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Exploring the relationship between land use and surface water quality using multivariate statistics in arid and semi-arid regions

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Abstract

The relative impacts of different types of land use on the surface water quality are yet to be ascertained and quantified. In this paper, the influence of different types of land use on surface water quality is investigated. Rain events samples from different land use in the central plateau, Iran, were analyzed for major ions. Statistical analyses were employed to examine the statistical relationships of land use and water quality on a regional scale in Iran central plateau. Principal component analysis was used to investigate the processes controlling the effects of land use on the water quality in this area. The higher correlations of range than other land uses with major ion, specifically pH and HCO_3, were showed and it's maybe reflecting the effects of the season the samples were taken.

Keywords: Surface water quality; Principal components analysis; Land use; Iran

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1. Introduction

Water quality models generally require large quantities of different types of data: meteorological variables (rainfall, air temperature …) for the forcing processes, spatial data (altitude, soil, land use…) for the description of the basin and human activities (waste water, agriculture water use, fertilizing calendar …). All these data are subject to uncertainties that can have significant effects on the model results. Thus evaluation of confidence in the model predictions should be a required step for modellers (Beven and Freer, 2001; Beven, 2002). The uncertainties on physical data (such as rainfall) are commonly analysed (see among others Bertoni, 2001). For spatial data such as land use maps, difficulties arise because the uncertainties are closely linked to the sophisticated methods used for obtaining the data (Payraudeau, 2004).

Land surface characteristics' influence on water dynamics, evapotranspiration, interception, infiltration, and percolation affect water fluxes and quality of receiving water bodies (Bhat *et al*, 2006 and LeBlanc *et al.*, 1997).

Land use change is known to influence the biogeochemistry of watersheds (Deocampo, 2004; Tardy *et al.*, 2004; Grimm *et al.*, 2003; Parr and Mason, 2003; Wayland *et al.*, 2003; Poinke and DeWalle, 1994; Leo´n *et al.*, 2001; Ometo *et al.*, 2000; Mason *et al.*, 1999; Dassenakis *et al.*, 1997; Long and Saleem, 1974). As land use has changed from unaltered natural landscapes to agricultural and urban uses, forests and wetlands have been lost; road density has increased; surface runoff has increased; and anthropogenic chemical and wastewater inputs have increased (Breward, 2003; Parr and Mason, 2003; Wayland *et al.*,

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2003; Lee, 2002; Obbard, 2001; Blanchard and Lerch, 2000; Ometo *et al*., 2000; Buttle and Labadia, 1999; Mason *et al*., 1999; Nirel and Revaclier, 1999; Carpenter *e* 1998; Gergel *et al.,* 1999; Goulding and Blake, 1998; Shafer *et al*., 1997; Amrhein *et al*., 1993). Physical alteration of the landscape also occurs as a result of land use change, affecting the hydrogeologic dynamics of watersheds (Tang *et a*l., 2005; Pijanowski *et al*., 2002). As a result of these human activities, the conditions of many aquatic environments have been degraded. It has been suggested that the relationships between land use and water quality may be obscured by other factors, complicating the development of distinct biogeochemical fingerprints of land use on water quality (Fitzpatrick *et al*, 2007, Wayland *et al*., 2003; Mason *et al*., 1999).

Therefore, understanding the effects of changes in land use and land cover (LULC) is important for maintaining a desired level of water quality and for restoring water quality in affected areas. However results from previous studies in similar environments can inform that changes in land use and land management practices are primary factors responsible for the alteration of receiving water quality. One of the most common approaches to examine these relationships is to develop statistical correlations between water chemistry and current land use in the drainage basins of surface-water sampling points (Wayland *et al*, 2002).

The sampling of runoff and storm events is often used to examine the effects of land use on water quality (De Carlo *et al*., 2004; Steuer *et al*., 1997; Andoh, 1994). Runoff is an important component of water quality investigations because runoff introduces sediment and mobilizes chemicals directly off the landscape (De Carlo *et al*., 2004; Steuer *et al*., 1997; Andoh, 1994). However, low or base flow in temperate, perennial streams is supplied predominately by shallow groundwater discharging to the stream channel (Wayland *et al*., 2003; Land *et al*., 2000; Grayson *et al*., 1997). Since the shallow groundwater has moved through the landscape in the recent past, it provides a signal that is representative of the surface geology, recent climate and land use (Wayland *et al*., 2003; Land *et al*., 2000; Grayson *et al*., 1997). Thus runoff chemistry of the dissolved fraction is used to represent the effects of regional and land use characteristics on stream quality in the study site, the Iran central plateau watersheds (Fig. 1).

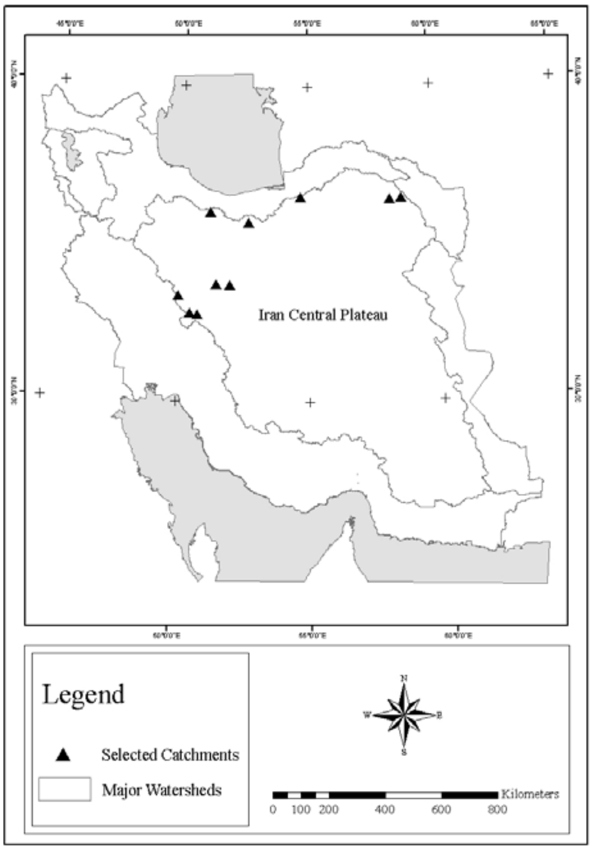

Fig. 1. Location of selected catchments in Iran central plateau

The objective of this study was to use an approach to examine the statistical relationship of landuse on quality of the surface water under a broad regional scale in the Iran central plateau and to model relative impacts of different types of landuse in a regional watershed.

2. Materials and methods

2.1. Study area

The study area is located in the Iran central plateau (25° 56′ 41″ to 37° 17′ 32″ N, 47° 57′ 17″to 61° 24′ 37″E,) in the center of Iran, which belongs to the continental arid and semi-arid climate in the temperate zone. The Iran central plateau encompasses more than 850000 km^2 of central Lowland area and several sub catchments in different size.

2.2. Selection of sites

The presence of large areas within the watersheds that are relatively undeveloped, combined with distinct areas of human impact, make the Iran central plateau an exceptional area to study the effects of landuse on water quality. The extensive stream networks in the Iran central plateau doesn't permit the selection of sampling sites on tributaries where one land use dominates. For the purpose of this study, ten subcatchments were chosen as the independent tributaries of the main stream. These sites (Fig. 1) were chosen to represent watersheds with multiple category of land use. So Karaj, Polasjan, Zaianderood, Bonrood, Ghahrood, Gabrabad, Namrood, Tash, Bar and Taghoon catchments were selected within arid and semi-arid regions located along the north and west boundary of Iran central plateau in Iran on the basis of their potential land use impacts and their accessibility for sampled collection.

2.3. Data preparation and sample collection

The map of the 10-digit Hydrological Units for the Iran central plateau was obtained from Watershed Management and Soil Conservation Research Center (WSRC). The surface catchments for each of the sites were delineated using ArcGIS software. It was used as base map for the analysis. The catchments were then used to clip the 2002 land use coverage allowing calculation of the land uses affecting the catchments. The land use categories used in this study were: (1) rangeland (Ra), (2) agriculture (Ag), (3) forest (F), (4) urban (U), and (5) bare land (Br) (Table 1). The water quality data for the period of 1997- 2005 in the study area were obtained from the Iran Water Resources Research Organization (TAMAB). TAMAB is a repository for water quality, quantity and physical data. The data are in database format. There are 15 water quality variables. Each monitoring site is referenced in latitude and longitude. The permanent gauging station is considered a reference station for the catchment. Most of the samples were collected during, or within, 48 hours of rainfall. Other data was gathered during periods of no rainfall to represent normal flow period. In this study we used 142 water quality data that were collected after rain events and from stream sites in the Iran central plateau sub catchments where the basin supplying the sites by multiple types of land uses.

Table 1. Landuse percentage and area of selected catchments

Catchment	Area (ha)	Landuse types (%)				
		Ag	Ra	F	Br	U
Bonroud	7408	6.65	93.35	0.00	0.00	0.00
Ghahroud	12895	3.12	96.73	0.00	0.00	0.15
Golpaigan	81123	8.85	89.13	0.00	1.98	0.04
Karaj	72970	3.14	96.85	0.00	0.00	0.01
Zaianderoud	142279	38.92	47.81	13.11	0.00	0.16
Polasjan	166648	49.49	46.77	0.00	2.32	1.41
Namroud	75940	4.99	90.37	4.57	0.00	0.07
Tash	7888	7.39	31.17	61.44	0.00	0.00
Bar	12862	6.34	64.11	29.55	0.00	0.00
Taghoun	10112	3.83	36.14	60.03	0.00	0.00

2.4. Statistical analysis

Statistical analyses were utilized to test the null hypothesis that water quality is not related to the landuse types at a regional scale. The large number of analyses determined makes it difficult and time consuming to thoroughly analyze the data one variable at a time. Multivariate statistics are useful for reducing the number of components in a dataset by identifying the relationships between the variables. Principal component analysis (PCA) is used to identify relationships between variables. The results of the PCA were used to select a few variables for a final PCA (Hair *et al.*, 1998).

3. Results

3.1. Principal components analysis

The SAS 9.1 statistical software program was used to perform PCA of the data. The default variables (Eigenvalue >1) was used for the initial analysis. Since the decision of how many factor to extract is based on Eigenvalues, scree plots and the interpretability of the components, subsequent analyses were done with both more and fewer components than the default to determine which number of factors was optimum. The results of the initial principal component analyses were used to inform selection of variables for analysis of major ions. Therefore, the two component solution was selected for interpretation (Table 2). The first component has moderate loadings of SAR, Na, Ca and SO_4. Second component includes moderate loading of K, Mg and pH. First and second component have strong correlations of HCo_3. TDS, EC, CO_3 and Cl would not explain to any components (table 3).

Table 2. Dependency coefficients of two major principal component analyses

Landuse types	Principal Component	
	First	Second
Agriculture	0.515434	-0.027986
Rangeland	-0.172999	-0.739033
Bare land	-0.259858	0.668661
Forest	0.534418	0.039498
Urban	0.592682	0.066177

Moderate loadings (0.50≤ X≤ 0.75) are shown by bold type.

Table 3. Coefficients of effective principal components on water quality variables

Variable	Intercept	Component	
		First	Second
SAR	0.916	-0.145^{**}	0.002
Ec	430.2	12.9	11.6
pH	7.88	-0.01	0.07^{**}
TDS	286.7	3.69	13.95
Na	1.25	-0.19	0.002^{*}
Ca	2.3	0.17^{**}	-0.005
So_4	1.17	-0.13^{*}	-0.07
K	0.027	-0.0009	-0.005^{*}
Mg	1.28	0.036	0.11
Co_3	0.03	-0.009	0.0007
Cl	0.85	-0.04	0.01
Anions	4.62	0.05	0.15
Cations	4.45	0.064	0.156
HCo_3	2.77	0.195^{**}	0.179^{**}

**significant in 0.01 level
* Significant in 0.05 level

4. Discussion and conclusions

The purpose of this paper was to refine methods for quantifying the specific effects of land use on surface water quality. The analyses of dissolved major ions in different land use streams of the Iran central plateau. Principal component analysis demonstrated similar associations of Na, Ca, SAR and SO_4 with urban, forested and agriculture land use and of K, Mg and pH with range and bare land that have been found. This supports the hypothesis that there are specific associations of land use with surface water chemistry. It is becoming clear that there are distinctive and consistent patterns to the impacts of land use on water quality. These data indicated that the variance can be quite high for certain parameters, particularly at the human impacted sites, but it was clear that the different land use sites could be differentiated on the basis of these water quality parameters and rain events have been shown to contribute substantially to major ion loading by surface runoff contributions.

Also this study exhibits the complexity of water quality indicators and their spatial distribution. Such complexity implies that different indicators often reflect different aspects of a water body and the status of water quality may be affected by many factors in different ways. Although water chemistry in some catchments of the Iran central plateau was at good condition (several of the water chemistry variables were at or below detection limit, which might have contributed to the fewer data available for the analysis), chemical indicators have picked up some effects of human activities on the receiving water. The PCA analyses showed that urban land and some another nonpoint sources such as range land use together might explain the higher chemical quality throughout the study area. This finding confirms that one of the greatest causes of water quality problem derives from urban land use as a result of the increasing intensity of human activities. Pollution has resulted in loss of species diversity within rivers (Haycock and Muscutt, 1995). The hydrological relationship between water systems and the land requires coordination between the water management and land management fields. Once the land water relationship is identified, it leads to the need of protecting water quality through proper land-use planning by identifying cost-effective pollution prevention and pollution correction approaches that can address all the sources of pollution in a comprehensive way. To take such challenge, it is necessary to look into water-quality management and land-use planning practices and draw the connection between the two. The objective of land-use planning is to maximize the uses of land by humans while minimizing the negative impact to humans' health and welfare.

The impacts of different land uses on river water quality demonstrated in this study suggests that the known land water relationship is significant enough for planners and decision-makers to pay proper attention to water-quality issues in evaluating plans and facilitating collaborations. Achieving the sustainable management of water and land resources could be a major consideration in exploring planning alternatives within a watershed (Wang, 2001).

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