape scale. However, a significant relationship between forest areas and water quality was not observed in this study because the Zayanderoud basin is located in a semi-arid area of Iran, where forests are very limited and are only in small patches with low density. Thus, in semi-arid areas like the Zayanderoud basin, rangeland conservations play a more important role for the management of water quality.

This study indicates that landscape characteristics are significantly correlated to stream water quality in the Zayandehroud basin. Water quality parameters had more significant correlations with the edge density of rangeland and also with PLAND of the bare lands in the study area. Therefore, these landscape metrics are better indicators for monitoring and are more accountable in predicting water quality in this region. Therefore, in characterizing stream water quality using landscape metrics, the composition indices and spatial configuration indices are both important.

For management and restoration actions, reversal of land use to a less-developed state is rarely practical so improvement of the stream condition more often depends on the improvements in landscape management and design.

Results of this study can be used in establishing and implementing effective water management at landscape scale, in this region. In addition, the information on the hydrologic effects of land use can provide

guidelines, not only for resource managers in restoring the aquatic ecosystem but also for policy makers in evaluating alternate land management decisions.

**Acknowledgments** We express our appreciation to the Isfahan regional water authority and the Department of Environment (DOE), Isfahan Provincial Directorate of Environmental Protection for providing us with the water quality data and useful information on the study area.

## References

- Alberti, M., Booth, D., Hill, K., Coburn, B., Avolio, C., Coe, S., et al. (2007). The impact of urban patterns on aquatic ecosystems: an empirical analysis on Puget lowland sub-basins. *Landscape Urban Plan*, 80(4), 345–361.
- Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. *The Annual Review of Ecology, Evolution and Systematic*, 35, 257–284.
- Amiri, B. J., & Nakane. (2008). Entire catchment and buffer zone approaches to modeling linkage between river water quality and land cover—a case study of Yamaguchi prefecture, Japan. *China Geographical Science*, 18(1), 085–092.
- Basnyat, P., Teeter, L., Lockaby, B. G., & Flynn, K. M. (2000). Land use characteristics and water quality: a methodology for valuing forested buffers. *Environmental Management*, 26, 153–161.
- Callender, E., & Rice, K. C. (2000). The urban environmental gradient: anthropogenic influences on the spatial and temporal distributions of lead and zinc in sediments. *Environmental Science and Technology*, 34, 232–238.
- Changnon, S. A., & Demissie, M. (1996). Detection of changes in stream flow and floods resulting from climate fluctuations and land use drainage changes. *Climate Change*, 32, 411–421.
- Cretaz, A. L. & Barten, P. K. (2007). *Land use effects on streamflow and water quality in the northeastern United States, Florida and London*: CRC Press-Taylor & Francis Group, Boca Raton, 319 pp.
- Gustafson, E. J. (1998). Quantifying landscape spatial pattern: what is the state of the art. *Ecosystems*, 1(2), 143–156.
- Hill, A. R. (1981). Stream phosphorus exports from watersheds with contrasting land uses in southern Ontario. *Water Resource Bulletin*, 17(4), 627–663.
- Howarth, R., Donald, A., Cloern, J., Elfring, C., Hopkinson, C., Lapointe, B., et al. (2000). Nutrient pollution of coastal rivers, bays, and seas. *Issues in Ecology*, 7, 1–17.
- Iserendinoa, M., Casauxa, R., Archangelsky, A. M., Di Prinzi, A. C. Y., Brand, A. C., & Kutschker, A. M. (2011). Assessing land-use effects on water quality, in-stream habitat, riparian ecosystems and biodiversity in Patagonian northwest streams. *Science of the Total Environment*, 409, 612–624.
- Jensen, J. R., Cowen, D., Narumalani, S., & Halls, J. (1997). *Principles of change detection using digital remote sensor data*. In *Integration of Geographic*



- Information Systems and Remote Sensing*. New York: Cambridge University.
- Johnson, L. B., Richards, C., Host, G. E., & Arthur, J. W. (1997). Landscape influences on water chemistry on Midwestern stream ecosystems. *Fresh Water Biological*, 37, 193–208.
- Jones, K. B., Neale, A. C., Nash, M. S., Van Remortel, R. D., Wickham, J. D., Ritters, K. H., et al. (2001). Predicting nutrient and sediment loadings to streams from landscape metrics: a multiple watershed study from the United States. *Landscape Ecology*, 16, 301–312.
- Lee, S. W., Hwang, S., & Lee, S. B. (2009). Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics. *Landscape and Urban Planning*, 92, 80–89.
- Lenat, D. R., & Crawford, J. K. (1994). Effects of land use on water quality and aquatic biota of three North Carolina piedmont streams. *Hydrobiologia*, 294(3), 185–200.
- Madansky, A. (1988). *Prescriptions for working statisticians*. New York: Springer.
- McGarigal, K. (1995). *Fragstats: spatial pattern analysis program for quantifying landscape structure*. General Technical Report PNW-GTR-351. Portland: USDA Forest Service, Pacific Northwest Research Station.
- Mehaffey, M. H., Nash, M. S., Wade, T. G., Ebert, D. W., Jones, K. B., & Rager, A. (2005). Linking land cover and water quality in New York City's water supply watersheds. *Environmental Monitoring and Assessment*, 107, 29–44.
- Meyer, W. B., & Turner, B. L. (1994). *Changes in land use and land cover: A global perspective*. New York: Cambridge Univ. 537 pp.
- Murray-Rust, H., Sally, H., Salemi, H.R. and Mamanpoush, A. (2000). *An overview of the hydrology of the Zayandeh Rud Basin*, Esfahan Province, Iran. IAERI-IWMI Research Reports 3.
- Olsen, A. R. (2009) Introduction to R Statistical Software, western ecology division, corvalis (541) 754–4790.
- Pour moghadam, H., Afsharzadeh, S., Saniei, M. (2001). Water pollution and river algae: study in Zayandeh Rood River–Isfahan, *Journal of Research in Medical Sciences*, 6(2).
- R Development Core Team, (2007). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.
- Rothenberger, M. B., Burkholder, J. M., & Brownie, C. (2009). Long-term effects of changing land use practices on surface water quality in a coastal river and lagoonal estuary. *Environmental Management*, 44(3), 505–523.
- Royappan, M. (2001). Survey of effect of change of land use to runoff by SWAT model in South Africa, Kentucky University, 482
- Salemi, H. R. (2004). An overview of the hydrology of the Zayandeh Rud Basin, Iran. *Water and Wastewater (Isfahan)*, 1(50), 2–13.
- Schoonover, J., Graeme, E., Lockaby, B., & Shufen, P. (2005). Changes in chemical and physical properties of stream water across an urban–rural gradient in western Georgia. *Urban Ecosystems*, 8, 107–124.
- Sliva, L., & Williams, D. D. (2001). Buffer zone versus whole catchment approaches to studying land use impact on river water quality. *Water Resources*, 34(14), 3462–3472.
- Smith, S. V., Swaney, D. P., Talaue-Mcmanus, L., Bartley, J. D., Sandhei, P. T., McLaughlin, C. J., et al. (2003). Human, hydrology, and the distribution of inorganic nutrient loading to the ocean. *Bioscience*, 53, 235–245.
- Strayer, D. L., Beighley, R. E., Thompson, L. C., Brooks, S., & Nilsson, C. (2003). Effects of land cover on stream ecosystems: roles of empirical models and scaling issues. *Ecosystems*, 6, 407–423.
- Tong, S. T., & Chen, Y. (2002). Modeling the relationship between land use and surface water quality. *Journal of Environment Management*, 66(4), 377–393.
- Tu, J. (2011). Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. *Applied Geography*, 31, 376–392.
- USEPA, (2001). Our Built and Natural Environments: a technical review of the interactions between land use, transportation, and environmental quality 2001, pp. 49. <http://www.smartgrowth.org/>. Accessed 12 May 2012.
- White, M. D., & Greer, K. A. (2006). The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Peñasquitos Creek, California. *Landscape Urban Plan*, 74(2), 125–138.
- Wu, J., & Hobbs, R. (2002). Key issues and research priorities in landscape ecology: an idiosyncratic synthesis. *Landscape Ecology*, 17, 355–365.
- Yuan, F. (2008). Land-cover change and environmental impact analysis in the Greater Mankato area of Minnesota using remote sensing and GIS modeling. *International Journal of Remote Sensing*, 29(4), 1169–1184.