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Investigation of Effects of Land Use Land Cover Changes on Quantity and Quality of Groundwater in Qazvin Plain

Pouyan Dehghan Rahimabadi[1], Esmail Heydari Alamdarloo[1], Marjan Talebiniya[1], Hassan Khosravi[1*], Hossein Azarnivand[1]

[1] Faculty of Natural Resources, University of Tehran, Karaj, Iran. Email: hakhosravi@ut.ac.ir

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ABSTRACT

Groundwater is a very important natural freshwater resource for drinking and irrigation purposes. In the present study, the aim is to investigate the effect of Land Use/Land Cover (LULC) changes on the quantity and quality of groundwater in Qazvin Plain from 2005 to 2020, through RS-GIS using LULC maps from Landsat 5 TM and 8 OLI images, Groundwater Resource Index (GRI) and Groundwater Quality Index (GQI). For this purpose, the data from groundwater level and quality parameters including K^+, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, TDS and EC were employed. The results indicated that in the central and eastern parts of the plain, the area of agricultural land and the number of exploitation wells were more than other parts. The plain was mostly covered with rangeland and agricultural lands. The area of agricultural land had the most changes over the time. GRI results illustrated more droughts in the eastern parts of the plain over time, and GQI results showed that groundwater quality has significantly decreased in the eastern parts in 2020. The non-vegetated lands had increased in the eastern parts of the plain, which can be due to the increase in agricultural lands, in which the excessive use of groundwater resources had reduced its level and thus decreased its quality. Generally, increasing agricultural lands and high density of exploitation wells in these lands had the greatest impact on the quantity and quality of groundwater in the Qazvin plain. So, the use of groundwater resources should be properly managed to prevent the reduction of its quantity and quality.

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1. Introduction

Groundwater is an important resource of fresh water for using in drinking and irrigation purposes in some parts of the world. Since the availability of surface water is limited in these regions, the largest resource of freshwater depends on groundwater (Ranjan *et al*., 2006). Groundwater quality protection is of great importance due to its extensive uses in agricultural, industrial and domestic sectors (Yazdani and Mansourian, 2019). The inflow and outflow of groundwater should generally be maintained in balance, although a low depletion in groundwater table occurs during the dry season. One of the best ways to prevent groundwater contamination is to identify aquifer damages and land use management. Human activities and Land-Use/Land-Cover (LULC) changes can affect the available groundwater resources by changing in recharge rates (Lerner and Harris, 2009). Land use is a major factor in changing hydrological processes across a range of temporal and spatial scales (Ghafari *et al*., 2020). Recently, human activities have impacted on the quantity and quality of this freshwater resource (Gehrels *et al*., 2001). Additionally, these activities have caused changes in LULC (Xiuwan, 2002). Monitoring of human activities on groundwater resources is an equipment and tool for the detection and protection of water quality. Consequently, it is vital to assess the relationship between changes in different compounds of ecosystems in more detail for managing the ecosystems properly.

One of the most popular techniques in study of LULC changes is Remote Sensing and Geographical Information System (RS-GIS) technologies which have been mainly used at different scales (Singh *et al*., 2010). The prominent advantage of using RS-GIS in LULC changes and hydrological monitoring is its ability to generate spatial and temporal information and provide efficient information for proper management (Venkateswarlu *et al*., 2014). Additionally, many researches have indicated that satellite images are useful tools for evaluating the effect of LULC changes on groundwater resources (Wakode *et al*., 2018; Alqurashi and Kumar, 2019; Verma *et al*., 2019).

Recent studies have supported the impact of LULC changes on groundwater level and its quality. Pulido-Velazquez *et al*. (2015) assessed the impact of climate and land use changes on groundwater quantity and quality in the Mancha Oriental system, Spain. They found that the quality and quantity of groundwater decreased because of climate and land use changes along with nitrate pollution. Patra *et al*. (2018) studied the impacts of urbanization on LULC and its probable implications on local climate and groundwater level in the Howrah Municipal Corporation (HMC) in West Bengal, India. The results showed that urban and built-up areas increased during the last two decades and groundwater level had fluctuations in the northern, north-western and south-western sides of the city. Verma *et al*. (2019) assessed the impact of LULC changes on the sustainability of groundwater resources in Ganga Plain, India. They stated that the built-up lands increased, but the water bodies decreased. On the other hand, the groundwater levels significantly decreased over the past decade. Sertel *et al*. (2019) investigated the changes in hydrological water balance in LULC conditions in Buyukcekmece water basin of Istanbul city using the SWAT model. The results indicated that changes in LULC had a significant impact on hydrological dynamics under the same climatic conditions. Elmahdy *et al*. (2020) investigated the impact of LULC changes on groundwater level and quality in the Northern Part of the United Arab Emirates using Landsat images and hydrological information in the GIS environment. The results indicated that the urban and built-up area increased but farmlands decreased due to the decrease in groundwater level. Li *et al*. (2021) studied the LULC changes caused by anthropogenic activities and the human health risk of pollution in groundwater. The results highlighted that LULC changes caused by human activities increased fluoride and arsenic pollution in groundwater.

The results of these studies indicated that LULC changes affect the groundwater recharge and its quality. Singh *et al*. (2010) also reported the assessment of LULC changes and its relation with groundwater resources is essential for a correct understanding of the environmental problems and the study of the quantity and quality of these water resources and their special relationship with the characteristics of the earth's surface will be the minimal effort to protect these valuable resources (Thomas and Tellam, 2006).

Since there are agricultural land in Qazvin plain and a need for fresh water to irrigate these lands, it is necessary to study the impact of LULC changes on the hydrological response for proper management of groundwater resources in this plain. Therefore, the main objective of the present study is to conduct the RS-GIS technology to assess the effect of LULC changes on groundwater quantity and quality in Qazvin Plain from 2005 to 2020, through RS-GIS using groundwater quantity and quality data and LULC maps from Landsat 5 TM and OLI 8 images for 2005, 2010, 2015 and 2020.

2. Material and Methods

2.1. Study Area

The study area is Qazvin plain, which located in the south of Alborz mountain range, between 49° 10' - 50° 41' of east longitude and 35° 19' - 36° 30' of north latitude, with an area of 9546.54 km^2. The central and eastern parts of the plain have low height and are surrounded by mountains and the elevation ranges from 1132 to 2920 meter above sea level. The climate of Qazvin plain is generally cool in summer and cold in winter, with an annual rainfall of 230 mm (Zanganeh *et al*., 2019) and an average temperature of $14^{\circ c}$. In some parts of this plain including Buin Zahra, Abik and Takestan, there are numerous wells, which provide drinking and agricultural water for the residents in villages and cities in these areas. This plain has 5% of the entire agricultural lands of Iran (Babaee *et al*., 2020). Fig. 1 shows the situation of Qazvin plain in Iran and the used quantitative and qualitative monitoring wells.

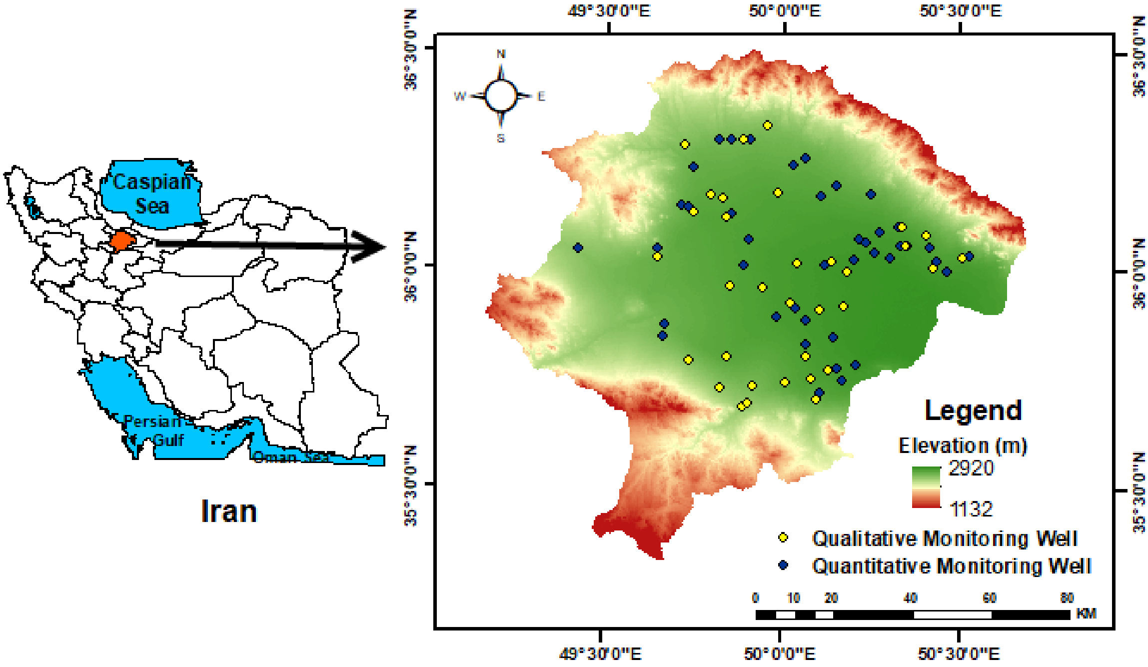

Fig 1. Location of the study area and quantitative and qualitative monitoring wells

2.2. Data Collecting

In the present study, in order to determine the effect of LULC on the quantity and quality of groundwater, the primary quantitative and qualitative groundwater data were obtained from Iran Water Resources Management Company from 2005 to 2020 to generate the groundwater maps. The LULC maps were generated using the images from Landsat 5 and Landsat 8 OLI satellites in 2005, 2010, 2015 and 2020.

Groundwater Resource Index (GRI) and Groundwater Quality Index (GQI) were employed to determine groundwater quantity and quality changes, respectively, using data for groundwater level and groundwater quality parameters including Potassium (K^+), Sodium (Na^+), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Sulfate (SO_4^{2-}), Chloride (Cl^-), Total Dissolved Solids (TDS) and Electrical Conductivity (EC). Table 1 summarizes the results of statistical analysis for the qualitative and quantitative parameters.

Table 1. Summary statistics assessment of the qualitative and quantitative data

Parameters	Unit	Minimum	Mean	Maximum	Standard Deviation
K^+	mg/lit	0.39	3.21	11.73	2.32
Na^+	mg/lit	24.83	220.66	747.41	147.38
Mg^{2+}	mg/lit	5.83	49.65	231.94	37.11
Ca^{2+}	mg/lit	13.03	92.87	326.65	60.86
SO_4^-	mg/lit	12.49	283.76	840.53	183.43
Cl^-	mg/lit	12.41	307.84	1684.23	320.57
TDS	mg/lit	227.00	1214.83	4220.00	751.78
EC	µmohs/cm	355.00	1901.38	6594.00	1172.02
Groundwater Level	meter (a.s.l)	1114.85	1199.39	1394.67	58.605

2.3. Methodology

In this study the effect of LULC changes on quantity and quality of groundwater is investigated in Qazvin plain from 2005 to 2020, through RS-GIS using LULC maps from Landsat 5 TM and OLI 8 images for 2005, 2010, 2015 and 2020 and quantity and quality data of groundwater. Inverse Distance Weighting (IDW) was employed to generate the spatial distribution maps of groundwater quantity and quality (Slama and Sebei, 2020; Soujanya Kamble *et al*., 2020; Verma *et al*., 2020; Kamaraj *et al*., 2021) in ArcMap 10.7. Fig 2 illustrates the flowchart of the adopted methodology.

- *Land use and Land cover*

Remote sensing technique is the acquisition of information from terrestrial objects and phenomena without direct contact with them. One of the uses of remote sensing technique is to provide the LULC maps. In the present study, LULC maps were generated using Landsat 5 images for years 2005 and 2010 and Landsat Operational Land Imager (OLI) 8 images for years 2015 and 2020. These images have been atmospherically corrected surface reflectance by their sensors. Table 2 indicates the spectral details of the adopted satellite imageries.

The next step is to classify the LULC maps. Some studies have been done to choose the most accurate classification methods, but in this study, LULC maps were classified based on supervised classifications of MODIS Terra and Aqua reflectance data. This classification identifies 16 land cover classes, which mainly includes water bodies, natural vegetation, bare lands and human-altered and non-vegetated classes.

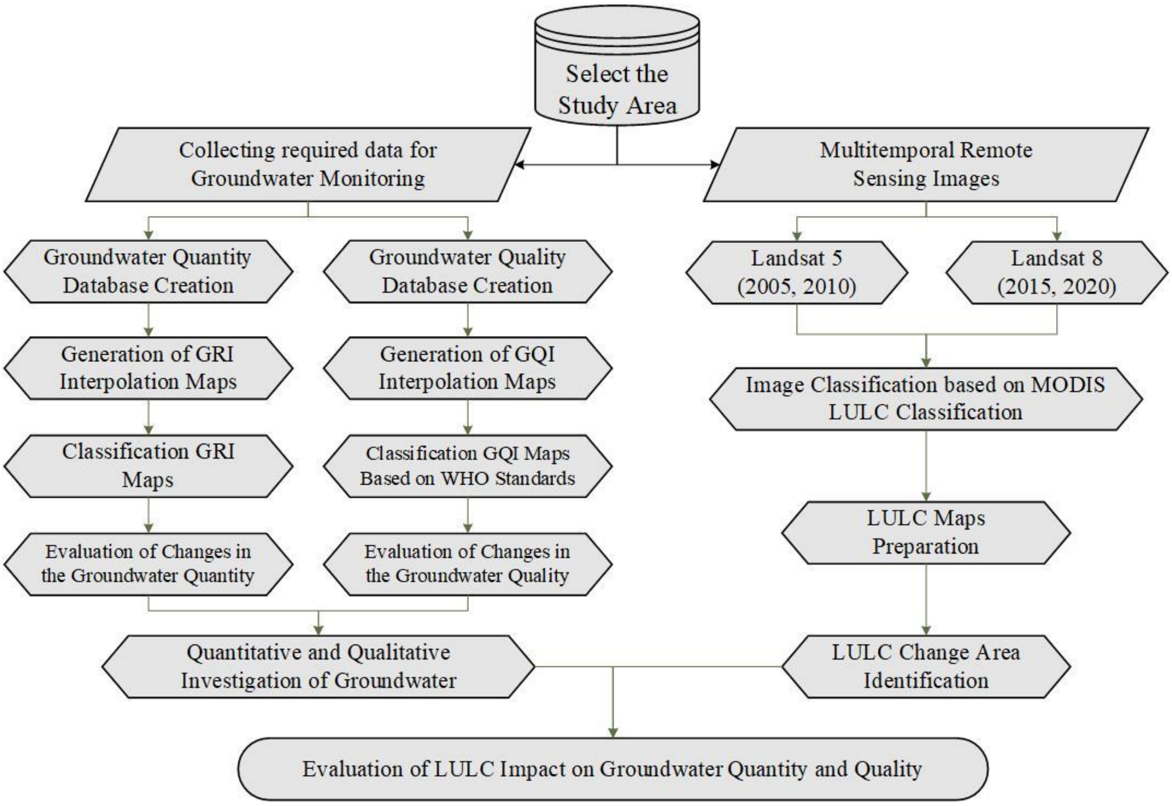

Fig 2. The flowchart of adopted methodology

Table 2. Details of satellite images used

Satellite name	Sensor name	Year	Number of bands	Row	Path
Landsat 5	TM	2005, 2010	7	35-36	165-166
Landsat 8	OLI	2015, 2020	11	35-36	165-166

- *Groundwater Resource Index*

GRI was invented by Mendicino *et al*. (2008) and assesses the hydrogeological drought and its intensity. Monthly groundwater level data for 41 quantitative monitoring wells during 2005-2020, was used in order to compute GRI in Qazvin plain, according to equation 1:

$$\mathrm{GRIy,m} = \frac{\mathrm{D}_{\mathrm{y,m}} - \mu_{\mathrm{y,m}}}{\sigma_{\mathrm{y,m}}} \tag{1}$$

Where; $GRI_{y,m}$ is Groundwater Resource Index value in each observation well for year y and month m; $D_{y,m}$ is the groundwater level in year y and month m in each observation well; $\mu_{D,m}$ is the average of groundwater level in the studied period and $\sigma_{\mathrm{D,m}}$ is standard deviation map of groundwater level in month m.

After computing GRI values for each well and generating GRI maps, they were classified based on Table 3. GRI has seven risk classes ranging from less than -2 to more than +2. If GRI value approaches more than +1, it shows wetter condition and if it approaches less than -1, it shows drought condition.

Table 3. Drought classification based on GRI (Mendicino *et al*., 2008)

Hydrological Drought Classification	GRI Range
Extreme Wet	$+2 \leq \text{GRI}$
Severe Wet	$+1.5 \leq \text{GRI} < +2$
Moderate Wet	$+1 \leq \text{GRI} < +1.5$
Normal	$-1 \leq \text{GRI} < +1$
Moderate Drought	$-1.5 \leq \text{GRI} < -1$
Severe Drought	$-2 \leq \text{GRI} < -1.5$
Extreme Drought	$\text{GRI} < -2$

- *Groundwater Quality Index*

Monthly data for 8 quality parameters including K^+, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, TDS and EC in 33 qualitative monitoring wells for years 2005, 2010, 2015 and 2020 were used in order to calculate GQI. To prepare the GQI maps, the concentration map of each quality parameter was separately generated based on standards recommended by World Health Organization (WHO) according to equation 2:

$$C = \frac{c_i - c_{WHO}}{c_i + c_{WHO}} \tag{2}$$

Where; *C* is the contamination index value for each pixel of each quality parameter map, c_i is contamination of each parameter and c_{WHO} is contamination of each parameter based on standards recommended by WHO (Table 4).

Table 4. Groundwater quality limitation based on (WHO, 2011)

Parameters	Units	WHO standard (S_i)
K^+	(mg/lit)	12
Na^+	(mg/lit)	200
Mg^{2+}	(mg/lit)	50
Ca^{2+}	(mg/lit)	75
SO_4^-	(mg/lit)	250
Cl^-	(mg/lit)	250
TDS	(mg/lit)	500
EC	(µmohs/cm)	500

In the resultant normalized difference map, contamination index values will range between -1 and 1. If the value of each pixel is closer to -1 shows the lower contamination and if it is closer to 1 shows the lower contamination (Khosravi *et al*., 2018). In next step, in order to remove the negative values, the normalized difference map was transformed into a rank map (1 to 10) using equation 3 (Babiker *et al*., 2007):

$$r = C^2 \times 0.5 + C \times 4.5 + 5 \tag{3}$$

Where; *r* is the rate of each parameter map and *C* is the contamination index value for each pixel of each quality parameter map. In this transformation, -1 is changed to 1 and representing the minimum impact on groundwater quality maps, 0 is changed to 5 and 1 is changed to 10 and reflecting the maximum impact on groundwater quality maps (Dehghan Rahimabadi *et al*., 2022).

In order to create a map that represents all the quality parameters and quantitatively shows the groundwater quality comparing standards of WHO, the layers were combined using equation 4:

$$\mathrm{GQI} = 100 - \frac{(r_1w_1 + r_2w_2 + \ldots + r_nw_n)}{N} \tag{4}$$

Where; r is the rate of each map, w is the relative weight of the quality parameters (the average value of the concentration of the variable in r), N is the nth quality parameters. The weight of each parameter indicates the relative importance of that parameter in groundwater quality and the parameter with greater average is more important in the overall assessment of groundwater quality. After preparing the GQI maps, the maps were classified according to Table 5. In this research, each class has been divided into subclasses, so that every 10 values are considered as one subclass.

Table 5. Classes of water quality based to the GQI values (Babiker *et al*., 2007)

Class	GQI Value
Excellent	$90 \leq \mathrm{GQI} \leq 100$
Good	$70 \leq \mathrm{GQI} < 90$
Medium	$50 \leq \mathrm{GQI} < 70$
Poor	$25 \leq \mathrm{GQI} < 50$
Very Poor	$0 \leq \mathrm{GQI} < 25$

3. Results

- *LULC Changes*

LULC maps were prepared based on images from Landsat 5 for 2005, 2010, and Landsat 8 for 2015 and 2020 (Fig. 3). According to these maps, LULC in the plain includes 5 classes: shrubland, rangeland, agricultural land, urban & built up and non-vegetated land. It can be seen that rangeland has the most area and urban & built up is the least. Agricultural land are located in the central areas of the plain, which are flat lands. From 2005 to 2020, the areas of shrubland, agricultural land and non-vegetated land have been increased, but the area of rangeland and urban & built up have been decreased.

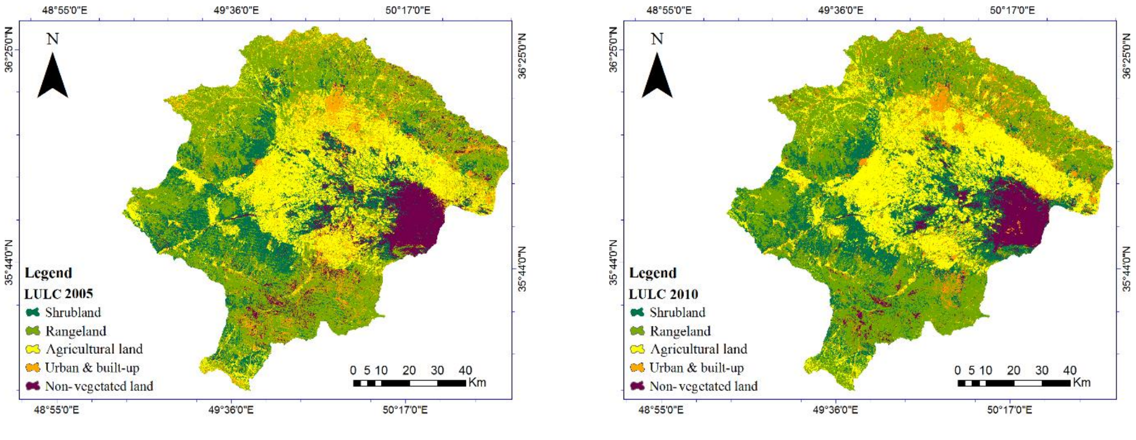

Fig 3. LULC maps for 2005, 2010, 2015 and 2020

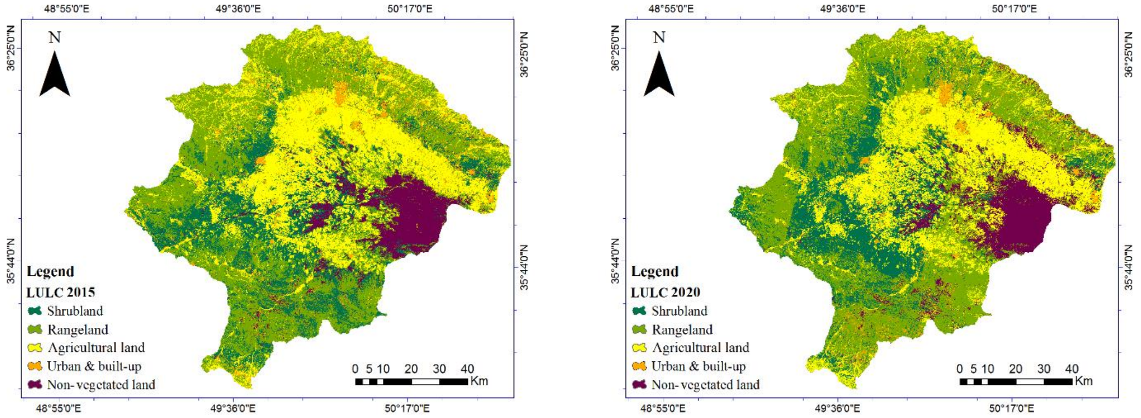

Fig 3. Continued

Table 6. The area of LULC classes

	Year	2005		2010		2015		2020	
	Area	Km^2	%	Km^2	%	Km^2	%	Km^2	%
LULC Type	Shrubland	1632.80	17.10	1671.62	17.51	1820.27	19.07	1862.10	19.51
	Rangeland	3857.36	40.41	3945.67	41.33	3668.96	38.43	3688.25	38.63
	Agricultural land	2253.88	23.61	2498.83	26.18	2763.47	28.95	2619.92	27.44
	Urban & built up	1029.38	10.78	860.84	9.02	489.72	5.13	461.26	4.83
	Non-vegetated	773.12	8.10	569.58	5.96	804.12	8.42	915.01	9.59
	Sum	9546.54	100	9546.54	100	9546.54	100	9546.54	100

- *Trend of GRI Changes*

In order to spatially and temporally assess the hydrogeological drought, GRI value was computed for each observation well in 2005, 2010, 2015 and 2020 (Fig 4). According to the GRI maps, the general trend of changes in this index is declining during the studied period and the driest situation occurs in 2020. It can be seen that in 2005, most of the areas have severe and moderate wet conditions, but in 2010 and 2015, almost the entire plain has normal condition. From 2015 to 2020, drought conditions occur and increase, with mainly moderate and severe drought conditions.

- *Trend of GQI Changes*

Combined evaluation of GQI was determined based on 8 parameters including K^+, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-, TDS and EC (Fig 5). Based on the weight of the parameters which reflect their importance in the overall groundwater quality, the order of their importance is as $K^+ < Mg^{2+} < Cl^- < Na^+ <$ EC $< SO_4^{2-} < Ca^{2+} <$ TDS. According to the maps, the general trend of GQI changes is declining during the studied period and there is the lowest quality in 2020. The whole plain has medium and good (with subclasses 1 and 2) conditions. In general, groundwater has higher quality in north and northwest sides of the plain than the central and eastern parts, which are mainly flat.

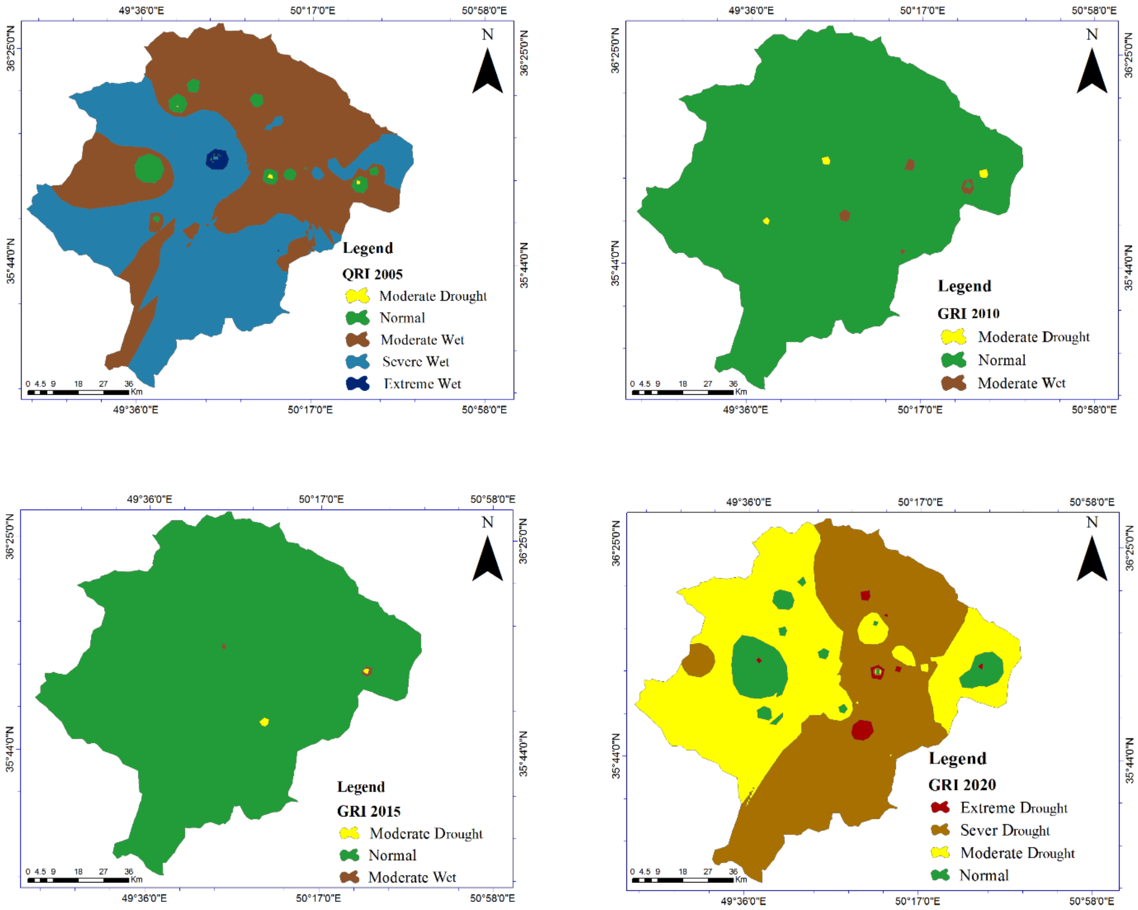

Fig 4. GRI maps for 2005, 2010, 2015 and 2020

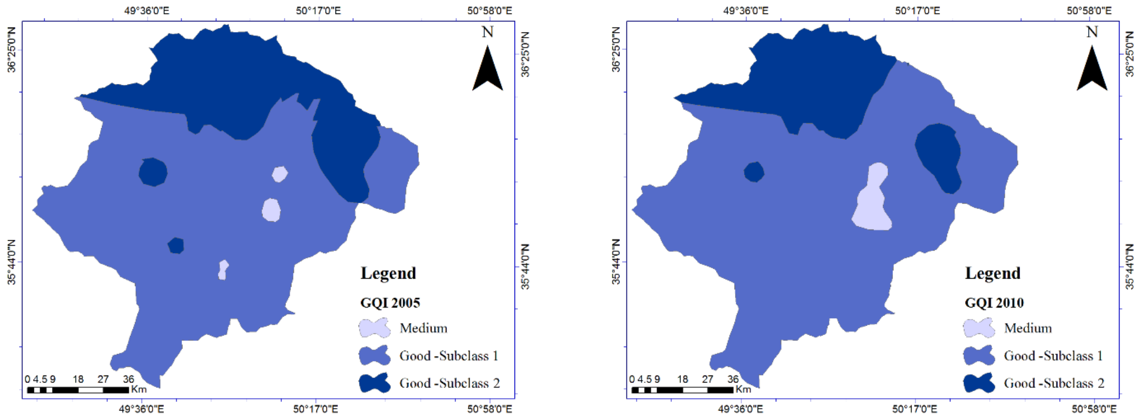

Fig 5. GQI maps for 2005, 2010, 2015 and 2020

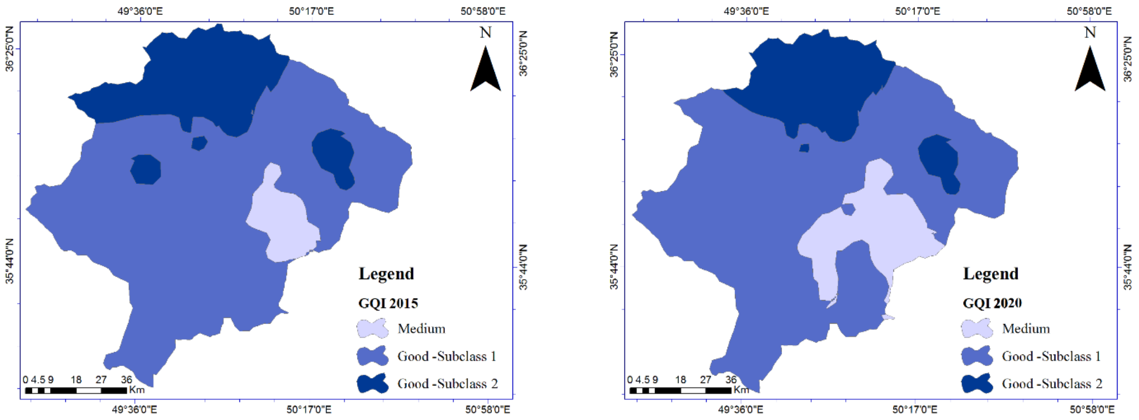

Fig 5. Continued

- *Relationship between GRI and GQI*

According to the results, GRI and GQI do not have a steady condition during the studied period and their trends are decreasing. Decreasing the quantity of groundwater affected its quality and caused it to decrease. This issue has increased more in recent years. Moreover, GRI results show more droughts in the eastern parts of plain over time, and GQI results show that groundwater quality has significantly decreased in the eastern parts in 2020.

The trend of changes in the average of GRI and GQI is provided in Fig. 6. The correlation between these two indices is 0.972 ($P < 0.05$). This value indicates that changes in groundwater quality depend on its quantity changes.

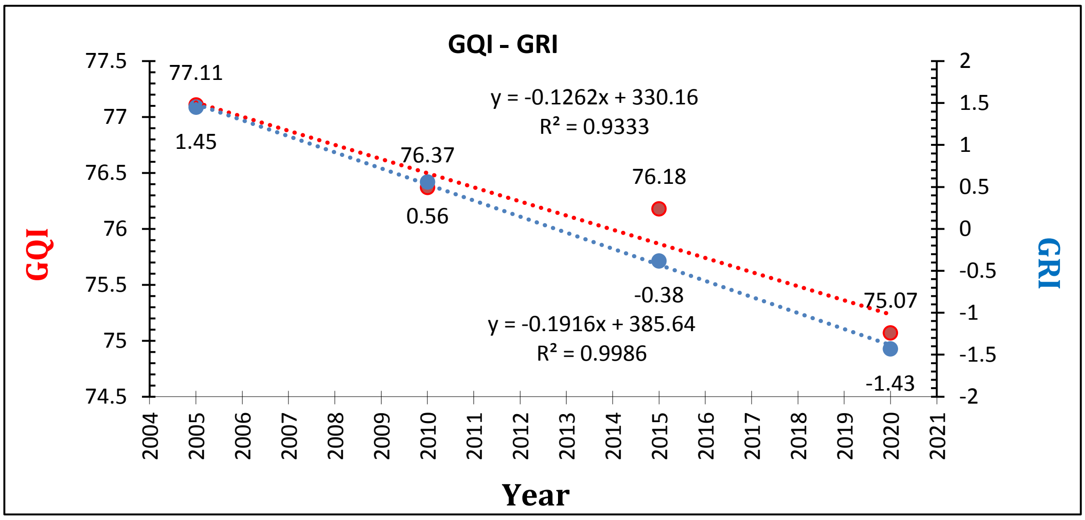

Fig 6. Trend of changes in GRI and GQI

4. Discussion

Groundwater resources in Qazvin plain are mainly used in agricultural and drinking purposes. Recently, agricultural activities by excess exploitation wells have caused to decrease groundwater levels and can increase hydrogeological drought. Therefore, knowing and being aware of quantitative and temporal and spatial changes in water quality, as well as studying the effects of land use changes on groundwater conditions in order to maintain and improve its quality is of particular importance.

This study disclosed the changing pattern in LULC which caused growing demand groundwater resources in Qazvin plain. LULC maps and distribution of exploitation wells in Qazvin plain indicated that in the central and eastern parts, the area of agricultural land and the number of exploitation wells are more than other parts. The results of changes in land use illustrated that rangeland and agricultural land had the most common class, and agricultural land had the most changes during the studied period. These results are consistent with Zarei and Bahrami (2016) and Yazdanpanahi *et al*. (2019). Also, agricultural use in these parts reduced the quantity and quality of groundwater.

From 2005 to 2015, the area of agricultural land was increased, during this period, the area of rangeland and non-vegetated around agricultural land decreased and changed for agricultural uses, which increased the demand and overexploitation of groundwater in these areas. Also, GRI maps indicated a depletion in the level of groundwater in agricultural land (west side of the plain). This result is consistent with the reported results by Karimian *et al*. (2019). Moreover, the most changes of groundwater quality belonged to the western part of the plain, where it had been deteriorated. While from then to 2020 its area was decreased and was changed for the degraded and non-vegetated area. Its reason could be the depletion in both quantity and quality of groundwater in the agricultural land.

5. Conclusion

The present study assessed the effect of LULC changes on spatially and temporally changes in groundwater in Qazvin plain. As mentioned above, the growth in the area of agricultural land has led to the growth of fresh water required for irrigation in Qazvin plain, which mainly depends on groundwater resources. Due to improper and excessive use of groundwater resources in this plain, the groundwater level has gradually decreased and this depletion has deteriorated its quality. This issue led to an increase the area of degraded and non-vegetated land around agricultural land over the time.

In the eastern parts of the plain, the non-vegetated land has increased over the time, which can be due to the increase of the area of agricultural land, in which the excessive use of groundwater resources has caused da depletion in its level and quality. Also, the use of agricultural inputs has affected the quality of groundwater in this sector. In general, increasing the area of agricultural land and high density of exploitation wells in these parts, had the greatest impact on the quantity and quality of groundwater in Qazvin plain. Finally, it can be recommended that the use of groundwater resources in this plain should be properly planned and managed to prevent the reduction of its quantity and quality and achieve the sustainable and correct management of these fresh water resources.

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