Evaluation of the spatial and temporal changes in groundwater level and mineralization in agricultural lands under climate change in the Syrdarya province, Uzbekistan

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Abstract. Salinization processes are taking place as a result of rising groundwater level and its mineralization rate due to inefficient and unsustainable use of water and land resources in Uzbekistan. This leads to a reduction in arable land productivity and a decrease in nationwide yield production. Especially, salinization is the case in the plain irrigated areas of Uzbekistan where the groundwater is closer to the surface. Salinization processes occur as a result of an increase in the level of groundwater and the degree of their mineralization due to inefficient and irrational use of water and land resources in Uzbekistan. This leads to a decrease in the productivity of irrigated land and a decrease in yields throughout the country. Principally, salinization takes place in irrigated plain areas like the Syrdarya province, where mineralized groundwater is closer to the surface. Considering the geo-location of Uzbekistan as an aridic zone, there is a massive stress on groundwater because of surface water shortage. Since the estimation of the salinization consequences on groundwater is critical, this research, therefore, was aimed to understand and evaluate the long-term changing behavior of groundwater level and its mineralization in the irrigated areas of the Syrdarya province of Uzbekistan from 2000 to 2015 by using traditional methods, and GIS-based methods for from 2016 to 2019.

The level and mineralization of groundwater in each administrative district of the province were for the first time studied and assessed. Consequently, the dependence of the groundwater level and its mineralization on soil conditions and climatic factors were determined. Based on the results of the study, agricultural specialists and farmers of the province were highly advocated to take the following measures considering the actual condition of groundwater mineralization in the irrigated areas of the Syrdarya province: (1) targeted and economical use of irrigation water; (2) ensuring that existing drainage networks are in an adequate working condition and can operate with full-efficiency; and (3) to conduct annual monitoring of groundwater table and its mineralization of irrigated lands using traditional and GIS technologies.
1. Introduction

Irrigated area in the Aral Sea basin has increased from 3.5 million hectares (ha) to 8.0-8.5 million ha since 1950, as well as a sharp increase in the use of river water resources for irrigation and development of new and previously idle lands in catchments of two main rivers, Syrdarya and Amudarya, in Central Asia led to the deterioration of the ecological situation in the region. The upheaval drying up of the Aral Sea has led to a decrease in the quantity and quality of water resources available in the basin and a violation of the ecological and hydrological balance of the region [6, 42]. Irrigated land in Uzbekistan is 4,312.2 thousand ha or 9.7% of the total land area, and about 50% of the national water resources are used mainly for agriculture (85-90%) and other purposes. Extensive use of irrigated lands in the country, as a result of non-compliance with agro-technical requirements, has led to an increase in the groundwater table (GWT), increased mineralization, and salinization contents of the soil. This was predominantly caused by using excessive water resources for irrigation purposes, insufficient maintenance, and cleaning of existing drainage systems [6, 16, 42]. The formation of groundwater in Central Asian countries is inextricably linked with the quantity and quality of surface water resources and glaciers [1, 12]. However, in many cases, in such countries located in arid and semi-arid regions, groundwater mineralization (GWM) processes are not sufficiently taken into account in the study of groundwater. Therefore, the rise of highly mineralized groundwater table and the increase in its dissolvent solids lead to the decommissioning of irrigated agricultural lands and a decrease in their productivity, which is often overseen by agricultural experts [5].

The mineralization processes of groundwater can be controlled mainly by managing the geological conditions of the area, the hydraulic gradient, as well as the irrigation (runoff) water infiltrated to the underground in agriculture [7, 19]. In the assessment of GWM, the chemical cation elements (Na, K, Mg, Ca, - mg/l), anionic compounds (NO\textsubscript{3}, HCO\textsubscript{3}, SO\textsubscript{4}, Cl and Br - mg/l), electrical conductivity (EC), and the pH value of the groundwater are taken into account [20]. Therefore, an in-depth analysis of GWM requires regular large-scale hydrogeological and hydro-chemical studies.

In recent years, remote sensing and geographic information systems (GIS) as up-to-the-minute technologies are highly efficient in receiving, processing, analyzing, and evaluating large geographic data in addition to traditional scientific research methods for geological, hydrogeological and geomorphological survey [29]. In particular, studies have shown that the integration of traditional methods and GIS technologies is an effective tool in the study of groundwater [14, 24, 26, 29]. Digital enhancements in GIS provide the maximum level of scientific and practical information that is sufficiently accurate and useful for studying groundwater. GIS technologies facilitate the integration and analysis of large amounts of data, while field research in turn helps to justify and verify the accuracy of GIS results. The effective use of these approaches gives its positive effect only when the right methodology is designated and applied [21, 28, 29, 30]. Appropriate results have been obtained in the study of GWT using GIS technologies, and these results play an important role in the accurate measurement and evaluation of GWT [22, 23].

GIS technologies are also used to determine and assess GWM and soil salinity. Many scientists and experts in developed and developing countries of the world have thoroughly studied the relationship between the current state of GWM and soil salinity of irrigated areas through GIS methods (interpolation, vegetation and hydrological indices) [3, 10, 11, 13]. As a result, the acceleration of the salinization process of irrigated lands because of the effects of climate change on GWM has been largely studied remotely and the desired scientific result has been achieved. It was noted that the GIS methods used in these studies were more likely to give the expected sound results if they were repeated for areas akin to the geomorphology of the studied area.

In Central Asian countries with arid and semi-arid climates, the determination of GWT and GWM is important in addressing the reclamation status of irrigated areas and the causes of soil salinization. At present, minor studies have been carried out by local and international scientists on the definition and evaluation of surface water mineralization and GWM in Uzbekistan. Ibragimov [8], Kulmatov [15],
Kulmatov and others [16, 17, 18], Wahyuni and others [32], Chernishov and Shirokova [39], and Eshchanov [41] assessed GWT and GWM in Navoi, Syrdarya, Jizzakh and Khorezm provinces of the country and determined the potential drivers influencing the groundwater. In the research undertaken by Kulmatov [15], Kulmatov et al. [16, 17, 18] and Chernishov and Shirokova [39], the assessment of GWM was carried out using traditional methods, mainly on the basis of perennial data on GWT, soil salinity, and land reclamation status. Besides that how GWM was affected by climate change was comprehensively understood and evaluated. This has rendered positive results due to the accuracy and scientific validity of the research. In contrast to the above studies, Ibragimov [8] and Eshchanov [41] also used GIS technologies in the analysis and evaluation of GWM. In these studies, three different GIS methods were used to determine the spatial distribution of GWM: Inverse Distance Weighting (IDW), Kriging, and Spline. Kriging and IDW methods were compared with the spline method in the evaluation of GWT and GWM. The Kriging method showed satisfactory results in determining GWT, while the IDW method splendidly resulted in determining GWM. According to the results of the study, the error of the Spline method is high, it is not advisable to evaluate GWM, and instead, using the IDW method is recommended to apply. The above-mentioned research results show that the advantage of traditional methods in the analysis of perennial data on GWM, as well as the use of GIS technologies to see the changing dynamics of GWM with reference to the irrigated areas, were only carried out only in a short time period and in a small spatial extent.

With this in mind, the main purpose of this research work is to determine the dynamics of perennial changes in the irrigated area according to the GWT and GWM level under the influence of climatic factors in the Syrdarya province by combining traditional research methods and GIS technologies and verifying the accuracy of GIS technologies.

2. Study Area
Syrdarya province is one of the main agroeconomic provinces of Uzbekistan, located in the center of the country on the left bank of the Syrdarya River. Syrdarya province is a semi-arid region prone to very high soil salinity. The province borders with Kazakhstan, Tajikistan, Tashkent, and Djizakh provinces of Uzbekistan (Figure 1).

Figure 1. A spatial location of the study area
Syrdarya province covers an area of 4,300 km$^2$ and the Mirzachul steppe occupies a large part of the study area. As of January 1, 2016, irrigated lands of the Syrdarya province make up 286,500 ha or 67.0% of province’s total land area [36]. In the territory of the province, there are mainly irrigated light gray, meadow, meadow-grass, meadow-gray and partly swamp-meadow soils. These types of soils have low humus content, mainly 0.85-1.10%, with reserves of 32-45.8 tons per ha. The province is divided into nine administrative districts: Sirdarya, Saykunabad, Gulistan, Boyout, Khovost, Mirzaabadi, Akaltin, and Sardoba districts [11, 36]. There are 20 agricultural sectors and 5,170 farms in the study area.

The climatic conditions of the province are sharply continental, characterized by dry and hot summers. Precipitation is mainly observed in winter and spring. Often a hot wind (garmsil) blows and dries the soil moisture, adversely and considerably affecting plant development [36].

According to Uzhydromet [38], in 2009-2019, the average annual air temperature at the Sirdarya meteorological station was 14.8 °C, the highest was 15.82 °C in 2016 and the lowest was 13.72 °C in 2014. To triangulate the values, the average annual air temperature at the Aqaltin meteorological station 15.43 °C, the highest was 16.51 °C in 2016 and the lowest was 14.2 °C in 2014. At the Yangier meteorological station, the average annual air temperature was 15.44 °C, the highest was 16.57 °C in 2016 and the lowest was 14.37 °C in 2014 (Figure 2).

In general, the province had higher annual average air temperatures in 2016 than in other years, and lower temperatures in 2014. In 2016, the weather was warm in winter and the air temperature was high in summer. In 2014, the winter months were chilly and the summer was cooler. The largest amount of precipitation in the province falls in the winter and spring months. The largest and smallest amounts of precipitation were observed at the Yangier meteorological station, with 447 mm in 2018 for the highest and 236 mm in 2014 for the lowest.

In the last decade, the rainiest year was observed in 2012 and the driest in 2014. The main reason why more attention is meanwhile paid to the climate of the province is that the hydro-meteorological data of the study area are among the factors that directly affect the GWT and GWM.

3. Methods

GWM in the irrigated lands of the Syrdarya province has been regularly monitored since 2000 by the State Committee for Land Resources, Geodesy, Cartography, and State Cadaster from about 1,500 observation wells [37]. To constantly monitor the level of groundwater in irrigated areas, the land reclamation expedition under the Lower Syrdarya Basin Administration of Irrigation System studies the level of groundwater in irrigated areas in each quartile and creates maps of groundwater based on the in-field data collected.
The maps illustrate the actual GWT in the arable lands of the province per quartile. The data derived from the maps, by comparing with other maps created for either former quartile or corresponding quartile in the previous year, enable to determine the actual areas per each classified groundwater level. Also, according to the dynamics of GWT in the arable land of the province, the root causes of the negative changes in land reclamation conditions and their forecast indicators, as well as the amplitude of perennial changes can be determined through comparing the maps of groundwater. The mapping is based on measurements taken simultaneously from all types of control points studied in the existing groundwater wells in the province. In particular, to determine the level of GWT in the irrigated areas of the Syrdarya province as of October 1, 2016, the following research was conducted; for monitoring, measurements on groundwater level were taken on all 1,540 groundwater control wells available in the province.

Monitoring and evaluation processes of groundwater physio-chemical contents take place mainly in the spring (April) and autumn (October) months of the year. The primary data were mostly analyzed for the 2000-2015 years, and to verify and validate the GIS-based results by comparing with the primary data, the GWM distribution maps for the 2016-2019 years were created [35]. The map is based on simultaneous measurements taken from all types of groundwater monitoring points in the province.

As this research aims at mapping the widespread of classified GWM in the irrigated lands of the province, the classification of GWM was below given. GWM depends on many factors, such as soil properties, salinity level, irrigation and land practice, critical depth, drainage efficiency, and crop type. Shmidt [40], based on Professor F.M. Rakhimbaev's survey results, classified GWM in irrigated lands of Uzbekistan as follows (Table 1) by determining the chloride contents that do not adversely affect the crop yield (growth) during the entire growing season [41].

| TDS | Cl value |
|-----|----------|
| 0 – 1 | 0.0 – 0.164 |
| 1 – 3 | 0.164 – 0.494 |
| 3 – 5 | 0.494 – 0.822 |
| 5 – 10 | 0.822 – 1.64 |
| > 10 | > 1.64 |

1. TDS: total dissolved solids
2. Cl: chloride ion

In this research, four remotely sensed images captured by Landsat in from 2016 to 2019 years were used. The Landsat data are derivable from an open-source (for more information about Landsat: https://uz.effrit.com/landsat/), and downloaded from the Earth Explorer database to integrate with primary data. As the primary data collected in April were used in this research, the downloaded Landsat images were taken in response to the primary data for April 2016, 2017, 2018, and 2019, respectively. The COST model was applied to enhance and filter the image quality using Erdas Imagine 2014 software [4, 34]. Although the remotely sensed images were coordinated, they were geometrically corrected again to accurately re-project into the national spatial coordinate system. Using ArcGIS 10.6 software, the spatial distribution maps of GWM for irrigated areas in the Syrdarya province were created by applying the IDW interpolation method.

The key reason for picking the IDW method out is that this method uses a simple mathematical algorithm based on statistical modeling which represents, often in considerably idealized form, the data-generating process [2]. This data-generating process is moderately efficient in this research by its
capability to fill the voids between non-observed groundwater wells. In this method, the square root value of the errors is minimized. According to the studies performed by Ibragimov [8] and Eshchanov [41], the smallest errors in the mapping of GWM were detected by the IDW method. In practice, the IDW method is widely wielded by national water management organizations since they are not significantly different from other interpolation methods and do not require special geostatistical knowledge. The IDW method has been revealed to give decent and consistent results in determining the spatial widespread of GWM. The results obtained in the aforementioned studies showed that the IDW method gives satisfactory results when there is sufficient information [8, 41]. Considering that the IDW interpolation method also does not give a 100% result, the overall accuracy level (\(ACC_{overall}\)) of GWM latitudinal widespread maps over the irrigated area was determined using the following equation according to Woodcock and Gopal [33]:

\[
ACC_{overall} = \frac{D_{maps}}{D_{reference}} \times 100\%
\]

Where: \(D_{maps}\) - data from maps, \(D_{reference}\) - primary data.

After having determined the accuracy of the GIS maps illustrating the spatial distribution of GWM by comparing primary data, to prove the scientific significance of the role of climatic factors (perennial seasonal average air temperature and perennial seasonal precipitation) in the classified GWM widespread in the arable land of the province, the correlation analysis between climatic factors and GWM spatial distribution was undertaken.

This statistical analysis was performed using the open-source R studio program. Long-term climate data from local meteorological stations in the province were obtained from the Uzhydromet [38].

4. Results and Discussions

4.1. Dynamics of groundwater table in the arable land of the Syrdarya province

According to the primary data derived from the responsible organizations, irrigated lands of 0.0-1.0 meter of GWT were almost not observed in the province over the period. However, a similarity to this GWT value was recorded in the last five years.

Also, the area of GWT with 1.0-1.5 m increased by 7.58% or 21,957 ha of the total area of irrigated land in the study area in April 2003, compared to 2.43% (7,033 ha) in 2017 and 1.45% (4,201 ha) as of July 1, 2019. The area of GWT with 1.5-2.0 m was 20.19% (58,464 ha) in April 2000, 36.68% (106,188 ha) in 2004 reaching its peak, and 14.47% (41,879 ha) as of July 1, 2019. Similarly, the area with GWT 2.0-3.0 m was 64.76% (187,473 ha) in April 2000, peaked by 72.88% (210,980 ha) in 2011, and 65.71% (190,224 ha) as of July 1, 2019 returning its starting point. The area with GWT > 3.0 was 11.63% (33,672 ha) in April 2000, 4.49% (13,000 ha) in 2007, reaching its nadir, and peaking by 17.29% (50,050 ha) as of July 1, 2019 (Figure 3).

The results above showed that in 2015, the groundwater level in 3,454 ha of irrigated areas of the province increased at different levels compared to the corresponding month of 2014. As of October 1, 2015, irrigated lands with GWT 0.0 - 1.5 m of the study area increased by 546 ha (0.2%) compared to the same month last year. In terms of administrative districts, there was an increase by 214 ha in Sardoba district, following that 159 ha in Akaltin district, 63 ha in Mirzaabad district, 61 ha in Khavast district, and 49 ha in Boyovut district.

The area of the groundwater level at 1.5-2.0 meters in the province increased by 2,908 ha in 2015 compared to the last year. In terms of districts, this increase went as follows; in Sirdarya district - 794 ha, in Gulistan district - 601 ha, in Mirzaabad district - 435 ha, in Sayahunabad district - 411 ha, in Boyovut district - 394 ha, in Khavast district - 249 ha, in Akaltin district - 119 ha, and lastly in Sardoba district - 15 ha.

Areas, where groundwater level was at a depth of 2.0 m to 3.0 m, decreased by 7,768 ha compared to the observation in 2014, which can be explained by the dependence of the amount of water received
from irrigation of arable lands in the districts. The area of groundwater at a depth of > 3.0 meters in the province rose by 4,332 hectares compared to the observation results in 2014. This is considered as an unwanted indicator.

![Figure 3](image_url) Changes in irrigated areas corresponding to GWT of the Syrdarya province from 2000 to 2019

From the point of view of soil salinity, it is expedient and safe if the depth of GWT is not less than 2-3 m. The irrigated areas where the GWT is found to be 2-3 m in the province accounted for 67% of the total area. Areas with GWT above 5.0 meters in the province were negligible, 0.12% (349 ha) in 2014, while in the same period of 2015 such areas were 0.15% (421 ha) and no such areas were observed in 2016. This is a satisfactory indication.

In general, GWT above 1 m easily leads to soil salinization [16]. The highest levels of soil salinity were observed in conditions where the groundwater was close to the surface. Therefore, it is recommended to monitor the changing dynamics of GWT to understand the condition of agricultural lands.

Based on the results of the GWT study in the irrigated areas of the province, the following activities and measures should be addressed to ameliorate the situation: (1) targeted, economical use of irrigation water; (2) to ensure that all existing vertical drainage wells are in working condition and fully operate during salt leaching; (3) to inspect the technical condition of the existing drainages and to carry out cleaning works in the drainages in imperfect conditions before the salt leaching season; (4) to prevent the drainages from perilous effects of artificial barriers; (5) constant monitoring of pipe bends’ working condition; and (6) it is necessary to prevent the discharge of irrigation water into drainages.

4.2. Distribution of groundwater mineralization in the irrigated lands of the Syrdarya province from 2000 to 2015

GWM data for irrigated areas of the Syrdarya province were obtained from the Lower Syrdarya Basin Administration of Irrigation System for each year (in April) at the districts’ scale. Afterward, the annual data of GWM distribution by irrigated areas of all districts of the province were collected and analyzed for the whole province from 2000 to 2015, and the results are shown in graphs below (Figure 4).

Over the experimental period, approximately 40% of the irrigated area in the province was composed of GWM of 3 to 5 g/l (Figure 4). Areas with a GWM of 1–3 g/l accounted for approximately 85,000 ha (20%) in 2000, and in 2015 there was a significant increase to 125,000 ha (30%) reaching to the endpoint of the line appertain to GWM 3 - 5 g/l.
The increase in the GWM 1 - 3 g/l area caused a significant decrease by about 50% in the area of highly mineralized groundwater (5 - 10 g/l), and this is estimated as a magnificent indicator. The area with severe mineralized groundwater (> 10 g/l) and weak mineralization (0-1 g/l) at the bottom of Figure 4, virtually saying, remained unchanged for 15 years.

Figure 4. The territory of irrigated area corresponding to each classification of GWM of the Syrdarya province from 2000 to 2015

4.3. Distribution of groundwater mineralization in the irrigated lands of the Syrdarya province from 2016 to 2019 using geographic information systems

GIS is currently one of the most recent technologies of remotely assessing the ecological changes [29]. Figure 5 shows the map of differently classified GWM distribution per districts of the study area for the last four years. Kulmatov et al. [16, 17, 18] conducted effective research on groundwater hydrology in Navoi and Bukhara provinces using traditional methods without the advances of GIS technologies.

In this research, the potential of GIS technologies perfectly and sufficiently demonstrates the classified GWM distribution across irrigated lands in the Syrdarya province based on the accurate primary data. According to the map (Figure 5), created by IDW interpolation as a GIS tool, only in 2018, the areas with GWM 0 - 1 g/l can be easily spotted. In the remaining years, these areas were almost invisible on the map due to their insignificantly low values. During 2016-2019, the areas with GWM 1–3 g/l predominated than other GWM classifications in the study area. During the four-year period, the area where the GWM 1 - 3 g/l was widespread decreased significantly.

The areas of GWM 3 - 5 g/l and 5 - 10 g/l relatively decreased in 2019 compared to 2016, respectively. In the areas, where severely mineralized groundwater (> 10 g/l) was observed, slightly increased over four years.

The accuracy of the results obtained by IDW interpolation was examined according to the method presented by Woodcock and Gopal [33]. In performing so, the primary field data were compared to the quantified data derived from the IDW interpolation outcome corresponding to each GWM class.
Figure 5. Classified GWM distribution in agricultural lands per administrative districts of the Syrdarya province from 2016 to 2019
As a result of the comparison, IDW maps provided an accuracy of 84.1% (p = 0.000033) and enabled the widespread use of GIS technologies to assess the GWM. This similarity in map accuracy can be seen in the results of a study conducted in Khorezm province of the country [8, 41].

The areas corresponding to each GWM classification across the Syrdarya province were calculated in the form of histograms by administrative districts per ha (Figure 6). The territory of irrigated land with GWM 0 - 1 g/l only peaked in 2018. This is a relatively substandard indicator. The largest territory, where GWM 0 - 1 g/l was dominant, was in Boyovut district with 20,272 ha (40%), while in Gulistan and Khovost districts, the corresponding territory was 626 (2%) and 210 (0.5%) ha, respectively. In the remaining years, this territory was exceptionally minor and lost its significance on the maps. The sudden increase in Boyovut district is assumed to be a systematic error due to the calibration of fieldwork results.

The irrigated areas with GWM 1 - 3 g/l during the experimental years were slightly dynamic, with an increase in four districts and, simultaneously, a decrease in four districts. While the growth rate was low in Sirdarya, Sayhunabad, and Sardoba districts, it grew rapidly in Akaltin district, from 20,000 ha in 2016 (38%) to 33,000 ha (62%) in 2019. In Gulistan, Boyout and Khovost districts, this area has decreased by an average of 10,000 ha (22%) over the past four years. In contrast, this trend also decreased by 5,000 ha (8%) in Mirzaabad district (Figure 6a).

Irrigated areas with GWM of 3 - 5 g/l increased in four districts and decreased in four districts as observed patterns above. The areas where GWM 3 - 5 g/l increased were mainly in Gulistan, Boyout, Mirzaabad, and Khovost districts, with an average increase of 10,000 ha for four years per each. In Sirdarya, Sayhunabad, and Sardoba districts of the region, from 2016 to 2019, this area decreased by 5,000 hectares. It should be noted that the highest decrease within four experimental years, from about 33,500 ha (63%) to 17,500 ha (33%), was in Akaltin district, which is a positive indicator (Figure 6b).

During the experimental years (2016-2019) in the irrigated areas of the province with highly mineralized groundwater (5 - 10 g/l) decreased in four districts, however, it remained unchanged in three districts and increased in only one administrative district. At the same time, whereas in Sirdarya, Gulistan, and Khovost districts the decreasing temp of the trend was relatively low, in Mirzaabad district the area with highly mineralized groundwater (5 - 10 g/l) was almost 15,000 ha (23%) in 2016, and by 2019 the downward trend reached to 6,000 ha (9%). The irrigated areas with GWM 5 - 10 g/l
of Sayhunabad, Akaltin, and Sardoba districts varied over a four-year period and in 2019 reversed to the initial value. The growth in such an area was observed in only one district, Boyout district. Areas with GWM 5 - 10 g/l were approximately 1,800 ha (4%) in 2016 and 4,000 ha (8%) in 2019 (Figure 6c). This is such a negative indicator. Over the experimental years, irrigated areas with severe GWM (> 10 g/l) grew in four districts and were undetected in four districts. The increase in such area was observed in Sirdarya and Khovost districts, as well as in Akaltin and Sardoba districts. The growth rate in the latter two administrative districts was close to 700 ha (1.3%) in four years. This is also not considered as appropriate and indicates that an outdated drainage system with unfavorable working performance is still being used in this district. In Sayhunabad, Gulistan, Boyout, and Mirzaaabad districts, the areas with severe GWM (> 10%) were not reported (Figure 6d).

The GIS-based results are shown in the graph for the rest of the experimental years from 2016 to 2019 as an asset to Figure 4 above (Figure 7). While the trends for GWM 1 - 3 g/l and 3 - 5 g/l were connected to the post-2015 limit (black threshold) in Figure 7, the areas with GWM 1 - 3 g/l at the end of the period grew rapidly and reached almost 200,000 ha (48% - in response to the total irrigated area of the province). The trends corresponding to the remaining GWM classes have almost returned to the starting point (2016), even though some oscillations have been observed over four years. The area with weak GWM (0 - 1 g/l) reached its peak in 2018 with about 21,000 ha (5%) and returned to a much lower imperceptible rate in 2019.

![Figure 7. Changes in irrigated lands in the Syrdarya province determined by traditional methods for 2000-2015 years and using GIS method for 2016-2019 years (after the threshold), corresponding to the GWM classes](image)

The maps above and area calculations based on these maps per each classified GWM at an administrative district level in the Syrdarya province from 2016 to 2019 showed that the accuracy of these GIS-based results was higher than 80% when compared with the primary data collected. This can prove that the participation of GIS technologies can accurately map the groundwater mineralization and this, in turn, means that the GIS-based results obtained are scientific significant. Summarizing the results of the research (traditional method for 2000-2015 years and GIS approach for 2016-2019 years), the following conclusion can be drawn. Based on the study results of groundwater level and its mineralization maps in the irrigated areas of the province derived through conventional and GIS techniques, we believe that the following work should be addressed to improve the actual situation: - targeted, economical use of irrigation water; - ensuring that existing drainage systems are in sufficient working condition and monitoring their
operation; - studying the technical condition of existing drainage system and carrying out cleaning works in unsatisfactory drainage; - based on the GIS results above, taking into account the existing 16% error of created maps in the development of measures is recommended when this validated GIS method, used in this research, is applied in practice without the results of traditional methods in the province.

4.4. Impact of climate change on groundwater mineralization
Changes in temperature and precipitation are expected to have a significant impact on ground snow and glacier reserves. The terrestrial mountain ranges are located in hot and cold regions, as well as in different climatic zones with high relative humidity and dryness [9]. Thus, every mountainous region on the earth is affected by climate change in a different way that is not unique to each other. The contribution of glaciers to water resources is particularly important in immensely dry basins, such as the Aral Sea Basin [9]. The contribution of glaciers to water resources varies in the tributaries of the Amudarya and Syrdarya Rivers. The level of the glacial reserve of the two rivers differs significantly from each other (2% for the Amudarya and 0.15% for the Syrdarya) [27]. This can lead to different responses of the two river basins to climate change. The impact of climate change on the hydrology and water management of the Syrdarya River Basin is exceedingly wicked. It is estimated that glaciers in the Syrdarya River Basin have lost 14% of their total volume over the past 60 years and that 15-40% of them are anticipated to disappear over the next 40 years [9, 27]. Therefore, the targeted use of groundwater in the Syrdarya province, located in the Syrdarya River Basin, is perceived to reduce the level of surface water shortage in agricultural farmyards. At the same time, it is important to regularly monitor the climatic effects on GWT and GWM [16]. Below can be seen how annual average air temperature and annual precipitation, which are considered as climatic factors, affect the GWM level and its distribution.

Statistical analysis was performed to see the extent of the climate change impact on GWM through correlation coefficients (Table 2). Average perennial (2000-2019) seasonal air temperature - winter (December, January, February) and summer (June, July, August), as well as the sum of perennial seasonal precipitation, were counted on as independent variables. This is because, as the air temperature increases, in general, it can be observed that the groundwater evaporates and its mineralization content increases proportionally [20, 25]. In addition, the amount of precipitation also has a direct effect on the change in GWM. Precipitation can be infiltrated to groundwater during the rainy seasons to reduce the mineralization level [31]. This, in turn, leads to a reduction in certain irrigated areas with high GWM.

| Table 2. Coefficients indicating the correlation degree of climatic factors with changes in the area in regards to the GWM classes |
|-------------------------------------------------------------|
| Groundwater mineralization | Groundwater mineralization, 0 – 1 g/l | Groundwater mineralization, 1 – 3 g/l | Groundwater mineralization, 3 – 5 g/l | Groundwater mineralization, 5 – 10 g/l | Groundwater mineralization, > 10 g/l |
|----------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| Air temperature, °C (summer) | 0.309 | 0.068 | 0.032 | **0.493** | 0.236 |
| Precipitation, mm (summer) | **0.194** | **0.234** | **0.126** | **0.434** | **0.346** |
| Air temperature, °C (winter) | 0.018 | 0.214 | 0.096 | **0.401** | **0.354** |
| Precipitation, mm (winter) | **0.112** | **0.128** | **0.029** | **0.286** | **0.454** |
Similar correlation analyzes were performed by Kulmatov et al. [16] to examine the effect of climatic parameters on the mineralization of surface water and irrigated areas in the Navoi province of Uzbekistan. In this study, the average long-term air temperature and precipitation were considered as climatic factors, and the correlation coefficients of many external global and regional factors were also determined. The results of this study showed that climatic factors are weakly related to surface water mineralization (<20%).

According to the data presented in Table 2, weakly mineralized groundwater (0-1 g/l) showed a low correlation coefficient (0.309) on the average air temperature in summer, while the change in irrigated areas corresponding to this GWM class was weakly correlated to the amount of precipitation. Changes in the irrigated areas with GWM 1-3 g/l weakly corresponded to the seasonal precipitation and average air temperature in winter, and its correlation with the average air temperature in summer was negligible. Changes in irrigated areas with moderately mineralized groundwater (3-5 g/l) showed that they were not correlated to climatic factors. The dependence of the irrigated areas with highly and severely mineralized groundwater (5-10 g/l and >10 g/l) on climatic factors showed more significant results than other classes of GWM. In this case, the change in the irrigated area with these two classes of GWM revealed a significant correlation between all of the above climatic factors. Referring to the correlation table, it is assumed that the impact of climate change was mainly seen and significantly relevant to the change in irrigated areas with highly (5-10 g/l) and severely (>10 g/l) mineralized groundwater. While an increase in air temperature leads to an adverse change in the GWM of irrigated areas as a result of evaporation, it can be assumed that the territory of these irrigated areas with such GWM classes is relatively increased due to the addition of surface minerals.

5. Conclusion

GWT and GWM are constantly changing under the influence of factors such as irrigation, salt leaching, climatic conditions, and drainage condition. Due to the large volume of surface water used for irrigation, insufficient maintenance of drainage systems, there is an increase in the table and mineralization of groundwater in some areas of the Syrdarya province.

The closer the GWT to the surface and the higher its mineralization level, and the more evaporation from the soil surface, the faster and more rapidly the processes of salt accumulation and secondary soil salinization in the soil occur. The measures recommended to agricultural specialists and farmers can be summarized as follows:

1. To constantly monitor the change of quantitative and qualitative indicators of GWT and GWM at the same time every year;
2. To use water-saving technologies for irrigation purposes to prevent groundwater to rise;
3. To maintain the drainage system in perfect working condition to reduce the GWT;
4. To combine GIS technologies with traditional methods to determine the reclamation status of irrigated lands.

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