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Water Quality Restoration Using Landscape Metrics Analysis: A Case Study in the Golestan Province of Iran

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Abstract

The results of an integrated study aimed at restoring water quality in a large watershed including seven catchments in north east Iran are presented in this paper. This case study demonstrates how landscape metrics reflect direct or surrogate causes of the land use practices that are the determinants of water quality parameters. Water quality factors included EC, pH, Cl-1, HCO3-1, SO4-2, Mg+2, Ca+2 and Na+1 measured over the period 1988-2005. Forty-six spatial metrics of the catchments were computed using available GIS layers and MODIS and Landsat TM imagery. Based on a correlation analysis, the 46 parameters of the catchments were reduced to 14, and these were correlated with the eight water quality factors of the catchment variables, 10 were found correlated to water quality factors. Among these, 8 are modifiable and watershed managers should be able to alter these factors to restore water quality. As the first study of this kind in Iran, further applicability of the method and its importance in water quality management through quantitative metrics of the landscape is outlined and the procedures to adopt in future studies for proposing restoration actions in the study area is demonstrated.

Keywords: Modeling, Landscape, Water Quality Management, Rehabilitation

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1. Introduction

Many concepts and approaches have been offered and employed in recent years to define, evaluate and manage the quality and quantity of ecosystems resources. Terms have included ecosystem capability, land use planning and environmental impact assessment, and evaluation of ecosystem integrity, health, goods and services. Most commonly-used land evaluation and land use planning approaches at best only act to prevent further degradation of ecosystems. One of the main land use optimization applications with an element of restoration focus is the work conducted by Aerts and Heuvelink (2002) who applied simulated annealing to optimize site selection for restoration of an abandoned open pit mine in South Africa.

Environmental impact assessment (EIA) has a mitigation step to draw attention to prevention or restoration of negative changes to the ecosystems. Eventually, due to the diversity of development impacts, the mitigation step of EIA suffers from a lack of technical detail and applied procedures for its implementation.

Wiegand *et al.* (2010), Su *et al.*, (2010), Liu *et al.*, (2009), Paetzold *et al.*, (2009), Rapport *et al.*, (2008), Graymore *et al.*, (2008), Jian *et al.*, (2007), Xu *et al.*, (2005), and Whitford *et al.*, (1999) are just a few recent researchers dealing with ecosystem health and integrity. However, most of these studies focus solely on methods of assessing rather than restoring ecosystems health. This is the same for studies of ecosystem goods (see for example Posthumus *et al.*, 2010; Yapp *et al.*, 2010; O'Farrell *et al.*, 2007; Beaumont *et al.*, 2007; Winkler, 2006; Curtis, 2004; de Groot *et al.*, 2002; and Jewitt, 2002).

On the restoration side, again most of the related literature revolves around the issue of assessing the success of restoration measures mainly through devised indicators. In this context, Zhang *et al.*, (2010) evaluated the investigations within wetland science and reported that while treatment of the subject matter by relevant researchers has increased nine-fold during 1991-2008, they neglected practical restoration measures.

Fortunately, methods and studies that focus more on the restoration of ecosystem functions, goods and services are emerging. An early compendium (Saunders *et al.* 1993) compiled and edited a large set of papers on the reconstruction of fragmented ecosystems. Hobbs and Yates (1998) provided guidelines for managing remnant vegetation in Australia. Forman and Mellinger (1999) offered ideas on the best forest road networks to create ecologically desirable patterns and lessen the negative effects. Lambeck (1999) used a focal species approach to offer plans for biodiversity conservation and restoration in agricultural regions of Australia. Bryan (2000) conducted a detailed assessment for planning re-vegetation strategies in an agricultural landscape in Australia. Salman Mahiny (2004) recommended actions that could eventually restore those remnants remnant vegetation in the Boorowa region of Australia.

Dealing with vegetation restoration, most recent studies have focused on landscape metrics, as these are easy to calculate indicators of ecosystem health (see for example Mahiny, 2007). Larsen and Harvey (2010) predict distinct classes of landscape pattern, process, and restoration potential in shallow aquatic ecosystems. In this connection, Jones *et al.* (2001) successfully used landscape metrics to model water quality at the watershed scale. Wang *et al.* (2005) studied long term effects of land use change on non-point source pollution of a river and offered measures to restore water quality. Novotny *et al.* (2005) offer a multilayered schema for restoration of water quality through landscape metrics. Uuemaa *et al.* (2005) demonstrate that there are relationships between landscape metrics and water quality data in their study area in Estonia. Xiao and Ji (2007) affirm that landscape characteristics including proportion, edge density and contagion in mine waste-located watersheds could account for as much as 77% of the variation of water quality indicators. Goetz and Fiske (2008) evaluate the relationship between diversity and abundance of stream biota to landscapes in the mid-Atlantic USA. Roberts and Prince (2010) show that landscape metrics can be used to approximate the amount of total nitrogen (TP) and total phosphorous (TP) in their study site.

Even though there is a plethora of studies on ecosystem management, there is still a shortage of the approaches, detailed techniques and quantitative measures that are designed specifically for the restoration of degraded ecosystems. In this study, in Golestan Province, north eastern Iran, an attempt has been made to tie the landscape metrics and land use and land cover parameters to water quality factors. The main goals have been to generate a feasibility assessment for offering quantitative water quality restoration measures, given the lack of some required water quality and geographical data and to provide a paradigm for future work in Iran.

2. Materials and methods

Study area description

The study area is a large part of the Golestan Province, encompassing seven catchments of the main river Gorganrud. The area is located in the north east of Iran (figure 1). The surface area of the Province is about 20 000 square kilometers, about 1.3% of Iran’s total land area and of this, around 13 000 square kilometers fall inside the seven catchments used in this study. The southern boundary of the province is dominated by the eastern stretches of the Alborz Mountain, covered by lush temperate deciduous forests. In the north is the vast Gorgan plain that becomes semi arid in areas close to the boundary of Turkmenistan.

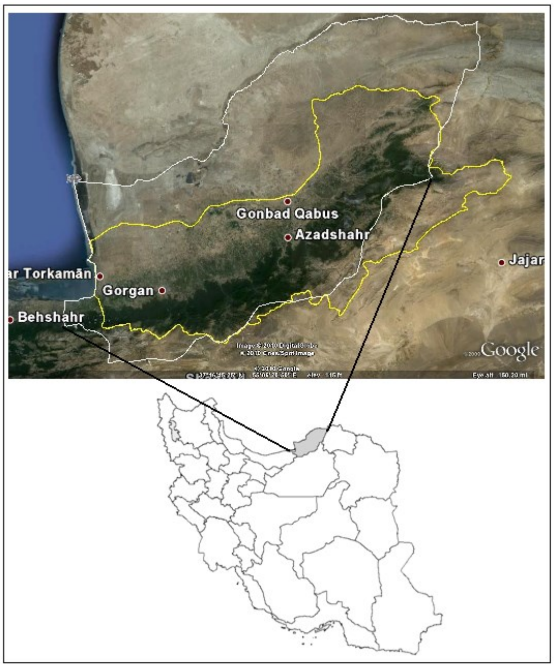

Figure 1. Golestan Province in the North East of Iran and the area of study inside

Average yearly rainfall of the area is around 601 mm and the average annual temperature is 17.8 °C. Most of the precipitation falls in March followed by November and October. The ombrothermic curve (Figure 2) shows that the area is under water deficit during June to September.

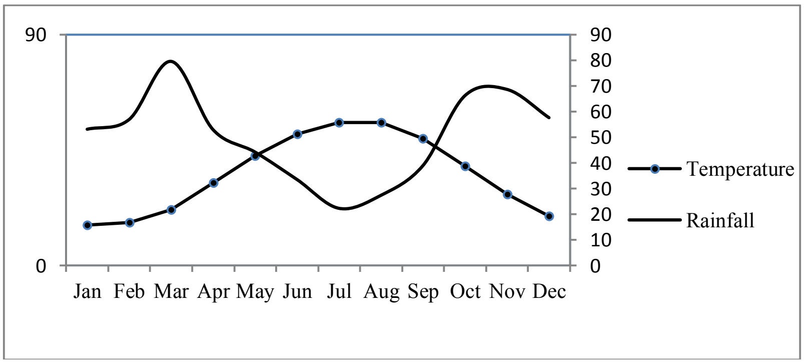

Figure 2. Ombrothermic curve of the study area

The Province has a considerable biological diversity and contains around 20 percent of the flora and fauna of Iran of these, many are being actively protected by the Department of the Environment of Iran under different IUCN categories such as wildlife sanctuary, protected area and Ramsar Wetland. The northern plains and the piedmonts along with some mountain forests are under heavy agriculture and that is why the area has become known as one of the main agricultural zones of Iran. The agricultural practices mainly include cultivation of wheat, oats, barely, vegetables, fruit orchards and olive groves. Also, heavy cattle and sheep grazing and animal husbandry are practiced in the proximity of streams and rivers and even on steep slopes facing rivers. In many places, the riparian vegetation has been removed as a result of agricultural practices and grazing by domestic animals and as a source of logs and wood for home use. This has exerted heavy pressure on the land, with rivers receiving major amounts of point and non-point source pollution. This has had ramifications as to the procurement of potable water for town residents. A few water treatment plants are located in the vicinity of Gorgan City and other main towns in the area, but the pollution load is heavy, such that the water managers are now providing part of the potable water through extraction from wells inside Gorgan City. This trend is impacting water quality and quantity both for domestic use and that entering the Caspian Sea- a water body famous for Sturgeon that produce the renowned Iranian Caviar. Hence, controlling the downgrading of the water supply is now ranked high on the agenda of the relevant administrative bodies.

Three main rivers including Gorganrud, Qara-Su and Atrak flow in the province in an approximately east-west direction and discharge their water into the Caspian Sea in the Gorgan Bay area. Of these, Gorganrud River was selected as it is highly impacted by the land use practices in the Gorgan Plain, the Ablorz mountain range and its piedmont in the south of the Province. Several small creeks, streams and tributaries join the river that flows around 211 km before reaching the Caspian Sea (Figure 3).

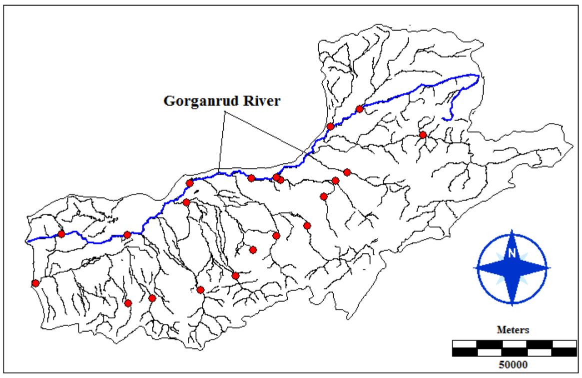

Figure 3. Gorganrud River, stream networks and water sampling stations used in the study

Using a digital elevation model (DEM) with a resolution of 30 meters (Figure 4), the river network was defined and the area was subdivided into 7 catchments (figure 5) which helped in further studies of the differences in land use practices and their eventual effect on water quality factors. The goal is to offer restoration measures for each catchment separately. The DEM was also used for derivation of terrain attributes such as slope, aspect and elevation means for the catchments. The average slope of the seven catchments ranges from 0% for catchment 7 to around 27.7% for catchment 5 while the maximum slope reaches 179%. Elevation ranges from 0 m in catchment 7 to about 3660 m in catchment 5.

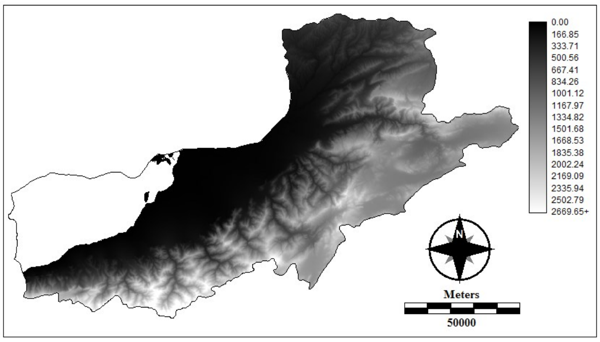

Figure 4. Digital Elevation Model of the study area

The staff and experts of the Department of Surface Water Assessment and Management in Golestan Province have monitored the status of water quality factors for around 20 years. Unfortunately, the sampling has been sparse, and for some locations no information has been recorded. However, through the Department, bi-weekly data from 42 regularly sampled stations along the rivers and river mouths was available for EC, pH, Cl^{-1}, $HCO3^{-1}$, $SO4^{-2}$, Mg^{+2}, Ca^{+2} and Na^{+1} for the period 1988–2005. After cross checking with river networks and assessing the completeness of the data, 21 stations were used for extraction of information on the selected water quality factors (Figure 3). The stations were selected such that water treatment in the facilities near towns had no effect on the readings.

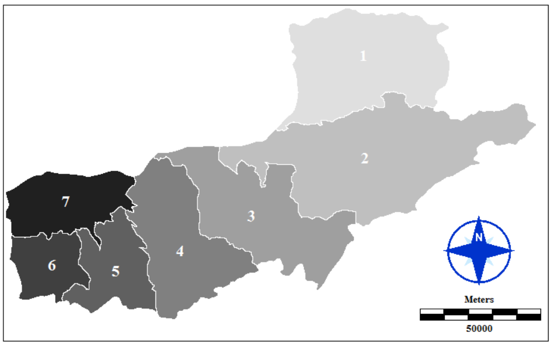

Figure 5. Seven catchments in the study area

To dampen the effects of rainfall events and other periodic phenomena and also in recognition of the lack of data, average values of water quality parameters for each catchment were used to conduct statistical analyses (Tab. 1). Additionally, the water quality recording stations were evaluated in terms of location and the pour points of the catchments. For catchment 1, the two stations are positioned nearly at the pour point with relatively similar average values. This is also the case with catchment 2 and for catchments 6 and 7; the stations represent the general condition of the area based on location and the average values recorded for their stations. Visually, catchments 3 and 5 present a challenge with their stations almost half way along the river. However, in both these cases, the location relative to terrain features; when the DEM layer is used indicates a good share of uphill areas where most of the drained water overland has a chance to impinge upon water quality of the stations. For catchment 4, there are both uphill and downhill stations and a test of water quality average values for these stations reveals no major difference and besides the averaging lumps the scores such that the final value represents; to some degree the input from the surrounding landscape. This is also strengthened by the fact that in most cases, the temporal trend of change in different water quality factors is similar among the stations located in each catchment.

Table 1. The Average Values Used for the Seven Catchments in the Study Area

Catchments	Water Quality Factors							
	EC (µs/cm)	pH	HCO3^{-1} (meq/l)	Cl^{-1} (meq/l)	SO4^{-2} (meq/l)	Mg^{+2} (meq/l)	Na^{+1} (meq/l)	Ca^{+2} (meq/l)
1	2080.31	7.47	4.58	10.37	6.97	6.01	11.97	3.85
2	1023.93	7.43	4.05	4.12	2.89	3.36	4.75	2.91
3	704.20	7.33	3.59	2.93	1.25	2.03	3.31	2.38
4	2741.81	7.27	4.25	13.14	11.85	8.36	15.28	5.56
5	761.33	7.29	4.15	1.82	2.34	2.83	1.74	3.61
6	1531.21	7.36	4.99	6.57	4.66	4.97	7.28	3.83
7	4527.82	7.35	4.74	23.17	19.89	13.32	27.06	7.29

µs/cm: micro-Siemens per centimeter, meq/l: milli-equivalents per liter

Furthermore, to assess the accuracy of the water quality data presented in Table 1, ion balance was calculated using Equation 1 (Hounslow, 1995):

Equation 1. $$Error\,of\,ion\,balance = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions}$$

When using Equation 1, an error of up to ±5% is deemed acceptable while values outside this range indicate error in assessing or recoding the data (Hounslow, 1995). In this study, both the original and the averaged water quality data were used in Equation 1 and in both cases the results were well below the acceptable threshold, hence their suitability for further analyses.

To derive land use and land cover maps of the area, MODIS imagery of the Terra Satellite were used for the Province. These were pre-classified to an average of the yearly condition and shown in Figure 6 in which increasingly lighter colors indicate higher values of NDVI. A separate classification of three Landsat TM scenes of the year 2002 was also conducted. The layer that included patches of woodland and vegetation was read in the Fragstats Software (McGarigal *et al.,* 2004) and landscape metrics were calculated and assigned to the patches at the landscape and patch level. Number of patches (NP), fractal dimension (FD), perimeter (Perim), contiguity (Contig) and Euclidean nearest neighbor (ENN) of the woodland patches were the metrics calculated and used in later analyses after ensuring no major correlation exists among them (Tab. 2).

Table 2. Metrics used in the study and their interpretations

Metrics	Description	Range	Units
Number of Patches (NP)	NP equals the number of patches in the landscape.	$NP \geq 1$, without limit.	None
Perimeter (P)	P equals the perimeter (m) of the patch	$P > 0$, without limit.	Meters
Fractal Dimension Index (FD)	FD approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane filling perimeters.	None	$1 \leq FD \leq 2$
Contiguity Index (Contig)	Contiguity equals 0 for a one-pixel patch and increases to a limit of 1 as patch contiguity, or connectedness, increases.	None	$0 \leq Contig \leq 1$
Euclidean Nearest Neighbor Distance (ENN)	ENN approaches 0 as thedistance to the nearest neighbor decrease.	Meters	$ENN > 0$

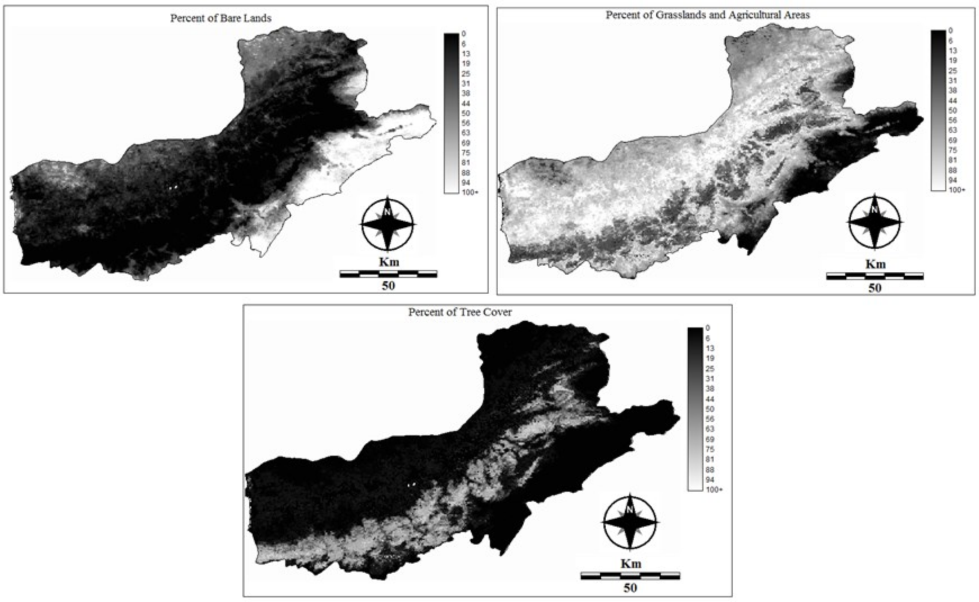

Figure 6. Three layers of information extracted out of the MODIS imagery

Among the social and economic aspects of the catchments, surrogate layers including the main and secondary roads and towns (Figure 7) were generated and included in the study. Maps of villages and industrial sites at different buffer widths were derived and used. Climate layers available on the internet under the rubric WORLDCLIM (Hijmans *et al.,* 2005) were used in our study. For compiling a database, the layers were co-registered and converted to raster grids at 30 meter resolution. The database included 46 parameters covering all aspects of land use and land cover together with landscape metrics, climatic and surrogate social and economic layers and metrics targeting riparian vegetation through calculations in river buffer zones.

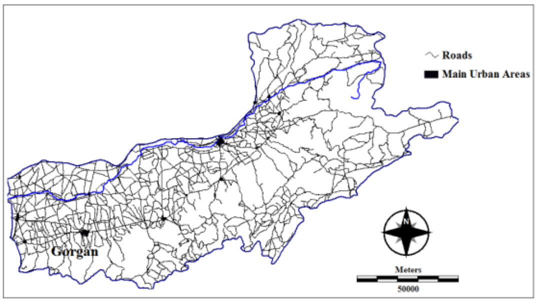

Figure 7. Road networks and Gorgan as the main town in the study area

A correlation analysis was used to single out the uncorrelated independent layers of the catchments. Next, correlation analysis was used with the catchment parameters against each of the water quality factors and significant correlations were established among them.

A catchment formula was devised and implemented through which the seven catchments were ranked in terms of deterioration level. This was accomplished through combination of three aspects of the catchments: (1) condition of the catchments based on their environmental parameters, (2) importance of these environmental parameters as weights, and (3) condition of the catchments in terms of the water quality factors when agricultural and domestic uses are considered.

Condition of the catchments for environmental parameters was assessed based on classifying these parameters into two groups: those that benefited the condition when increased and those that benefited the condition when decreased. For example, the higher the area of tree cover, patch density and contiguity, the better the situation is for the catchments. The reverse trend was used for variables such as road density, agriculture and patch proximity. Water quality standards for potable and agricultural use generated by the Iran Department of Environment (DOE) and FAO were resorted to in the process. Values for the three aspects of the catchments were integrated using a weighted linear combination. Using the relationships between independent and dependent variables, general restoration measures were derived that could potentially lead to improvement in water quality. The process benefited from the quantitative metrics that are amenable to modification by relevant authorities

3. Results and discussion

Application of the correlation analyses showed that of the 46 parameters, a subset of 14 is uncorrelated, ecologically meaningful and interpretable. Hence, they were selected for further analysis (Tab. 3).

Table 3. Catchments of the study area and the 14 parameters extracted for each

Catchment	Percent Vegetation Cover	Percent Agriculture and Range Cover	Percent Bare land Cover	River Density (km /Sq km)	Road Density (km /Sq Km)	Mean Slope (%)	NP	Mean FD	Mean Perim (km)	Mean Contig	Mean ENN (m)	Percent of Towns and Villages	Percent of Roads in 30 m Buffer of the River	Min Annual Rainfall (mm)
1	6.68	81.6	11.3	19.4	23.2	16.8	47	1.029	58.85	0.21	154371	1.48	0.02	22
2	19.8	40.8	38.9	13.9	27.4	21.6	63	1.028	61.82	0.19	147926	1.07	0.01	17
3	32.2	67.1	0.20	15.2	30.6	16.7	12	1.025	62.67	0.17	192820	1.45	0.01	18
4	35.9	63.6	0.13	18.8	35.8	21.3	19	1.026	65.35	0.15	113273	1.18	0.02	17
5	38.6	59.7	1.36	19.0	33.7	27.7	20	1.030	65.17	0.16	142072	1.55	0.03	16
6	31.3	66.9	1.03	15.6	45.9	12.1	5	1.018	63.78	0.18	114861	1.46	0.01	17
7	0.31	86.3	12.8	15.6	43.8	0.01	5	1.029	67.48	0.13	114291	1.26	0.01	36

Another close look at the 14 parameters of the catchments and their correlation coefficients showed the high individual coefficients of 10 of the parameters out of 14. In order to assess the effects of individual parameters on the selected water quality factors, the number of times each of the parameters showed high correlation with the water quality parameters was also tabulated (Tab. 4) and inserted as the column "Count" in the table.

Table 4. Correlation coefficients between catchment parameters and water quality factors

Independent Variables	Water Quality Parameters								Count
	EC	pH	$HCO3^{-1}$	Cl^{-1}	$SO4^{-2}$	Mg^{+2}	Na^{+1}	Ca^{+2}	
Min Annual Precipitation	0.91			0.78	0.72	0.74	0.79	0.73	6
Mean Nearest Neighbor Distance	-0.67		-0.91	-0.72	-0.82	-0.81	-0.7	-0.87	7
Mean Contiguity	-0.55	0.73						-0.55	3
Mean Patch Perimeter	0.56	-0.79						0.61	3
Mean Slope	-0.8	-0.56	-0.54	-0.87	-0.67	-0.69	-0.89	-0.66	8
Road Density in 30m Buffer	0.57							0.67	2
Agriculture Density	0.61		0.54	0.57	0.59	0.61	0.59	0.47	7
Tree Cover	-0.69	-0.7		-0.56	-0.59	-0.61	-0.57		6
Number of Patches		0.63							1
Road Density in Catchment			0.69						1

As can be seen from Table 4, mean catchment slope, mean nearest neighbor of the woodland patches and percent of agriculture and range area relative to the catchment size show correlation 7 out of 8 times for the 8 water quality factors. For percent vegetation cover and mean annual rainfall this share was 6 out of 8. Next are the mean perimeter of the woodland patches and their contiguity which have been ranked first in 3 bouts of correlation analyses. River length relative to catchment size has been ranked 1 in two cases of the correlations while percent of the roads within 30 meters of the rivers and number of woodland patches have only ranked top once in the analyses. This list also shows that out of the 10 parameters, 8 are relevant to management actions. However, it should be noted that the correlations showed here do not necessarily imply cause and effect relations. In other words, in most cases, the parameters have acted as a surrogate of the real underlying causes of changes in the physical and chemical properties of the rivers. The result of the correlation analyses show that the higher the perimeter of the woodland patches, the area under cultivation and the percent of roads in the catchment, the water quality is lower.

Condition of the catchments was assessed based on considering catchment variables in two groups: (1) percent tree cover, vegetation patch density, patch contiguity, and (2) agriculture, barren areas, road length, fractal dimension, patch perimeter, patch Euclidean nearest neighbor distance, the area under villages and towns in each catchment and also the percent of road network within 30 m of the river and streams. For the group 1 variables, the less the measure, the worse is the condition of the catchment. For the group 2 variables, the reverse is true. In other words, in these instances, the higher the figure, the worse is the condition of the catchments. Thus, number 7 was assigned to the worst catchment and number 1 to the best. This assessment was also complemented by the weights derived from the importance of the catchment variables in the correlation analyzes (Tab. 4, last column). To avoid multiplying values with a weight of zero, a value one was added to all weights. Furthermore, the process was completed by considering the condition of the catchments for water quality factors. The water quality of the catchments was within standard levels set by the DOE and FAO for potable and agricultural uses. However, Cl-1 and Na+1 were the two factors close to exceeding the standards. The condition of the catchments for these two water quality factors was considered in the final integrated ranking through the following equation:

Equation 2. $R_i = W_i * X_i + Q_{Cl\,i} + Q_{Nai}$

in which R_i is the rank of the catchment i, W_i is the weight of the catchment variable i based on Table 3 (last colum), X_i is the condition of the catchment for the catchment variable i, $Q_{Cl\,i}$ is the rank of the catchment i for Cl^{-1} and finally Q_{Nai} is the rank of the catchment i for Na^{+1}. Using formula 1, the catchments were ordered in terms of degradation. The calculations are depicted in Table 5.

Table 5. Data used to rank the seven catchments

	Rank of Independent Variables											Rank of Water Quality Factors	
Catchment	Percent Vegetation Cover	Percent Agriculture and Range Cover	Percent Bare land Cover	Road Density (km /Sq Km)	NP	Mean FD	Mean Perim (km)	Mean Contig	Mean ENN (m)	Percent of Towns and Villages	Percent of Roads in 30 m Buffer of the River	Cl^{-1}	Na^{+1}
1	6	6	5	1	3	6	1	1	6	6	6	5	5
2	5	1	7	2	2	4	2	2	5	1	1	3	3
3	3	5	2	3	6	2	3	4	7	4	4	2	2
4	2	3	1	5	5	3	6	6	1	2	2	6	6
5	1	2	4	4	4	7	5	5	4	7	7	1	1
6	4	4	3	7	7	1	4	3	3	5	5	4	4
7	7	7	6	6	7	5	7	7	2	3	3	7	7
Weight	7	8	1	3	2	1	4	4	8	1	2	1	1

Based on the relationships inferred through the regression analyzes, no matter causal or surrogate, general scenarios were derived for rehabilitation of water quality through the 8 parameters that are within reach of the watershed managers. As such, reducing the area under agriculture, reshaping the remnant woodlands towards more continuous and less fragmented patches, decommissioning or relocating roads or providing riparian vegetation on both sides of the roads and river banks are some of the measures that could be taken to alleviate the river pollution. Planting native species of trees in the vicinity of woodlands to diminish patch perimeter and increasing their contiguity will provide more vegetated areas and automatically diminish the area under cultivation.

Application of these restoration practices can be best assessed in more detailed studies in future targeting one or all of the restoration measures. Where to reduce the area under agriculture can be decided based on a multi criteria evaluation (MCE) of the area for agricultural suitability coupled with economic-social assessments and the results of this study. Using more detailed data on the shape and size, perimeter and contiguity of the remnant vegetation patches, it is possible to apply different restoration measures and to see the results based on the modeled relationships. In this way, researchers and decision makers can evaluate the outcomes based on the time, effort and expenses incurred. Choosing the best plant species for reforestation can also be facilitated using local information and other studies conducted in areas within Golestan Province. For instance, Salman Mahiny and Mashayekhan (2008) applied a MCE approach to assess the success of reforestation in Golestan Province and evaluated the feasibility of using selected native species for this purpose. Applying a suitable river buffer width and covering it with suitable plant species can be pursued using the preliminary results obtained in the present study. Where to decommission roads and to relocate them deserves a detailed study of its own, as do other aspects covered briefly above. This study has provided a focused geographical context for directing restoration efforts. Hence, defining quantitative targets in this study can at least help select parameters when devising restoration scenarios and approximating near optimal solutions with multiple objectives such as the restoration measures presented in this study.

The ranking of the catchments was implemented to guide managers in terms of prioritizing rehabilitation efforts. Using these ideas, a final map was provided that should be of use to land managers in planning their rehabilitation actions (Figure 8).

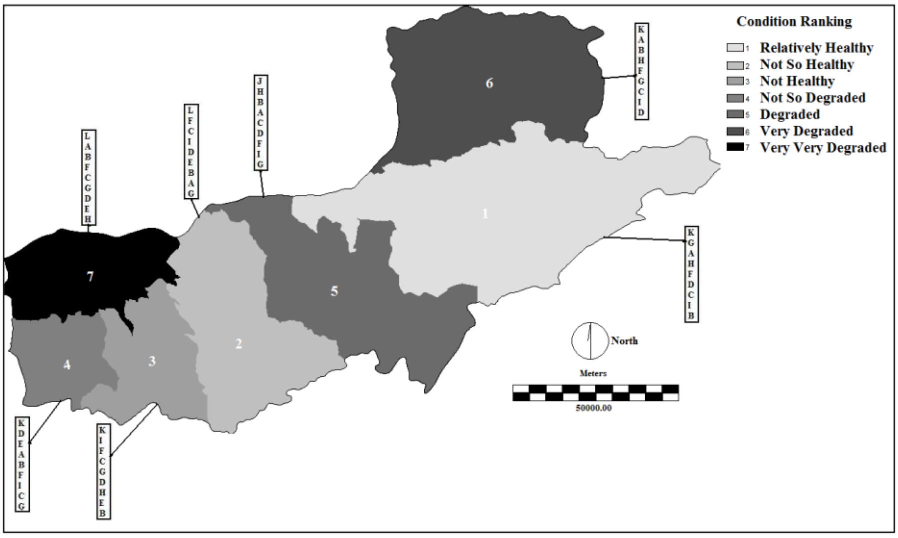

Figure 8. Management actions and their order to improve water quality in the catchments

Code of Actions: A: Planting Trees B: Reducing Agricultural Lands
C: Replanting Bare Lands D: Road Decommissioning
E: Increasing Woodland Patches F: Reshaping Woodlands to Rounded Ones
G: Filling in Woodlands with more Trees
H: Decreasing Distance among Patches I: Banning New Road Development in the Periphery of the Rivers
J: On-Site Pollution Control K: Relative Pollution Control L: Immediate Intensive Pollution Control

Restoration-oriented evaluation as opposed to assessment-oriented appraisal of landscapes is becoming popular among researchers and managers of natural resources. In this connection, some methods offer management plans for restoring only a single good or service within an ecosystem. Others deal with several elements of the natural and man-made environments in an integrated approach. Many of these restoration measures are also related to an increasingly diminishing resource: fresh water. In recent years, significant attention has been drawn to the fact that along with unsustainable use of the land and water resources and global warming, the freshwater supply will become even scarcer, and quality will also diminish.

The fact that quantitative landscape metrics have been found useful in these instances for restoration of water quality is considered a major step forward. Using these results it is easier to devise restoration plans, model their efficiency, associated costs and convey the message to the decision makers and the public alike.

In our study, parameters relating to land use and land cover together with landscape metrics, climatic and surrogate social and economic variables have been used in a geographical information system to provide rankings of causal or surrogate factors that affect water quality for seven catchments in north east Iran. The study has been conducted within the means and availability of data for the area and is considered a feasibility test both information wise and logistically.

4. Conclusion

In the present study, 8 independent parameters were amenable to management planning, through which watershed managers can take measures and to some degree reverse the diminishing trend of water quality. The Gorganrud River in Golestan Province, north east Iran with its tributaries was the subject of this study. The results showed the applicability of the method and suggested the necessity of using better geographical layers and collection of regular water quality data at locations selected through a scientific approach. These were hampering more in-depth analysis of the results in our study. Availability of more detailed pollution data could allow more targeted inference. Using the approach, it would be possible to arrive at scenarios of watershed management and restoration that are both feasible and effective in water quality improvement. This is the first study of this kind in Iran and application of the method is encouraged with higher resolution imagery, and in other watersheds of Iran for devising mitigation and restoration plans. The study has offered quantitative restoration metrics which lend themselves easily to modeling within a GIS environment. Hence, applying what-if scenarios becomes possible, through which decision makers can see the results of their actions. However, other aspects of the study area including lithology and pedology should be included in later studies to complement the results presented here.

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