



## Evaluating Salinity in Shallow and Deep Aquifers of Gorganrood Basin, Iran

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| Article Info                                                                                                                                                                                                                                                                                                                                                                | Abstract                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
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| <p>Article history:<br/> Received 1: November 2022<br/> Received in revised form: 3 April 2023<br/> Accepted: 18 April 2023<br/> Published online: 11 May 2023</p> <p>DOI:<br/> 10.22044/JHWE.2023.11536.1000</p> <p><b>Keywords:</b><br/> Salinity Management<br/> Gorganrood Basin<br/> Groundwater<br/> Density Current<br/> Watershed Management<br/> Deep Aquifers</p> | <p>Increasing groundwater salinity in countries facing water scarcity has raised severe environmental and health concerns. One of the best ways to prevent groundwater pollution is to study groundwater quality's spatial variation and identify vulnerable aquifer areas. The aim of the present work is to evaluate the salinity of groundwater in shallow and deep aquifers of the Gorganrood basin. In order to achieve this goal, values of electrical conductivity of groundwater in the mentioned aquifers are measured in situ for wet and dry periods. According to the obtained results, groundwater salinity in shallow aquifer is considerably greater than that in the deep aquifer. Moreover, the salinity of groundwater in both aquifers (shallow aquifer, in particular) for the wet period has been diminished compared to that for the dry period. The maximum electrical conductivity associated with the shallow wells is related to the well of Kuchek Khortum, which is 8350 <math>\mu\text{mho/cm}</math> due to the presence of sediments containing high-solubility materials. The fine grain content of sediment, and consequently, the rise of water due to the capillary force and its evaporation, and the remaining salts in sediments are the salinity factors. Also, the operation of Caspian fault has transmitted deep water to the surface aquifers, and has caused water salinity in these areas. Deep wells in the south of the basin with the lowest electrical conductivity feeding rivers' entry improves water quality, and reduces electrical conductivity. In the north of the basin, the water quality is reduced due to the desert area's passage, where the groundwater level is relatively high. The lowest electrical conductivity in deep wells with a value of 619 <math>\mu\text{mho/cm}</math>, and most of it is equal to 2085 <math>\mu\text{mho/cm}</math>. The results of the effect of geological formations and alluvial deposits on the aquifer salinity show that the springs located in the boundary of these formations have more salinity. Another important point observed in the results is the sudden decrease of groundwater salinity in the southern border of Gorganrood basin, which can be caused by groundwater aquifer feeding by groundwater fresh (especially in the limits of the rivers feeding groundwater aquifers including the rivers of Ağan, Chehel Chay, Khormalou, Qurchay, and Zarringol).</p> |

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## 1. Introduction

Groundwater constitutes a primary source of freshwater for many populations around the globe, especially regions where rainfall is scanty, surface water sources are absent, and all domestic and agricultural needs are fulfilled with groundwater (Jafari et al., 2018; Mosaffa et al., 2021).

The presence of saline groundwater is one of the most conspicuous problems globally. Decreased groundwater quality often leads to tensions in the water management and distribution system, and poses a serious threat to aquifers and freshwater. Therefore, understanding the salinity distribution in the aquifers as well as the past and future is important for managing groundwater resources (Barlow and Reichard, 2010; Wu et al., 2020).

Water salinity is a significant factor in soil salinity; soil salinization is a significant issue in arid and semi-arid areas, which has a major impact on decreasing soil fertility and is a significant factor in desertification processes world's dryland (Wei et al., 2019). Therefore, timely detection of groundwater salinity and evaluation and monitoring of its intensity and extent are necessary to manage the negative aspects such as destroying the soil structure, reducing the biodiversity and agricultural production, water pollution, and problems for human health (Majeed and Muhammad, 2019; Naser et al., 2020).

Factors leading to the salinization problem may be natural or anthropogenic. Natural factors include a wide range of various factors such as evaporation, low annual rainfall (for aquifer recharge), filtration from surface saline water, the upward intrusion of brines from deeper aquifers, accumulation of salt from rainfall over many thousands of years or from the weathering of rocks. Human activities can cause salinity through the following factors: use of salt-rich irrigation water, use of chemical fertilizer, rising water table, and bringing salt to the surface due to human activities (filtration from unlined canals and reservoirs), increase land use such as

agricultural, industrial and urban development, high pumping rates from groundwater, and poor drainage conditions. (Gutiérrez et al., 2018; Shamsi et al., 2019; Rajmohan et al., 2021).

In Iran, rapid developments in the agricultural sector and unplanned industrial growth have led to increased use of the shallow aquifer. Agriculture (80-90%) and then industry are the primary consumers of groundwater in this country. High pumping rates have led to low groundwater levels, salinization of groundwater, and nitrate accumulation in shallow aquifers (Hosseini et al., 2019; Bagheri et al., 2020; Troudi et al., 2020).

Numerous articles have been performed using statistical, numerical, hydrological, and physical models to predict groundwater salinity (Dieng et al., 2017; Gašparović and Singh, 2020; Abulibdeh et al., 2021). Abulibdeh and co-workers evaluated the impact of evaporation on groundwater salinity in the arid coastal aquifer using geochemical and multivariate statistical tools. The PHREEQC model was used to reveal groundwater minerals in this study (Abulibdeh et al., 2021). The salinity of groundwater coastal wetlands was assessed as moderate to high latitude with four natural reserves with contrasting hydrological and climatic conditions. The results show a saline groundwater increase along a latitudinal gradient with electrical conductivities varying from 0.3 mS/cm at 34°47' S to 154 mS/cm at 42°25' S (Galliari et al., 2021). Sahour *et al.* (2020) mapping groundwater salinity using hydrogeology and hydrometeorology data and statistical and machine learning techniques in the southern coastal aquifer of the Caspian Sea. Aquifer transmissivity, distance from the sea, the mean annual precipitation, the mean annual evaporation, elevation, and the depth to the water table were considered for this study. The results show that the aquifer transmissivity is the most crucial parameter affecting groundwater salinity in the region (Sahour et al., 2020). Troudi *et al.* (2020) monitoring the groundwater quality situation

showed the nitrate and salinity are one of the prime pollutants in the groundwater in the shallow aquifer of Guenniche (Northern Tunisia). The results indicate that nitrate and salinity variations during the period 2006–2015 follow the rainfall fluctuation patterns (Troudi et al., 2020).

Recently, a few case studies have been carried out on nitrate concentration in limited parts of the Gorganrood basin (Mahzari et al., 2016). In this research work, the main nitrate source is referred to as agricultural activities (especially nitrogen fertilizers) and urban and rural sewage.

There is no comprehensive study on the salinity of groundwater for the entire Gorganrood basin by reviewing the work done. Considering that the amount of groundwater salinity in shallow and deep aquifers in the Gorganrood basin is significantly different, the lack of comprehensive study finds more importance. The study's main objective is to investigate the salinity of groundwater in two shallow and deep aquifers of the Gorganrood basin. To achieve this goal, the electrical conductivity of water in two parts of the shallow and deep aquifers has been measured in wet and dry periods in the Gorganrood basin. One of the most common methods of measuring water salinity is the measurement of electrical conductivity, which is carried out with electrical conductivity meter devices with high precision and ease.

## **2. Material and Methods**

### **2.1. Studied area**

Golestan Province, with an area of about 21000 km<sup>2</sup>, consists of five watershed basins of Atrek, Qaraosu, Gorganrood, Gorgan Gulf, and Nekarod. This province has a border with Turkmenistan internationally from the south and is neighboring Semnan, Mazandaran, and North Khorasan from the south, west, and east. The province is located in the geographical coordinates of 53° 51' to 56° 14' E and 36° 44' to 38° 5' N. Figure 1 shows the map of Golestan province and the fivefold

watershed basins contained therein. The studied area in this research work is the Gorganrood basin, which is the most extensive and most important watershed basin in the province. Most of the province's agricultural land use surface water and groundwater in the basin. Also, drinking water from many of the major cities of the province (including Kalaleh, Galikesh, Minoodasht, Gonbad, Azadshahr, Khan Babin, Ali Abad, Gorgan, Aq-Qala and Bandar-Turkman) is provided by the Gorganrood river. Gorganrood Basin is limited to the Atrek basin from the north to the Mazandaran Sea and Qara-Souz basin from the west and the elevations of Semnan and Khorasan provinces from the east to the mountains of Semnan province and the Nekarod basin from the south. The area of the basin is 10197 km<sup>2</sup>. The elevations of the basin are mainly covered with forest and part of the Gorganrood basin including sub-basins of Rebate Qarah Bil, Plain, and Nardin, is located in the provinces of Semnan and North Khorasan.

### **2.2. Climatic conditions of region**

The studied area has a great variety of climates due to its vast expanse and topographic conditions. There are in the west of semi-arid, moderate semi-humid climates and in the east of the dry, cool semi-arid climates, which are affected by geographical factors such as the vicinity of the Caspian Sea and enclosed by the Alborz Mountains. As the sea moves eastwards, air humidity decreases, and air dryness increases. In this basin, annual precipitation decreases from west to east. The average annual precipitation in the basin's western regions is about 450 mm and in the eastern regions of the basin is about 180-250 mm. The minimum and maximum annual temperatures are 11 °C and 18 °C, respectively. From low-rise coastal areas to elevations, temperature decreases, reaching about 9 degrees in elevations (Lar Consulting Engineers, Meteorological Report, 2020).

### **2.3. Vegetation of region**

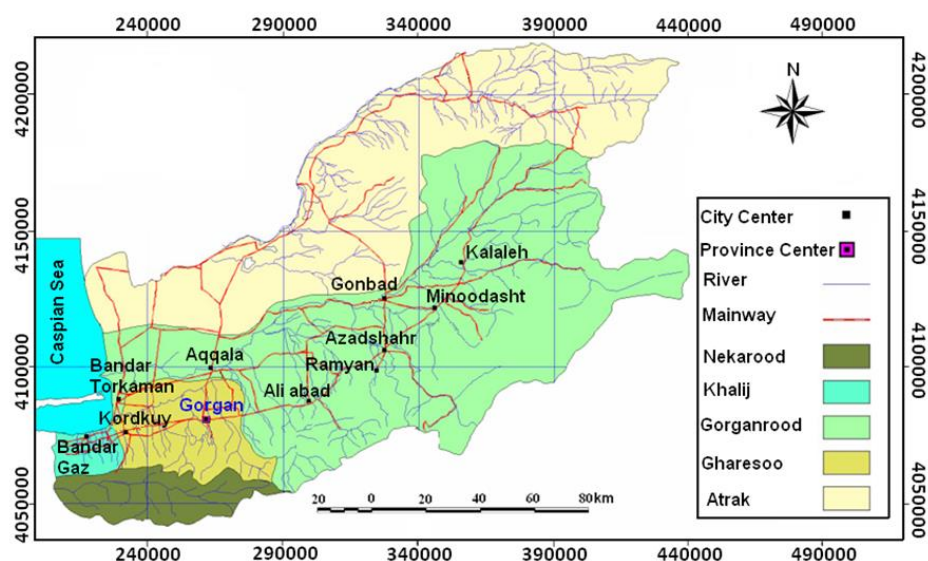
About 30% of the studied region area, especially in mountainous and upland areas, is covered by forests and woodland. Golestan National Park, with a forest area of about 40,000 hectares, is located in this region. The basin studied in Rabat Cheshme-Khan and Dasht branches have rangeland and forest vegetation. In elevations, sometimes without vegetation, and after the intersection of Rabat branch and Dasht basin, there is dense and protected forest vegetation without any operation. This basin's forests can be divided into two categories of semi-humid broad-leaved forests and drought-tolerant resinous forests. Two species of hornbeam and oak are the most abundant tree species in this area but in southward slopes, this ratio changes in favor of oak. Many of these species play an essential role in preventing evaporation, soil conservation, and erosion prevention. Because the moisture content decreases from west to east, this has a unique effect on the shape, species, and formation types (Lar Consulting Engineers, Forest Report, 2020). The region's rangelands are from the viewpoint of geographical and climatic conditions including Yaylak and Kishlak rangelands used for livestock forage. In the margins of villages and demographic areas, forest vegetation has gone away and has been burned down and sometimes turned into agricultural land.

#### **2.4. Geology of region**

Based on the studied basin's geological studies, the intersection of two important geological zones in the northeast of the country is named the eastern Alborz zone (Binaloud) and Kopet Dagħ zone (Khosro-Tehrani, 1989). The boundary of this zone is along the Gorgan-Bojnourd road. The stratigraphy of the rocks and deposits of various geological periods from the Paleozoic to the present time is in the studied area. There are no outcrops of metamorphic rocks in the studied area, but some extrinsic species of igneous rocks are in this region. The mainly

region's stone units are sedimentary rocks, including limestone, sandstone, shale, dolomite, marl, conglomerate, clay, and alluvial deposits. Because the most ancient deposits of the Kopet Dagħ zone are related to the second geological period, a significant part of the basin is covered by Jurassic period rocks. Limestone rocks of formation of Chaman Bid, Mazdavand, Lar, and sandstones and shales of Shemshak are among the most enriched rock units (Khosro-Tehrani, 1989). In Paleocene, there is the sedimentation of semi-condensed conglomerate with weak cement. In the glacial period, extensive loess deposits consist of silt and clay in the form of high hills in the north basin. Quaternary deposits, alluvial plain, and bedrock deposits are widely distributed in different areas of the basin. In terms of tectonics, the studied area is the intersection of Kopet Dagħ and East Alborz.

Due to this, properties and structural conditions such as folding and thrust can be observed in the region. The presence of folded deposits in the area indicates tectonic activity related to different geological times, which, along with other stresses in the late Cenozoic, has had the most significant impact on the area's present morphology. The main system of the faults in the study area is the thrust fault, most of them along the northeast-southwest, showing movement from northwest to southeast and causing several classes to move on to each other. The severity of these faults' operation in parts of the study area is such that it causes the creation of crushed areas (Khosro-Tehrani, 1989). Among the studied area's important faults are the faults of Alborz, Rebate Qarah Bil, Tang Rah, and Golestan fault. The major part of the construction site's geomorphology has been affected by the thrust fault as anticline and syncline areas. The hydrographic network is mainly aligned with the tectonic fault network of the region.



**Figure 1.** Map of Golestan province and its five-fold watershed basins.

To evaluate the salinity situation in shallow and deep aquifers of the Gorganrood basin, the electrical conductivity values were measured in 105 deep wells in November 2019 and 92 wells in May 2020. The Hach Co. Conductivity Meter Model 50150 from HACH Company to measure water samples' electrical conductivity at the sampling site was used. Figures 2 (a) and (b) show the position of sampling wells in November 2019 and May 2020, respectively. As shown in Figures 2 (a) and (b), sampling wells have been distributed reasonably well throughout the Gorganrood watershed basin's plain section. Of course, the number of wells in the north part of the Gorganrood plain is slightly lower because of the inappropriate water and soil resources in this part of the plain. Since the shallow and deep groundwater aquifers are two separate aquifers and their salinity is entirely different, they are discussed separately in this research work. In addition to the wells, electrical conductivity measurements for 12 springs located on the border between the complex formations and alluvial deposits of the Gorganrood basin, have also been carried out. The springs' electric conductivity values are used as control samples and compared the wells' electrical conductivity values with the springs' values. The measurement of electrical

conductivity for these springs was done only in November 2019. The reason for this is that springs are relatively small. The dominant current is Diffuse flow, and according to various researchers (Shuster and White, 1971; White, 1988; Raeisi and Karami, 1997)), the variation of physical and chemical characteristics of these springs are very small. Therefore, it is not necessary to measure the electrical conductivity in different seasons. As mentioned, the electrical conductivity measurement in the wells of the area was carried out in two distinct periods, November 2019 and May 2020. Before examining different qualitative maps in these two periods, precipitation in the Gorganrood basin is compared in these two periods. To compare the precipitation in November 2019 and May 2020 in Gorganrood basin, the precipitation data of 7 stations are located in different parts of the Gorganrood basin was collected. Figure 3 shows the histogram of the monthly precipitation of these stations and their average in November. It is also observed that the average precipitation in these two months was 58.1 and 93.1 mm, respectively. Regarding the average rainfall in the Gorganrood basin, which is usually more rainfall than in May, compared to November, the precipitation situation in these two months

was contrary to the situation that occurred in previous years.

### 3. Result and Discussion

#### 3.1. Investigation of electrical conductivity of groundwater in shallow wells

Figures 4 (a) and (b) show electrical conductivity maps of shallow aquifers in November 2019 and May 2020, respectively. As shown in Fig. 4-a, the maximum electrical conductivity associated with the shallow wells, which was sampled in November 2019, is related to the well of Kuchek Khortum, which is 8350  $\mu\text{mho}/\text{cm}$ . The reason for this is

likely to be the presence of sediments containing high-solubility materials and, consequently, degradation of water quality. One of the important reasons is that the high solubility of these materials in these sediments, its fine grain content and, consequently, the rise of water due to the capillary force and its evaporation, and the remaining salts in the shallow of these sediments. Of course, the Caspian fault can also be considered as a weak possibility. In this way, the operation of this fault has transmitted deep water to the shallow aquifers and has caused water salinity in these areas.

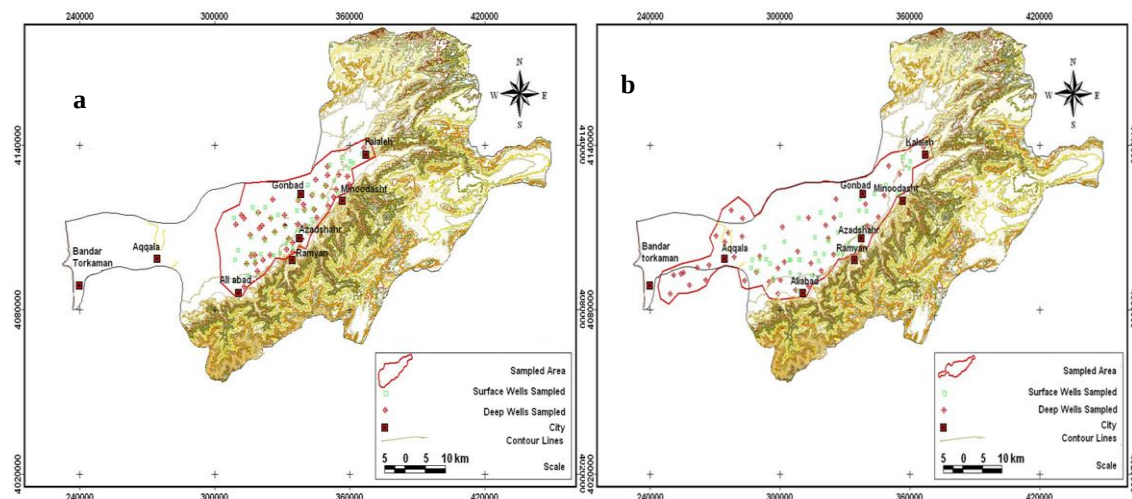
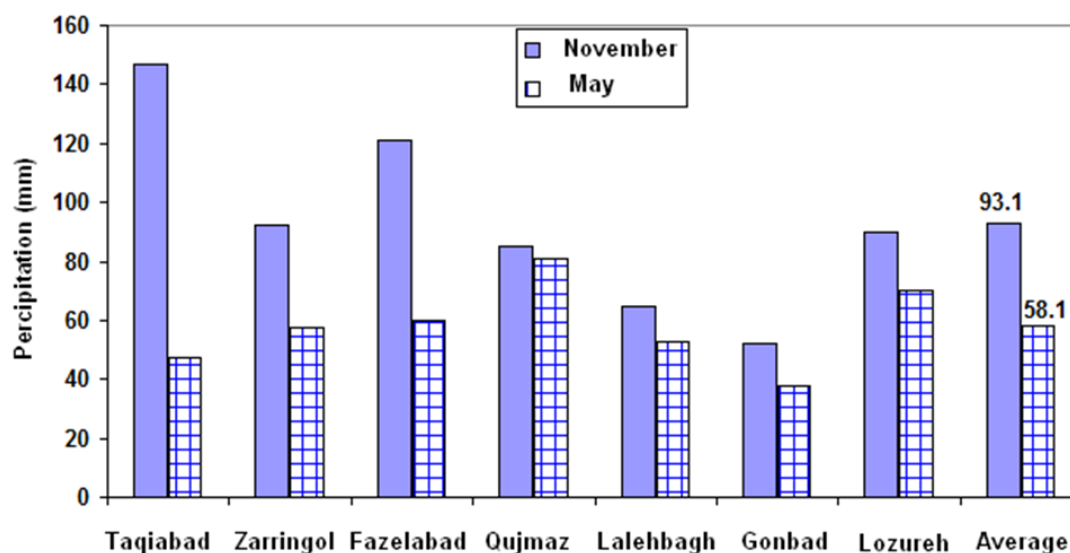


Figure 2. Location of sampling wells in a) November 2019, b) May 2020.



**Figure 3.** Comparison of precipitation of stations in the region and their average in November 2019 and May 2020.

The amount of electrical conductivity ( $\mu\text{mho/cm}$ ) in the southern margin of the Gorganrood basin (for example, the range of Kalaleh to the southwest of Minoodasht, Azadshahr range to Khan Bebin and Aliabad area) is low. Thus the electrical conductivity is in the range of 400 to 700  $\mu\text{mho/cm}$ . Due to the low level of electrical conductivity in this area, the groundwater aquifers are fed by underground freshwater theater (especially in the limits of the rivers feeding groundwater aquifers, including the rivers of Aġan, Chehel Chay, Khormalou, Qurchay, and Zarringol). Due to the entry of a relatively salty water theater from the Tamar river basin, the groundwater quality has been destroyed within the range of the north of Kalaleh and, gradually, the electrical conductivity improves by mixing this flow with inadequate quality with the mainstream of the region, which is relatively good quality. In this way, the electric conduction from the north of Kalaleh to the Doogh River decreases.

In the area of Gonbad Kavus to the east of Aq-Qala, groundwater quality is inappropriate, so that the electrical conductivity in this range reaches more than 6000  $\mu\text{mho/cm}$ . This saline water flow, which originates mainly in saline flows in

the north part of Gorganrood (between Gonbad Kavus and Aq-Qala), causes groundwater quality degradation moving from the south and southeast to Gorganrood. About 10 km north of Khan Bebin, there is a very high electrical conductivity range (more than 8000  $\mu\text{mho/cm}$ ). Also in the southwestern of Gonbad Kavus, high electrical conductivity areas (between 4000 and 6000  $\mu\text{mho/cm}$ ) are considered. In the areas mentioned, the cause of high groundwater salinity is the same as explained at the beginning of this section. The range of electrical conductivity changes in shallow wells in May 2007 is 318  $\mu\text{mho/cm}$  in the well of the northern part of Khan Bebin up to a maximum of 10855  $\mu\text{mho/cm}$  in the shallow wells of Kord village (east Aq-Qala). Based on the electrical conductivity map of the shallow aquifer in May 2020 (Fig. 4-b), although the general trend of electrical conductivity change is more or less in line with the trend of the electric conductivity map of November 2019; however, it also includes changes that are presented briefly:

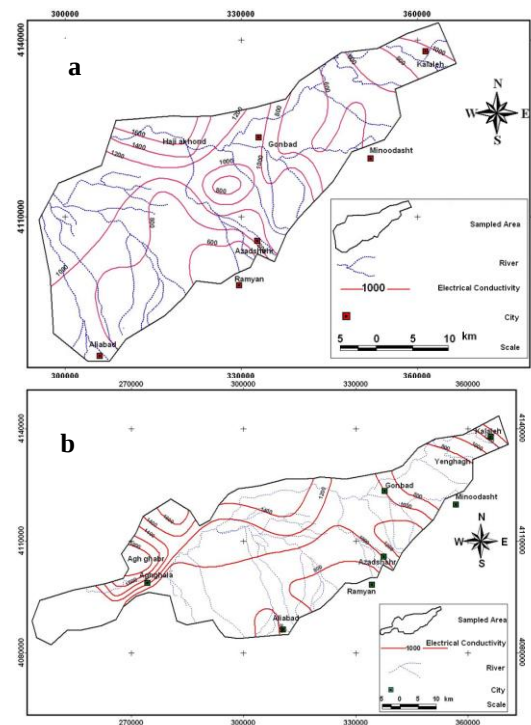
One of the most significant differences between the shallow aquifer's electrical conductivity map in May 2020 and November 2019 is that in May 2020, all

electrical conductivity values increased more or less. Thus the electrical conductivity in the southern margin of the Gorganrood basin varies from 600 to about 1000  $\mu\text{mho/cm}$ . Also in the northern part of Khan Bebin, the electrical conductivity is over 8800  $\mu\text{mho/cm}$ . Also in the range of Kalaleh in November 2019, the electrical conductivity in the west Kalaleh was about 1000 or less than 1000  $\mu\text{mho/cm}$ . However, in May 2020, the electrical conductivity in the west Kalaleh reaches about 4000  $\mu\text{mho/cm}$ . The reason for the significant difference in the electrical conductivity in different parts of the Gorganrood basin in May 2020 compared to November 2019 is that in November 2019, the precipitation was very high, and even during sampling, there has been precipitation that diluted solids soluble in groundwater and thus reduced the electrical conductivity of these waters.

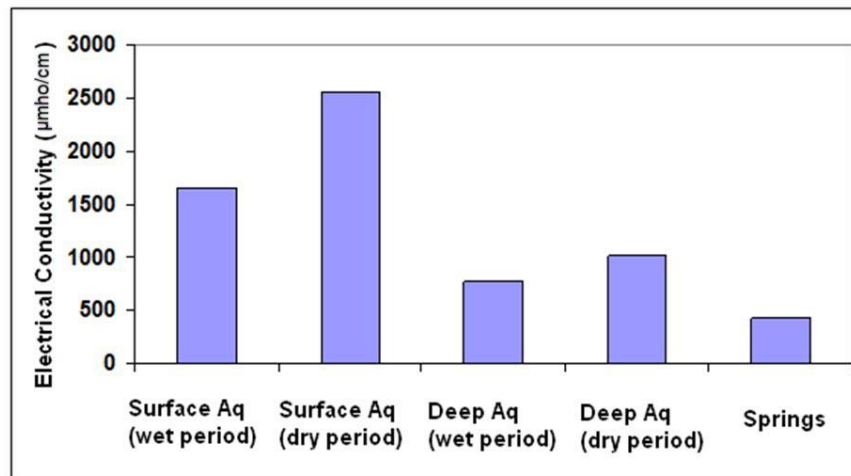
### 3.2. Investigation of electrical conductivity of groundwater in deep wells

Figures 5 (a) and (b) show electrical conductivity maps of deep wells in November 2019 and May 2020, respectively. As shown in Figures 5 (a) and (b), electrical conductivity in November 2019 is significantly lower than in May 2020 because surface currents feed the southern margin of the Gorganrood basin, and the coarse-grained alluvium, more surface nutrition, and precipitation effects are quite evident. However, in the north of the Gorganrood basin, which has relatively low permeability and no feeding rivers, electrical conductivity does not significantly differ. In November 2019, the electric conductivity in deep wells varied from the minimum 426  $\mu\text{mho/cm}$  in Ramian well to the maximum of 1422  $\mu\text{mho/cm}$  in Haji Akhond (in the west of Gonbad Kavus). It is noted that the minimum and the maximum of electrical conductivities are related to the

south and north of the basin, respectively. In the south of the basin with the lowest electrical conductivity, feeding rivers' entry improves water quality and reduces electrical conductivity. In the north of the basin, the water quality is reduced due to the desert area's passage, where the groundwater level is relatively high. The lowest electrical conductivity in deep wells, which was sampled in May 2020, is located in the deep well of Neoghak, north of Minudasht, with a value of 619  $\mu\text{mho/cm}$ , and most of it is related to the deep well of Agh Ghabr located in the north of Aq-Qala, which is equal to 2085  $\mu\text{mho/cm}$ .



**Figure 5.** Map of electric conductivity ( $\mu\text{mho/cm}$ ) of deep aquifers in **a)** November 2019 and **b)** May 2020.



**Figure 6.** Comparison of the average electrical conductivity in shallow and deep aquifers with springs.

### 3.3. Comparison of salinity in area aquifers with springs

In addition to the wells in the area, electrical conductivity measurements for 12 springs, located at the boundary between the complex formations and alluvial deposits of the Gorganrood basin, have also been carried out. In order to compare the salinity of shallow and deep aquifers as well as to compare their salinity in wet and dry periods, the mean values of electrical conductivity of water wells for these cases were calculated separately and compared with the mean values of the electrical conductivity of the springs (Figure 6). As it can be seen in Fig. 6, the mean values of electrical conductivity in the shallow aquifer are significantly higher than that of the deep aquifer and, in addition, for both shallow and deep aquifers (in particular the shallow aquifer), the mean electrical conductivity values during the wet period have significantly decreased. The reason for this is that during the wet period, both the aquifers (especially the shallow aquifer) are fed with rainwater or surface currents. Since the solids of the solution in the rain and the surface currents are far lower than groundwater aquifers, this reduces the salinity of groundwater aquifers. According to Fig. 6, it is also seen that the mean electrical conductivity values of both

groundwater aquifers, even in the wet period, are significantly higher than the mean values of the electrical conductivity of the springs. This is due to that the flow of groundwater during the upstream movement solves more solids in itself, increasing the amount of electrical conductivity in the Gorganrood Plain compared with the beginning of the range of alluvial aquifers (where the aquifers are located).

### 4. Conclusion

According to the electrical conductivity maps (Figs. 4 to 5), it is observed that the amount of electrical conductivity of groundwater in shallow and deep aquifers as well as in different parts of the basin is noticeably different. In both shallow and deep groundwater aquifers, the water quality is appropriate in the south of the basin where nutrient flows enter the basin, while water quality is degraded towards the center and north of the basin. For example, in the shallow aquifer in the south and east of the basin, groundwater's electrical conductivity is about 1000 µmho/cm or less. However, in the center of the basin, for example, 20 kilometers northeast of Ali Abad or 20 kilometers east of Aq-Qala, the electrical conductivity reaches over 5000 µmho/cm or more. In electrical conductivity maps in the deep aquifer, the amount of electrical

conductivity and variations exhibit a slightly different behavior from the shallow aquifer. Thus, the amount of electrical conductivity is the same in most of the Gorganrood basin from the east of Kalaleh to the west in the Aq-Qala area and from the south to the north, with slight changes. However, in this aquifer, the groundwater quality in the region of Aq-Qala to the west and northwest is relatively degraded. By comparing the mean values of electrical conductivity in shallow and deep aquifers, it is observed that the water quality in the deep aquifer is significantly higher. For both shallow and deep aquifers (especially shallow aquifer), water quality has improved considerably due to aquifers' feeding (especially shallow aquifer) during the wet period. Also the mean comparison of the electrical conductivity values of both groundwater aquifers with the mean values of the springs' electrical conductivity indicates that water quality in both aquifers has decreased significantly compared to the springs (located at the beginning of the alluvial aquifer). The main reason for this is the increase in the length of the groundwater flow in groundwater aquifers.

### Data Availability

The data used to support the findings of this study is available from the corresponding author upon request.

### Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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