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Impacts of land-use change on groundwater resources using remote sensing and numerical modeling

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Key words: Land use change, Groundwater dynamic, GIS, RS, MODFLOW

Abstract

Groundwater consumption, climate condition, and human activities should affect the groundwater dynamics. In this study, the impact of land use change on groundwater dynamic was investigated based on water balance modeling using MODFLOW, GIS and Remote Sensing (RS). The land-use maps (1991, 2000, 2013 and 2017) were prepared with details using ENVI. The main land-use in the study area was rural, agricultural, and rangeland area. The main land-use changes between 1991 and 2013 were the expansion of agricultural area. According to results, agricultural area was increased by 190%, whereas rangeland area decreases by 80%. Groundwater and surface water are the main sources for irrigation. According to land-use planning, irrigated area will increase by 3% in 2017 compared to 2013. The results of mathematical modeling indicate that the annual water consumption in agricultural area should increase during 1991-2017. The results of the calibrated model show that return flow is a major contributor to groundwater recharge. Furthermore, the source of water used for irrigation (*i.e.*, river and/or groundwater) has a high impact on groundwater. The impact of land-use change on different water balance components (recharge and discharge) was significant. Increase of agricultural areas cause an increasing of annual discharge, as well as an increasing of annual recharge from irrigation water. Yearly groundwater recharge from return flow in the study area should increase from 7.1 MCM in 1991 to 20.4 MCM in 2017. But groundwater decline should continue due to increasing of agricultural water demand and over-pumping.

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Introduction

Groundwater is the most important source of industrial, drinking and irrigation water in arid and semi-arid regions. It is the vital local water source for agriculture, industry, wildlife and human development activity (Ghazavi *et al.*, 2012). Groundwater consumption, climate condition, and human activities should affect the groundwater dynamics (Ghazavi *et al.*, 2010). Estimation of groundwater quantity change depends on different factors and is more complicated by environmental changes such as climate (Maxwell and Kollet, 2008; CCGS, 2009) and land-use change (Walker *et al.*, 1991; Scanlon *et al.* 2007; Favreau *et al.*, 2009; Huang and Pang 2010).

Land use change is the most important factors that considered in global change study (Tsarouchi *et al.*, 2014; Gamoa *et al.*, 2013; Loveland *et al.*, 2000; Lambin 1997; Houghton, 1994). Land use describes utilization of land resources by humans (Pielke *et al.*, 2002). Land use change can modify hydrological processes at temporal and spatial scales especially in the arid regions. (Foley *et al.*, 2005; Leng *et al.*, 2011). Over-pumping due to land-use change will cause ongoing aquifer depletion in developed aquifers. The effects of land use change on groundwater recharge should be investigated, especially in the arid and semi-arid regions (Yun *et al.*, 2011).

Exact estimation of regional groundwater recharge requires a good understanding of the hydrological processes in the area, which could be greatly altered by global change and human activities (Nolan *et al.*, 2007). Investigation the impact of the future land-use changes on the groundwater quantity has not been studied extensively. Hydrological models are useful tools for prediction the response of hydrological parameters to changes in input conditions such as land use change (Morán-Tejeda *et al.*, 2014). Accuracy of the hydrological model depend largely on precision of input information.

Remote sensing and GIS are useful tools to produce information in temporal and spatial field, which is very critical for analysis, prediction and validation of hydrological models (Venkateswarlu *et al.*, 2014; Ulbricht and Heckendorf, 1998).

One of the greatest advantages of remote sensing data for hydrological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation (Venkateswarlu *et al.*, 2014). Landsat data have been also employed for determination of land cover and land use change since 1972, mainly in agricultural and forest areas (Campbell 2007).

Estimation of groundwater recharge is more complicated in irrigation area, where groundwater recharge and discharge occur via agricultural pumping and return irrigated water. In this area, study of evaporation, recharge and transpiration is important for sustainable management of water resources (Gartuza-Payan *et al.*, 1998). Numerous methods were used to estimate the impact of land use change in groundwater recharge, but rare study was focused on arid and semi-arid environment (Scanlon *et al.*, 2002; De Vries and Simmers, 2002).

Replacing rangeland area to agricultural area in arid and semi-arid region should influence groundwater discharge, water demand, and returned irrigated water to the aquifer. The main objectives of this research are: 1) to examine the land use change and water resources utilization change over the past 23 years; 2) to evaluate the impact of land use change on groundwater resource; 3) to estimate groundwater recharge from return flow using remote sensing.

Material and methods

Study area

The study area (Mosian Aquifer) located in the west of Iran (32°22′N–32°35′N, 47°21′E–47°37′E). The study watershed has a total area of 260 km², a mean altitude of 155 m. The mean annual precipitation of the study area is 270 mm that concentrated between November and April, whereas the mean annual potential evaporation is 3451 mm (Fig. 2). The mean annual temperature at the region is about 27 °C. The major river in the study area is Doiraj river (Fig. 1).

The average flow of this river is 1.8 cubic meter per second, in which 45 MCM per year is used to irrigate agricultural area. The main land-use of the study area contained of agriculture, rangeland and urban.

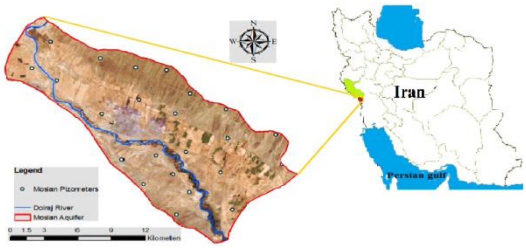


Fig. 1. Location of the Mosian plain.

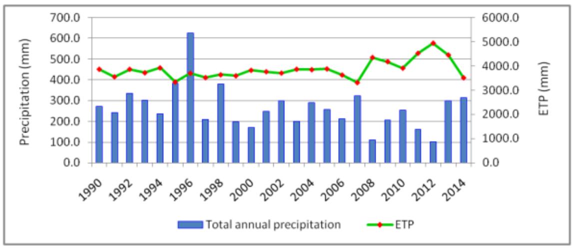


Fig. 2. Annual rainfall and potential evapotranspiration on Mosian plain from 1991-2014.

Methodology

Mathematical model

MODFLOW is a three-dimensional finite-difference groundwater flow model that was first published by the USGS in 1984 (Harbaugh *et al*., 2000). The model domain (aquifer) broke down into grid squares and the principal equation is solved using iterative methods at the center point of each grid square (Rabb, 2011). Equation (1) indicate the principal partial differential equation used in MODFLOW:

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)=S_S\frac{\partial h}{\partial t}+W \quad (1)$$

Where t is time [T], h is groundwater head [L], K is the hydraulic conductivity [L T $^{-1}$], Kx,, $K y$ and Kz are hydraulic conductivities along the x, y and z axis respectively. Ss is the specific storage of the porous material [L $^{-1}$]. W is a volumetric flux per unit volume representing sources and/or sinks [L^3T^{-1}].

W<0 represents flow out of the system and W>0 for flow into the system. W can be broken down into four major phases (Eq.2):

$$W = R + Qr + Qs + Qg \quad (2)$$

Where Qr, Qs and Qg represent discharge from rivers and springs and groundwater pumping respectively and R is recharge [L^3T^{-1}].

When Equation 1 is combined with boundary and initial conditions, it describes fully saturated, transient three-dimensional groundwater flow in a heterogeneous and anisotropic medium. MODFLOW solves the finite difference form of the partial differential in a discretized aquifer domain, represented using rows, columns and layers. It is a modular code and numerous packages have been developed to simulate different boundary conditions, e.g. springs, rivers, observation wells and abstractions (Harbaugh *et al*., 2000).

In this study, the model enclosed a total area of 260.32 km², split up into 100 x 100m cells, giving a total of 26000 active cells (261 columns and 236 rows). The recharge time series constrains the MODFLOW model runs to between November 1991 and October 2017, a total of 52 stress periods. The initial heads for the model matched to an interpolated groundwater surface for October 1991. Accurate and prevalent pumping data was obtained from local water organization. The top and bottom of the aquifer were determined from existing maps using GIS. Spatially continuous K, T and S values are optimized inversely based on recharge flux from initial values and groundwater level observations using modeling in steady conditions.

Aquifer recharge from return flow of excess applied water is estimated at locations delineated as irrigated lands. Irrigated lands data are obtained for seven years in the model calibration period. Data from the bordering year are used for years without data.

Recharge from infiltration on non-irrigated lands, discharge via evapotranspiration in shallow areas, and attendant recharge on irrigated lands is represented in MODFLOW using the recharge (RCH) package. Recharge is assigned to model cells as a positive and groundwater pumping assigned as a negative stress. Groundwater pumping is represented in MODFLOW using the WEL package. For these cells, MODFLOW calculates the stress applied to the layer based on hydraulic conductivity (Panday, *et al.*, 2013; USGS, 2014).

The land use classification of the study area was created based on Landsat 5 Thematic Mapper (TM) from 1991 , Landsat 7 Enhanced Thematic Mapper (ETM) data from 2000 and Landsat 8 Enhanced Thematic Mapper (ETM) data from 2013(Table 1). For visual assessment of land-use trends and land use change within the area, historical Landsat imagery from 1991 and 2013 were used (Fig. 3). Three dated Landsat images were compared via supervised classification technique using Maximum Likelihood algorithm in ENVI 4.8.

The land use maps of the study area were classified in three classes includes rangeland and unused area, rural area, and agriculture land.

The accuracy of the classifications evaluated via overall accuracy and Kappa coefficient. The Overall accuracy was defined as the total number of correctly classified pixels divided by the total number of reference pixels (total number of sample points) (Rogan *et al.,* 2002). Kappa coefficient ranges between 0 and 1. The greater value indicate a better agreement between classified and references pixels (Miller and Yool, 2002).

Table 1. Satellite data used in the study.

Row	Data used	Path/row	Date of pass	Spatial resolution (m)
1	LANDSAT TM	166/038	1991-06-30	07 Bands, 30 m (1-4 bands), Range: 30–120 m
2	LANDSAT ETM+	166/038	2000-06-06	08 Bands, 30 m (1-4 bands), Range: 15–90 m
3	LANDSAT – 8 ETM	166/038	2013-06-10	11 Bands, 30 m (1-5 bands), Range: 15–100 m

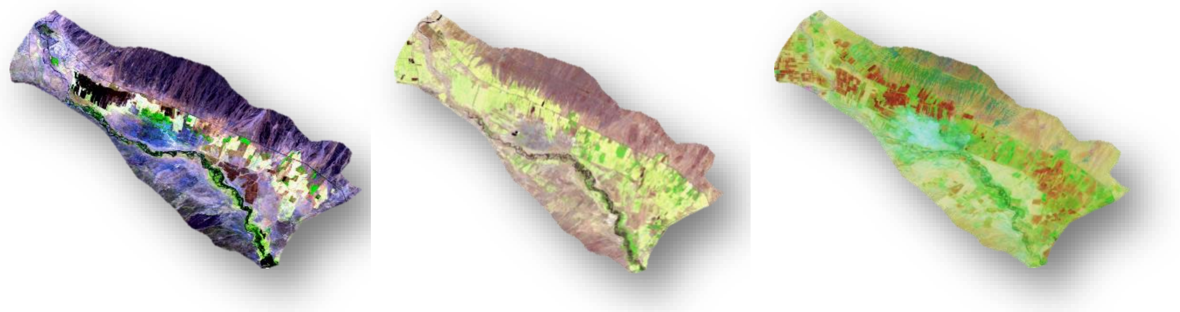


Fig. 3. From left to right: Satellite image 30 June 1991, 06 June 2000, and 10 June 2013.

Results and discussion

In order to understand the surface and groundwater dynamics in the study area, recorded data of utilization wells (Iran Water and Power Resources Development Company, 2014), irrigation and crop pattern reports (JamAb Consulting engineers report, 1998 and 2004), satellite data information (Images of Landsat in 1991, 2000 and 2013), and field visits were collected, analyzed and integrated.

Table 2 indicate the volume of irrigation water met by groundwater and surface water resources from 1991 to 2017. Irrigation water demand in Mosian plain has increased almost 3-fold from 1991-2017. Groundwater irrigation demand in Mosian plain was 18.5 MCM in 1991 (Mahab Ghods Consulting engineers report, 1992). Based on our review and calculations, it has increased to 59 MCM in 2014. As a result, groundwater resources are at the risk of being over-exploited for irrigation purposes.

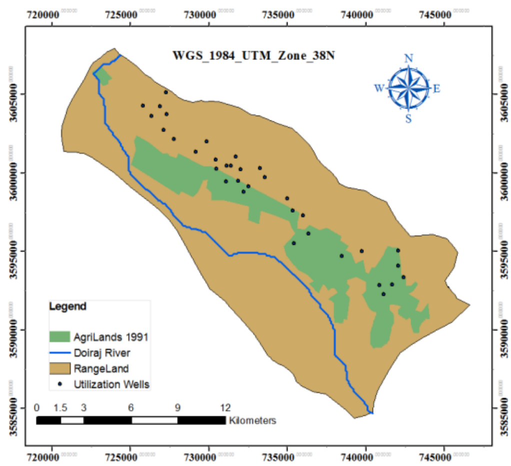
The surface water irrigation demand in Mosian palin was 28 MCM in 1991 (Mahab Ghods Consulting engineers report, 1992), while it has increased to 45 MCM in 2014.

Table 2. Irrigation water amounts at the study area for 1991-2017.

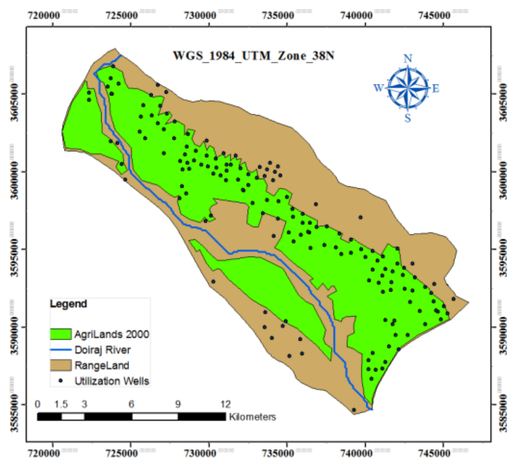
Year	Surface water (MCM)	Groundwater (MCM)	Total (MCM)
1991	28	18.5	46.5
1993	29	23.2	52.2
1995	30	26.9	56.9
1997	35	45.9	80.9
1999	40	49.2	89.2
2001	45	51.9	96.9
2003	45	55.6	100.6
2005	45	57.7	102.7
2007	45	59.1	104.1
2009	45	59.3	104.3
2011	45	59.3	104.3
2013	45	59.4	104.4
2015	45	59.4	104.4
2017	103	59.4	162.4

Spatial change of irrigated lands is obtained for 1991, 2000, 2013, using remote sensing and USGS satellite images .The land-use map of 2000 was gathered by modifying the polygons of the 2013 land-use change map. The land-use map of 1991 was produced by modifying the polygons of 2000. Land-use map of 2013, survey information and agricultural development of the study area was used as a base map for preparing the scenario of 2017. To establish the maps on future land-use change, the necessary information was obtained from irrigation system of Doiraj reservoir dam provided by the development and planning unit of regional water organization of Ilam (Iran Water and Power Resources Development Company, 2014). The land-use change detection maps for three time periods (1991-2000, 2000-2013, and 2013-2017) were prepared and the areas of the classes were calculated. According to results, the land-use maps were classified into Agricultural land, Built Up, and rangeland.

According to results of the land-use statistics, agricultural areas was increased from 18% in 1991 to 53.3 % in 2013 (Table 3). This indicates a significant rise in groundwater pumping (Fig. 5). Increasing of agriculture area was 164% between 1991 and 2000, 10% between 2000 and 2013 and 3% between 2013 and 2017. Urban area has also increased from 50 hectare in 1991 to 110 hectare in 2013. Increasing of agricultural and urban area accompanied with decreasing of rangeland area (Fig. 4). Rangeland area decrease from 21215 hectare (81% of the study area) in 1991 to 12156 hectare (46% of the study area) in 2013(Table 3). The total consumption of water for irrigation in 1991 and 2013 is 46.5 and 104.4 MCM respectively (Table 2). Due to land use change, annual irrigation water demand increased by 58 MCM from 1991 to 2013. So, Land use change cause a significantly increase in the water demand for agriculture in the irrigation districts of the Mosin. All three classification dates indicate a satisfactory accuracy. For example for agricultural lands, Overall accuracies was 83.2% for 1991, 85.1% for 1999 and 85.1% for 2013. Kappa coefficient for 1991, 1999 and 2013 was 0.823, 0.836 and 0.87 respectively (Table 4).



a



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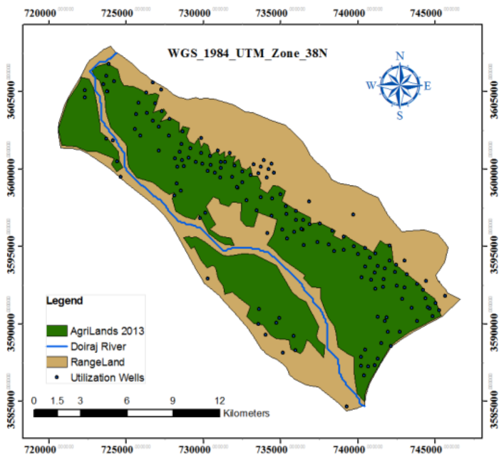

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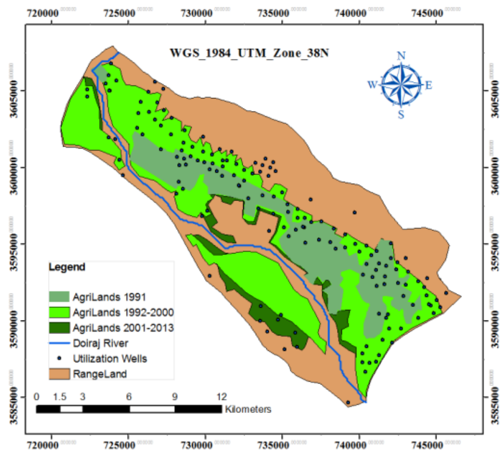

d

Fig. 4. Land use change and agricultural wells from 1991 to 2013 (Land use maps; a:1991, b:2000, c:2013 and d:overlayed).

Table 3. Area of land-use classes (ha) 1991, 2000, 2013 and 2017.

No.	Land use class	1991	2000	2013	2017
1	Agricultural Land	4766 (18.3%)	12539 (48.5%)	13766 (53.3%)	13766 (53.3%)
2	Rangeland	21215	13403	12156	12156
3	Urban	50	90	110	110

Table 4. Summary of classification accuracy assessment.

Standard criteria		Land use type		
		Agriculture	Urban	Unused and rangeland
1991	Kappa	0.823	0.781	0.792
	Overall	83.2%	75.7%	79%
2000	Kappa	0.836	.703	0.764
	Overall	85.1%	76%	82.1%
2013	Kappa	0.87	.784	0.851
	Overall	85.1%	75%	83%

The year of 1991 was determined for modeling of Mosian aquifer in the steady state condition. Period 1992-2017 selected as the unsteady condition. This period was divided to 52 time steps with 6 month length. The groundwater model was run for both steady-state and unsteady-state conditions to simulate the groundwater flow and estimate aquifer hydraulic parameters for the period 1991–2017. In the unsteady conditions, the main parameters of the model are recharge and discharge parameters. The initial values and the range of these parameters at the layer were provided by the previous researches and regional offices (Iran Water and Power Resources Development Company 2014). These data were imported into the constructed MODFLOW model as the authentic and accurate parameters .

The detailed land-use map delivers information about the agricultural land and also identifies the irrigated area. The detected irrigated areas were assigned with the initial irrigation return flow amount in the recharge file of MODFLOW model. The recharge in irrigated zone adjusted during the process of model calibration using try-test method for 13 observation wells. Model validated for 10 observation wells. Results show the accuracy of the model as a management tool to scrutiny of difference suggestions, policies and scenarios.

Based on the results of groundwater modeling, groundwater recharge via return flow increased from 1991 to 2017, but groundwater discharge for irrigation was more than groundwater recharge (Table 5 and Fig. 5). Groundwater recharge via irrigation return flow increased from 7.1 MCM in 1991 to 13.6 MCM in 2013, whereas groundwater discharge increased from 18MCM in 1991 to more than 60MCM in 2013.

Groundwater recharge from return flow has been changed due to change in irrigation method and groundwater depth. Rate of groundwater recharge via irrigation return flow should reduce due to change of the traditional and flooding method of irrigation to the new and modern methods. According to results, yearly groundwater recharge from return flow was 1489.7 m^3 per hectare in 1991 and it will decreased to 1470.1 m^3 per hectare in 2017 (Table 5).

Ground water table increasing in arid area should also increase evapotranspiration and consequently decrease groundwater recharge.

Based on the prediction land use change of the study area and groundwater modeling, the recharge by return flow in 2017 should increase to 20 MCM (about 50% of growth), while water consumption will increase to 60MCM. Consequently, excessive pumping can lower the groundwater table and ground subsidence. Reducing water pumping and artificial recharge should minimize groundwater depletion and land subsidence. The results of such study can be used to develop these strategies.

Table 5. Land-use change and groundwater recharge from Return flow from irrigation during 1991- 2017.

Year	Agricultural lands (ha)	Return flow (MCM)	Return flow to aquifer (mm)	Recharge computation factor
1991	4766	7.1	27.1	0.152
1993	5256	7.8	30.1	0.15
1995	7349	8.4	32.3	0.148
1997	10925	11.8	45.4	0.146
1999	12431	12.8	49.4	0.144
2001	12629	13.7	52.9	0.142
2003	12829	14	54.1	0.14
2005	13029	14.1	54.5	0.138
2007	13229	14.1	54.4	0.136
2009	13429	13.9	53.7	0.134
2011	13639	13.7	52.9	0.132
2013	13876	13.6	52.2	0.13
2015	13876	13.4	51.4	0.128
2017	13876	20.4	78.7	0.126

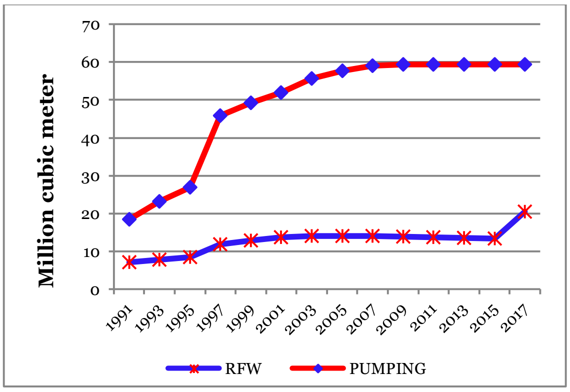

Fig. 5. Trend of pumping rate and return flow(RFW) in Mosian plain.

Conclusions

In the Mosian plain, precipitation is less than water demand of agricultural crops. Surface water and groundwater are the most important sources of the crop water demand. Surface water is diverted from the Doiraj river. Groundwater is extracted from the Mosian aquifer system. The Mosian plain has a well distributed canal network system, which supplies water mainly for irrigation during year.

The results of this study indicate that Irrigation affect the groundwater recharge of the study are This results is consistent with the results of Halik *et al.*, 2006. The results of this study showed that there is a close interaction between irrigated agricultural areas for groundwater levels. The source of water used for irrigation in the study area (Surface water/or groundwater) has also a high impact on groundwater levels. This results that was confirmed by other researchers (Keilholz *et al.*, 2015)

Our research results demonstrate the extremely increasing of water consumption in agriculture during 1991-2017. Amount of agricultural water demand is very much dependent on the cropping pattern. Change in cropping cultivation pattern based on the virtual water trade should decrease negative impacts of groundwater discharge.

Reduced groundwater resources due to land use change would exacerbate the difficulties already faced by the farmers and may inadvertently reduce their water rights. So, the sustainable allocation of water resources in arid Mosian plain can only be achieved by the correct rational allocation of surface water and groundwater resources.

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