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Research Article

Site selection for agri-aquaculture in the arid area using GIS techniques based on groundwater quality (Case study: Yazd-Ardakan plain, Iran)

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Abstract

The present study was conducted to mapping the groundwater quality of Yazd-Ardakan plain to find the appropriate areas for the integrated aquaculture and agriculture. An integrated analysis of spatial and filed data from multiple sources including cations, anions, hardness, alkalinity, pH, salinity, dissolved oxygen, carbon dioxide, and the temperature was performed in 37 agricultural wells. The geographic information system was carried out to prepare the different data layers and classified based on the standards for warm water (Carps) and cold water (Trout) aquaculture. The comparison of maps indicated that concerning the obtained data, it has no possibility to explore a unique region with the highest desirability towards the followed purpose. Furthermore, the northern parts of the study area were dominantly illustrated more appropriate for the culture of cold-water fish, accordingly. The main limiting factors for the warm-water fish were sulfate and magnesium ions in the water resources accounted for 118-354 mg/L and 1132-3085 mg/L, respectively. Conclusively, the agri-aqaculture development strongly depended upon the applied aeration equipment to reduce restricting ions.

Keywords: Warm water, Spatial analysis, Cold water, Mapping, Regional suitability, Evaluation

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Introduction

Water resources management is a major key to achieve sustainable development. It is more highlighted in arid and semi-arid regions, where the surface water resources are suffering from many constraints including rainfall scarcity and its inappropriate distribution. Accordingly, the evaluation of groundwater geochemical varieties is essential to manage the groundwater quality (Ravikumar and Somashekar, 2017). The exploitation of groundwater tables is a predominant water supply source in these regions, in general. Meanwhile, these tables are good for aquaculture because of the relative stability of their physio-chemical characteristics. It is noteworthy to highlight that the ground tables that are not qualitatively good for human consumption due to high salinity or $MgSO_4$ content, the majority could be utilized for the aquaculture development (Summerfelt *et al*., 2000; Aghazadeh and Mogaddam, 2011; Bora and Goswami, 2017).

Aquaculture is being recognized as an important way of increasing food production (Commission *et al*., 2007; Godfray *et al*., 2010; Fedoroff *et al*., 2010; Sullivan and Crespi, 2018). The aquaculture involves a wide variety of production systems that differ in their ability to increase food production and assist food security while protecting the environment (Lazard *et al*., 2010). The introduction of aquaculture in existing agricultural systems is being advertised as a sustainable substitute for the future of food production (Cassman *et al*., 2005; McIntyre, 2009; Pretty, 2008). The integration of aquaculture and agriculture facilitates the reproduction of synergies between farm components. Integrated agri-aquaculture systems (IAAS) are defined as the intersecting or sequential linkage between two or more agricultural activities, of which at least one is aquaculture (Little and Edwards, 2003). The resilience of IAAS has been demonstrated in many cases around the world, where these systems have remained for long times (Costa-Pierce, 2002; De Silva and Davy, 2010; Dabbadie and Mikolasek, 2017). Inland saline aquaculture may offer an opportunity for income diversification and potentially productive use of land that can no longer support traditional agriculture in salt-affected parts of inland production and investment levels are characteristically low (Chithambaran, 2016; Corner *et al*., 2020). It needs to develop somehow that the prevention of further agricultural land degradation alongside the opportunities of an alternative application has been simultaneously granted. This attitude also should be exerted with special attention to the economic situation of settlement rural communities. In this regard, most central areas of Iran are at high risk of salinization through shallow water tables. Therefore, the application of the saline groundwater due to misuse for aquaculture production could be considered as an available approach associated with water management

(Bemanikharanagh *et al*., 2018). Moreover, the development of aquaculture in these areas is encountered some limitations originated from various factors such as the suitable sites shortage, the strict of governed environmental regulations, etc (Alizadeh and Bemani, 2012; Chithambaran, 2016). These limitations, accompanied by the abundance of salt-affected land could be described as some of the key motivating parameters to accomplish the present investigation for identifying the suitability of these resources for aquaculture. Considering the aquaculture development strategies in salt affected areas, evaluation of potential areas and the implementation of numerous research projects on the feasibility of aquaculture development in water resources under the influence of two categories of warm water and cold water species could be a road map for inland aquaculture along with environmental consideration (Fersoy and Crespi, 2020; Pueppke *et al*., 2020). Yazd-Ardakan plain is considered as the main agricultural land in the Yazd province with an area of 14,905 km^2 (20 percent of the province area) that involves over 70 percent of the province population. It is annually subject to 68 mm precipitation and 3000 mm evaporation (Eslami *et al*., 2018). The introduction of aquaculture into the available agricultural systems has been proposed as a sustainable alternative for the future of food production in this region (Mehrjardi *et al*., 2008; Fathizad *et al*., 2018). The management of these synergies would reduce the need for external inputs, increasing total farm productivity, and profitability in an ecologically sound manner through the increase in resource-use efficiency (Zajdband, 2011). Accordingly, the main purpose of the present study was to estimate a suitable site for implementing the integrated agri-aquaculture system in this region. To meet this goal, the groundwater mapping concerning an immense range of physio-chemical parameters was conducted to distinguish the best location with the highest potential to perform the aquaculture plan in the mentioned region. The results of this study could significantly fulfill the available information gap and provide a by-pass to follow by researchers and policy-makers to manage water resources in the places with the same situation.

Materials and methods

Study area

Yazd-Ardakan plain is located at 53°24.7' and 54°56.7' E and 31°13.5' and 32°36.3' N in the northern part of Yazd province in the center of Iran (Fig. 1). The highest and lowest elevation in this region have belonged to the summit of Shir-Kuh mountain and Siah-Kuh desert with 4075 m and 970 m elevation, respectively (Ernani and Gabriels, 2008).

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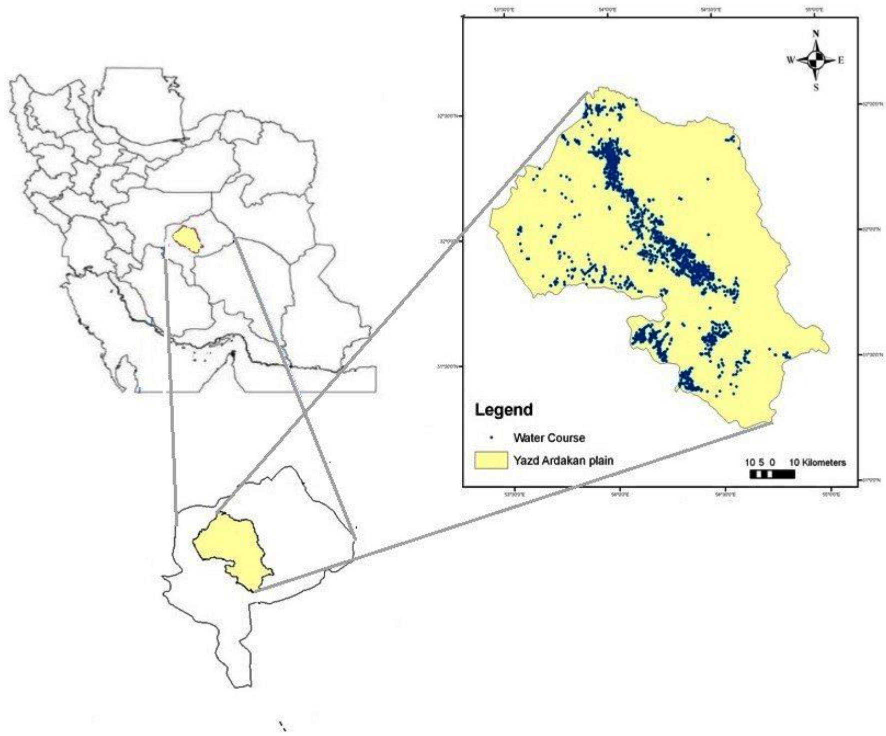

Figure 1: Location of Yazd-Ardakan plain in the Yazd province and its water resources.

Project implementation procedure

This study was performed by different statistics and databases such as meteorological database, satellite imagery, land-use map, spatial data of water resources of the plain (including wells, springs, and Qanats), and the sampling of the selected agricultural wells in the study site (Fig. 2).

The most of water resources in the study area are located on the thalweg in the northwest-northeast direction. Also, the distribution of springs and Qanats shows mostly concentrated in the west of the plain because of the mountainous topography of this area.

Considering the classification of salinity (Fig. 3a) and DEM of the Yazd-Ardakan plain (Fig. 3b) which reflected the effect of topography on the salinity of the groundwater bodies, the salinity is lower in the higher elevated lands than the lower lands. On the other hand, the proximity of the northern region with the Siah-Kuh swamp has influenced the agricultural activities and the natural resources of this region, especially in recent years resulted in the land use of some arable lands into the barren lands (Eslami *et al*., 2018). Thus, it seems that the northern regions of the plain possess the highest priority concerning the feasibility of agri-aquaculture activities. Therefore, the study continued with special consideration of the quality of water resources in this part of the plain. This part has been delimited by a red dotted line in Fig. 3.

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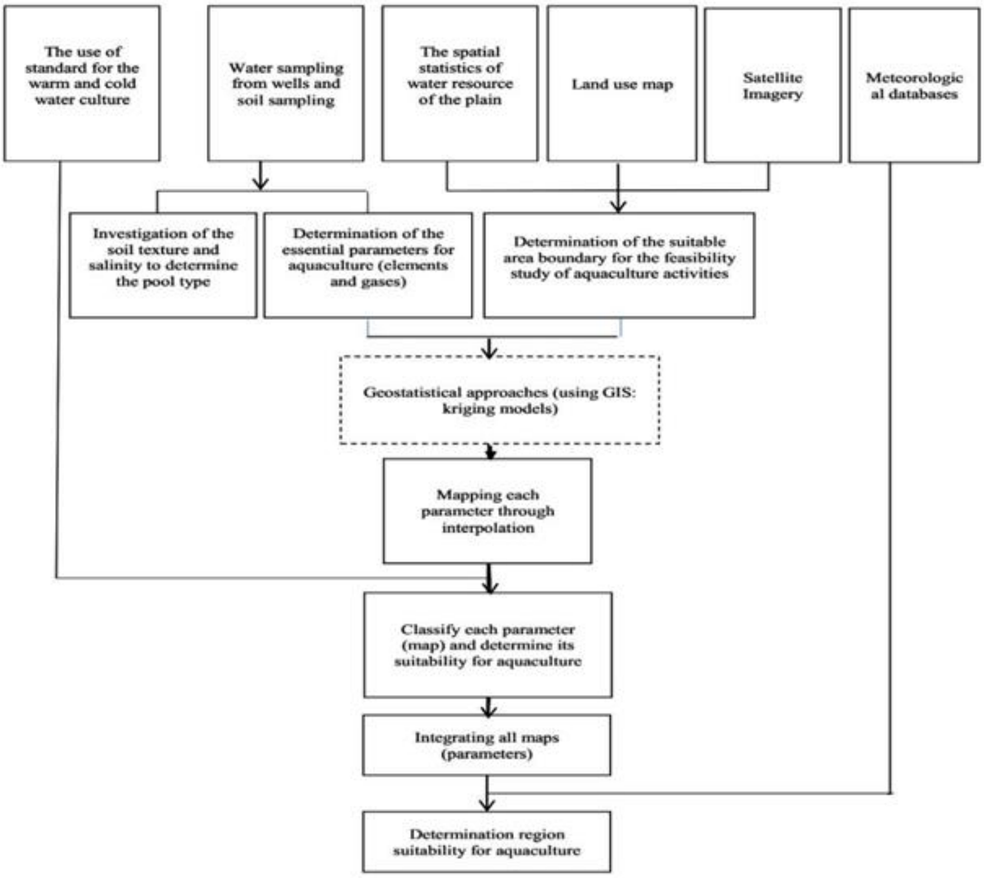

Figure 2: Schematic flow diagram for the project implementation.

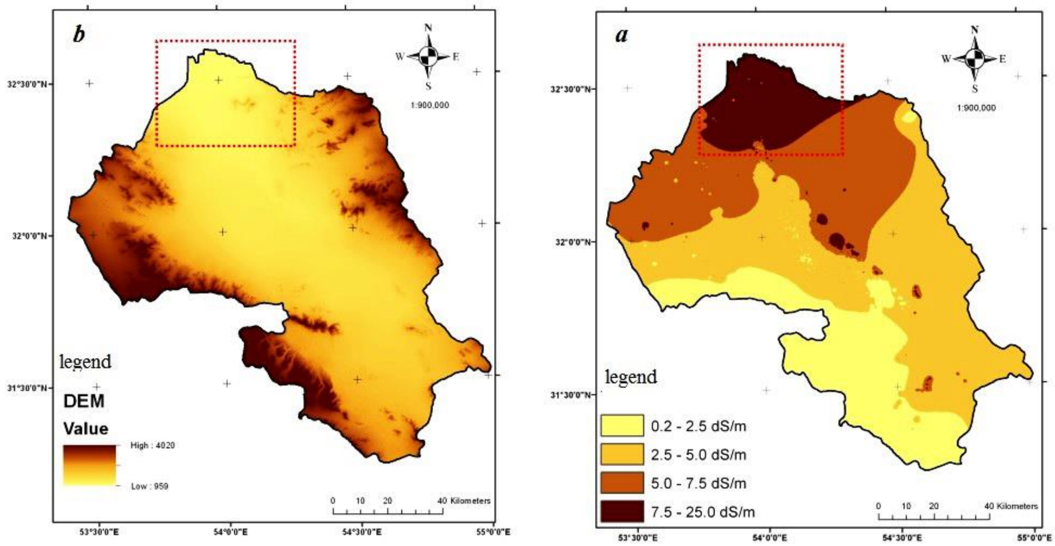

Figure 3: (a) The map of salinity classification of the groundwater, and (b) the digital model of elevations (topography) of the Yazd-Ardakan plain and selected site for studying the feasibility of aquaculture activities development (red dotted box).

Fig. 4a demonstrates the location of wells and Fig.4b indicates the agricultural region in the north of the plain. The region encompasses 37 agricultural wells and about 3600 ha of arable lands, mainly cultivated by pistachio and wheat (in agricultural parts) and Haloxylon (in the natural protected parts). These water resources are consumed by agricultural activities and aquaculture ones in some cases. There are no springs or Qanats in this area. According to the large size of the region and localization of agricultural wells in the central part (Fig. 4), the possibility of error occurrence is significantly high in prediction of quality parameters of groundwater sources through interpolating the points of the wells at the margin of the map. In the interpolation operation, the range of data points of wells was known and limited, so the figures derived from out-of-range interpolation data were obviously recognized. Considering the goal of project, the problem was tackled by separating parts of the map that were faced with no constraints in the land use and the direct use of agricultural wells. Hence, the buffering technique of Arc-GIS software package was used to separate the regions adjacent to the existing agricultural activities in the study site. Then, the interpolated maps attained enough accuracy.

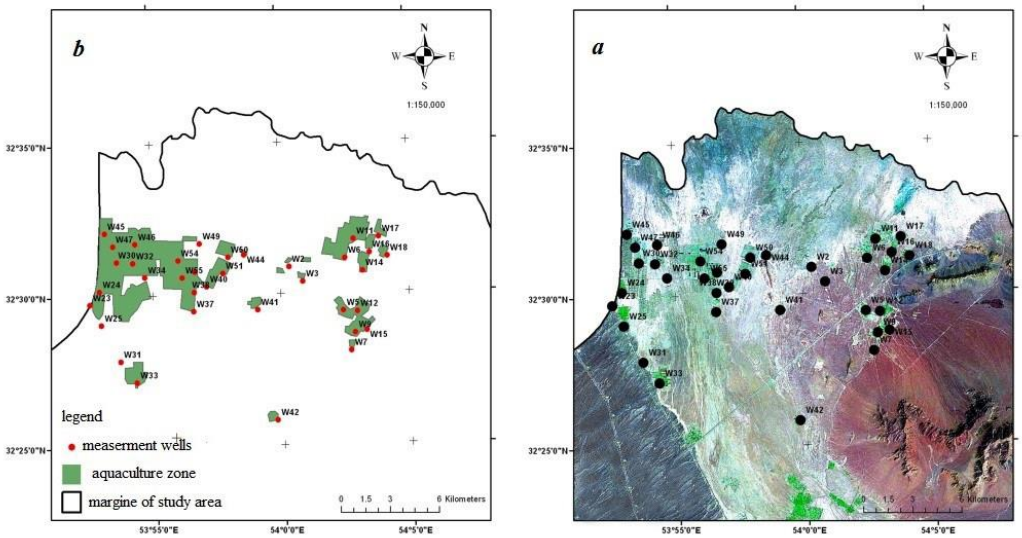

Figure 4: (a) The location of water resources and (b) the location of agricultural activities in north of Yazd-Ardakan plain.

Chemical data of the groundwater

Some essential chemical parameters were measured in the study site. They were determined regarding field study, literature review, and experts' opinion (Table 1). These parameters include cations such as sodium (Na^+), potassium (K^+), magnesium (Mg^{+2}), calcium (Ca^{+2}), anions such as chlorine (Cl^-), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-) and also salinity (Sal.), alkalinity (Alk), acidity (pH), and total hardness (TH). Due to the importance of temperature (T), dissolved oxygen

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(DO) and carbon dioxide (CO_2), these parameters were also measured and interpolated. Table 2 shows the measured parameters to determine the regions appropriate for the agri-acuaculrure activities in the study site.

All 37 agricultural wells were used as data layers in GIS in the study area. The parameters of water quality were mapped via interpolation kriging techniques. The study area was divided into the unsuitable, moderately suitable, and suitable parts for farming of cold-water and warm-water fishes based on the standards (Boyd and Pillai, 1985; Meade, 1989; Boyd, 1990a, b; Lawson, 1995).

Table 1: Water quality requirements for the culture of warm-water fish (Carps) and cold-water fish (Trout).

Parameter	Warm-water fish (Carps)	Cold-water fish (Trout)	Ref.
T (°C)	20-28	12-24	(Boyd, 1990a, b)
Alka. (mg/L $CaCO_3$)	20-400	20-400	(Lawson, 1995)
TH (mg/L $CaCO_3$)	50-2500	50-2500	(Boyd, 1990a, b)
pH	7-8	7-8	(Meade, 1989; Zweig *et al.*, 1999)
DO (mg/L)	>5	>6	(Zweig *et al.*, 1999)
CO_2 (mg/L)	<15	<10	(Boyd, 1990a, b; Lawson, 1995)
Sal. (g/L)	<10	<20	(Boyd, 1990a, b; Lawson, 1995)
Ca (meq/L)	<300	<500	(Boyd, 1990a, b; Lawson, 1995)
Na (meq/L)	<1500	<11000	(Boyd, 1990a, b; Meade, 1989)
Mg (meq/L)	0-100	<1500	(Boyd, 1990a, b; Meade, 1989)
K (meq/L)	1-100	<400	(Boyd, 1990a, b)
HCO_3^- (meq/L)	0-300	0-300	(Boyd and Pillai, 1985; Lawson, 1995)
Cl (meq/L)	<2000	<2000	(Boyd and Pillai, 1985)
SO_4^{2-} (meq/L)	5-100	<3000	(Meade, 1989)

Table 2: Criteria to classify the different parameters in determination of suitability of the study sites for the culture of cold-water and warm-water fish.

Parameter	Warm-water fish (Carp)			Cold-water fish (Trout)		
	Unsuitable	**Moderately suitable**	**Suitable**	**Unsuitable**	**Moderately suitable**	**Suitable**
T	>32	<20, 28-32	20-28	>26	22-26	10-22
Alka.	>500	400-500	20-400	>500	400-500	20-400
TH	>250	250-200	<200	>2500	2000-2500	<2000
pH	<6 and >9	6-7	7-9	<6 and >9	6-7	7-9
DO	<2	2-5	>5	<3	3-6	>6
CO_2	>25	15-25	<15	>20	10-20	<10
Sal.	>15	10-15	<10	>30	20-30	0-20
Ca	>500	300-500	<300	>700	500-700	<500
Na	>3000	1500-3000	<1500	>15000	-15000	<11000
K	>200	100-200	1-100	>500	400-500	<400
HCO_3^-	>500	300-500	20-300	>500	<20, -500	20-300
Cl	>5000	2000-5000	<2000	>25000	-25000	<20000
SO_4^{2-}	>500	300-500	<300	>3500	3000-3500	<3000

Geostatistical approaches

In this study, Arc GIS 10.22 software was used to prepare the maps. Recent reports suggest that GIS can be further deployed several ways that would be beneficial to the sustainability of aquaculture (Nath *et al*., 2000; McLeod *et al*., 2002; McIntosh *et al*., 2003; McDaid Kapetsky and Aguilar-Manjarrez, 2007). Using geospatial distributions, GIS, and DWQI provide support in groundwater studies (A Elubid *et al*., 2019). Interpolation is used to analyze the data in the GIS software. Kriging model or Gaussian process regression is one of the most important interpolation models in the spatial analysis (Paramasivam and Venkatramanan, 2019). Kriging is a marginal discipline, taking variogram as a basic tool, selecting various appropriate methods, and performing optimal linear unbiased interpolation estimates on the space structure and randomicity of parameters.

The general formula for the Kriging method follows as:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

where:

$Z(s)$ = the measured value at the *i*th location.

λ = an unknown weight for the measured value at the *i*th location.

s = the prediction location.

N = the number of measured values.

The geostatistical method applied for the modeling porosity included the Kriging and stochastic simulation. Kriging produces smoother results as the variance of the Kriging model is smaller than the variance of the data. Commonly used stochastic simulation methods include sequential Gaussian simulation or SGS (Deutsch and Journel, 1992) and Gaussian random function simulation or GRFS (Gutjahr *et al*., 1997). Then, the value of parameters comprising cations, anions, hardness, alkalinity, pH, salinity, DO, CO_2, and temperature mapped which represents the groundwater quality of the Yazd-Ardakan plain for agri-aquaculture. The reclassify function from the initial state (i.e. batch mode in the primary maps) was matched with the values from 1 to 3 (suitable, moderately suitable, and unsuitable) by the application of raster calculator function.

Cross-validation (CV) is used for error checking in Kriging estimates. According to the location, a plane variance contour, variance, deviation of each sample, and a deviation contour are drawn so as to observe error distribution status. When there are different numbers of sectors in each quadrant, two kinds of contours are different, based on which to confirm the appropriate number of sectors by comparison. It removes each data location one at a time and predicts the associated data value. Cross-validation is performed automatically, and results are shown in the last step of the Geostatistical Wizard (Shi, 2014)

To obtain the highest accuracy in the map generation, the different indices were estimated including the coefficient of determination (R^2), root mean square

(RMS), and root mean square error (RMSE).

Results

Water quality wells in the study site

Table 3 is presented the groundwater quality parameters of in study area.

Table 3: Statistical summary of the groundwater quality parameters in the study site.

Parameter	Unit	Mean	Minimum	Maximum
Na	mg/L	2330.2	935.0	3403.5
K	mg/L	27.5	9.4	62.8
Ca	mg/L	369.4	243.0	828.0
Mg	mg/L	219.6	118.2	354.0
Cl	mg/L	3726.7	1811.5	5738.3
SO_4^{2-}	mg/L	1419.6	60.5	2739.8
HCO_3^-	mg/L	248.9	119.0	500.2
Alka.	mg/L $CaCO_3$	210.82	100.02	409.92
pH	-	7.2	6.8	8.1
TH	mg/L $CaCO_3$	1839.3	1132.9	3085.8
EC	dS/m	12.2	6.9	17.9
DO	mg/L	5.4	3.6	7.6
CO_2	mg/L	9.4	2.5	26.6
T	°C	24.1	22.1	26.1

The accuracy results associated with the interpolated maps are provided in Table 4. The accuracy of the interpolated maps for each parameter could be recognized considering the tabulated values for R^2, RMS and RMSE. In this regard, the higher obtained R^2 values along with the lower values for the RMS and RMSE indicate the highest desirability, respectively.

Maps of cations (Na^+, K^+, Mg^{2+}, and $Ca2^+$), anions (Cl^-), salinity, alkalinity, hardness, SAR, and water-soluble gases are shown in the supplementary files. Comparison of these maps indicates that the position of the minimum and maximum values in each parameter significantly differs from the other ones and it is not possible to find an area with the highest desirability for all the applied parameters concerning the followed goal.

Table 4: The accuracy of the maps interpolated by the Kriging method.

Parameter	RMS	R^2	RMSE
Sal.	1.47	0.99	0.01
EC	2.10	0.99	0.02
TH	452.20	0.51	358.39
T	0.88	0.47	0.72
pH	0.22	0.38	0.18
Alka.	2.87	0.99	0.04
DO	0.75	0.65	0.55
CO_2	4.80	0.88	2.30
K	5.60	0.97	2.09
Na	416.00	0.99	5.70
Mg	48.90	0.98	8.42
Ca	116.30	0.43	92.63
SO_4^{2-}	429.60	0.68	325.62
Cl	754.10	0.99	80.19
HCO_3^-	48.97	0.99	0.67

Suitability of the study sites to farming the cold water fish (Trout)

Concerning the standards for cold water fish farming, the results showed that the temperature of well water was not optimal for the cold water fish farming

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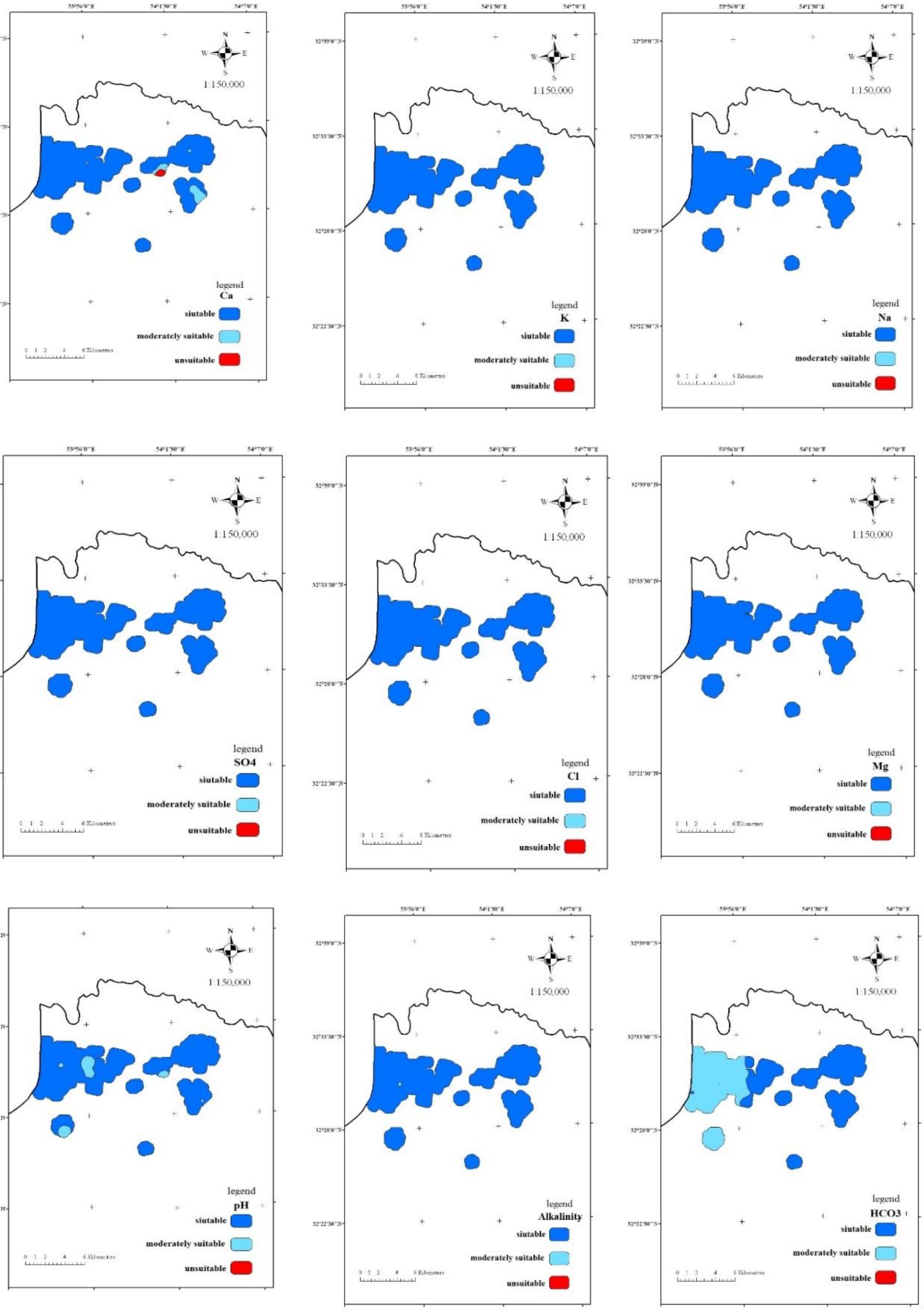
immediately after pumping, so the water resources could be placed in a moderately suitable group (Figs. 5 and 6).



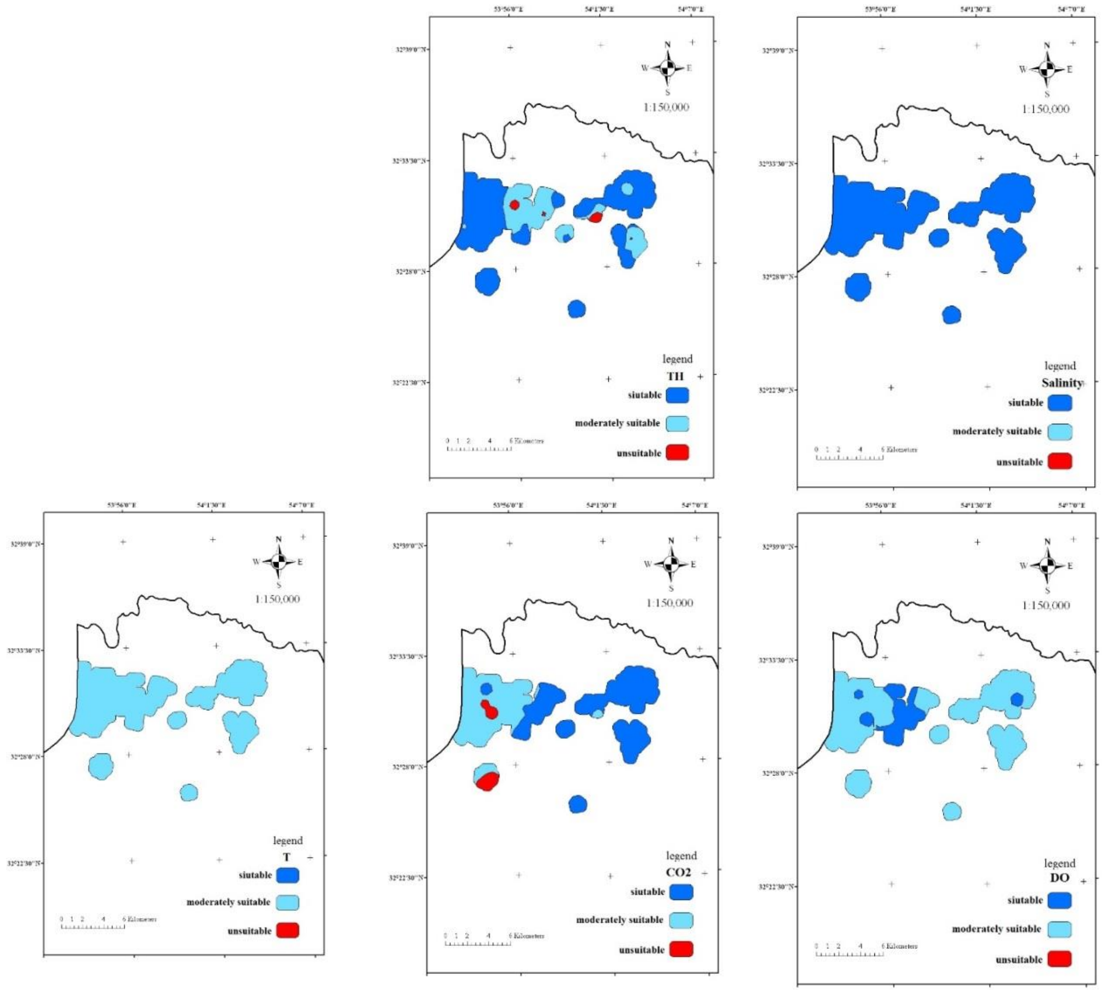
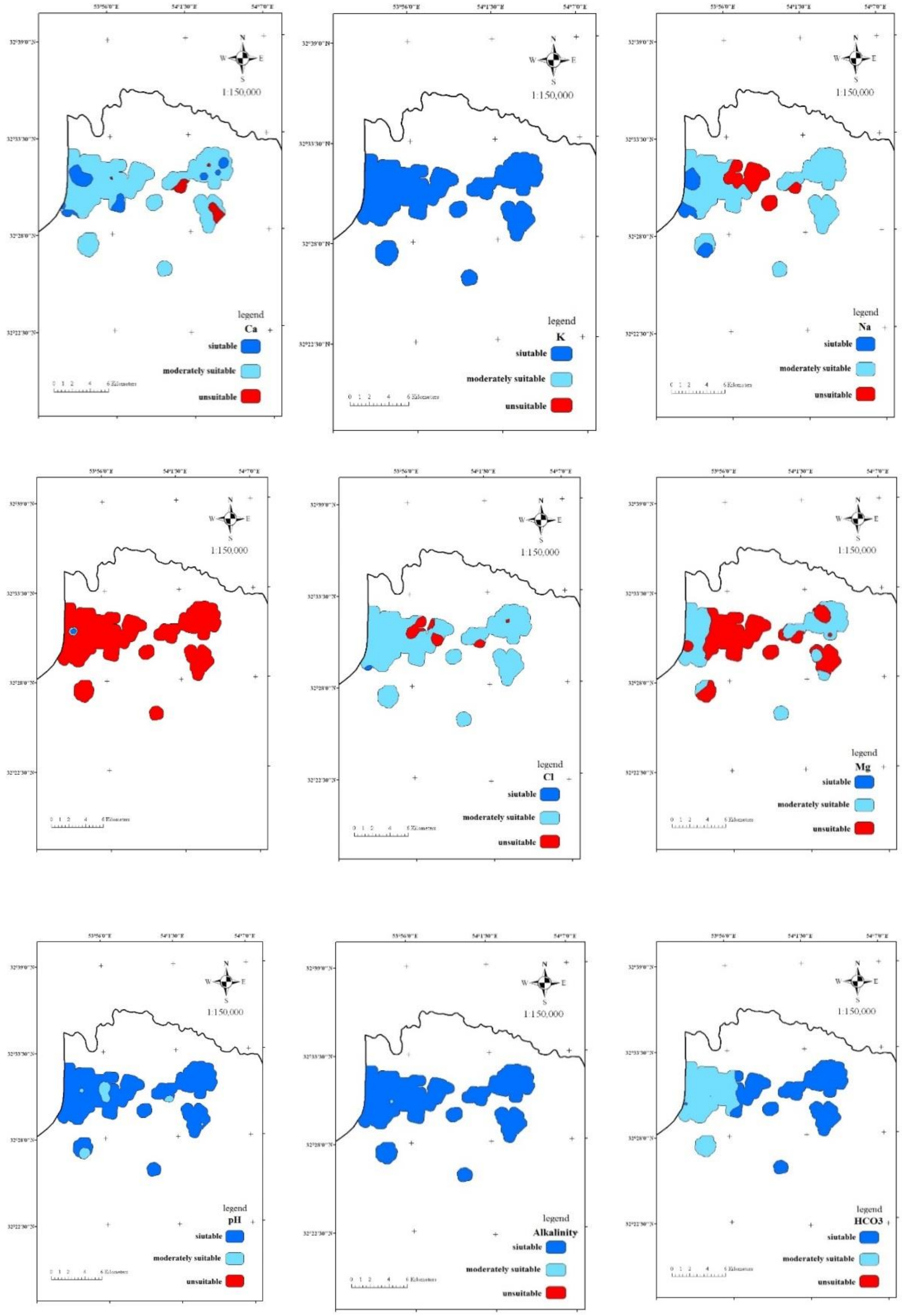


Figure 5: Suitability maps of the study area for the coldwater fish culture according to the measured water quality parameters.

This also influenced dissolved oxygen of water, which led to the reduction of their efficiency for the aquaculture application. In this study, the most underground water resources demonstrated high CO_2 content, although it can be reduced to the permissible level after pumping and brief aeration. According to collected obtained data, well water temperature in the study area is more than 20^{o}C and it may decrease when arriving in fish tanks in cold seasons, as a positive factor for farming the coldwater fish in agriculture farms. The percentage of suitable, relatively suitable and unsuitable classes for the coldwater fish culture is shown in Table 5.

Fig. 7a shows the suitable areas for coldwater fish farming regarding water hardness and bicarbonate constraints. According to Fig. 7, all parts of the study site were found to be suitable or moderately suitable for coldwater farming fish (Trout) except for the small parts in the south as depicted by maps.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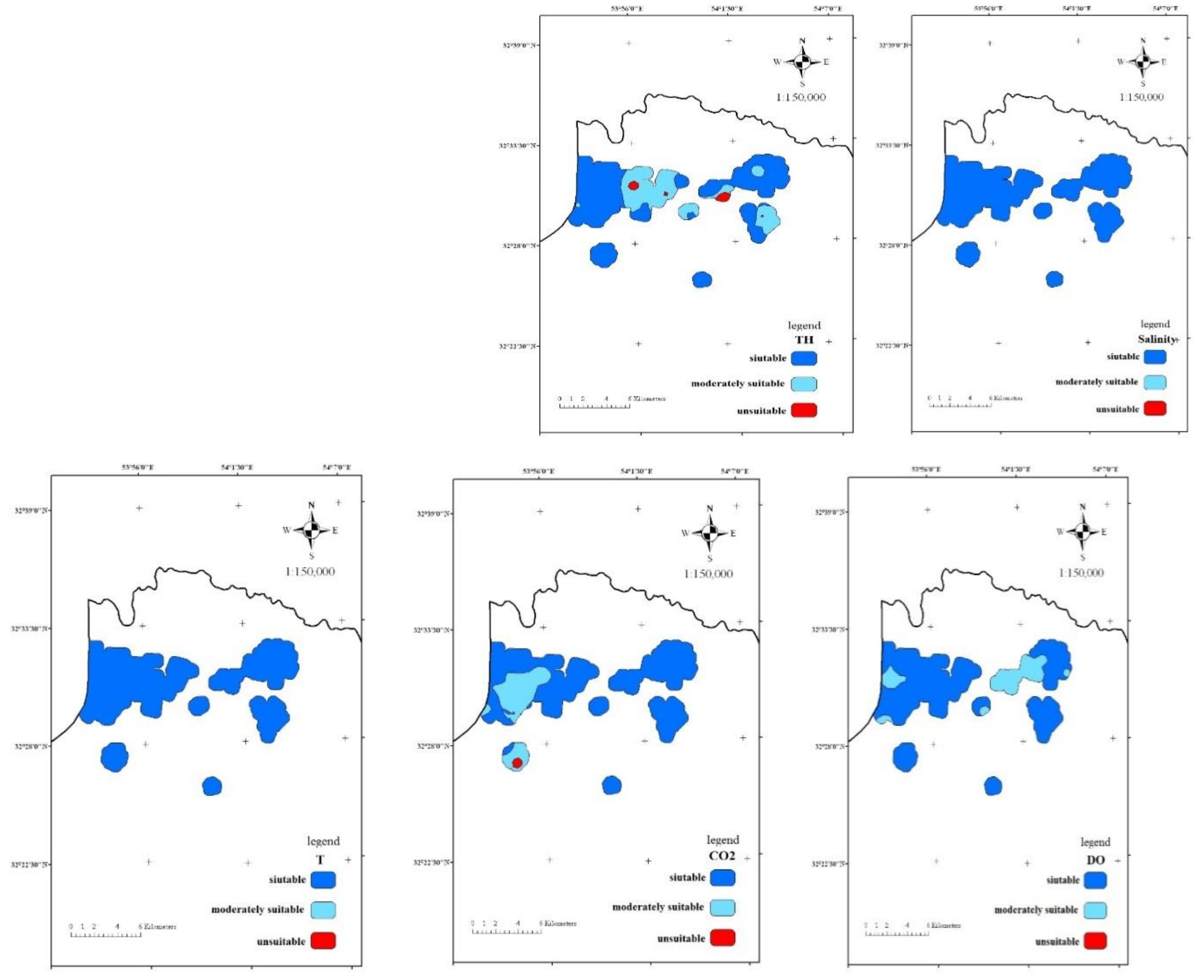

Figure 6: The suitability maps of the study area for warm-water fish culture are based on measured water quality parameters.

Suitability of the study sites to farm warm water fish (Carps)

The main factors for farming the warmwater fish in this study were SO_4^{2-}, Mg^{2-},Na^- and Cl^-ions (Fig. 6). Concerning the hardness map which dominantly discloses the concentrations of Ca and Mg, different conditions were obtained for the map of Mg^{-2} dealing with the suitability for farming the warmwater fish. Given this, the study area was found to be suffering from severe limitations, but these constraints were not reflected by the total hardness. This can be attributed to the different quality ranges of the defined classes for Mg^{-2} and total hardness for the warmwater fish and their measurements in the study (Table 3).

In this study, the measured values of Mg and hardness were 118.2-354 and 1132.9-3085.8 mg/L, respectively. Regarding table 1, it is indicated that the study area is restricted by Mg^{-2} content, but not for the total hardness.

According to the results, $SO_4^{2-}$and Mg^{-2}, were the most limiting chemical parameters in water, so 99.2% and 55% of study areas will be categorized into the unsuitable class for the culture of warmwater fish, respectively. The maps of regions that were suitable for the culture of warmwater fish were elicited from the integrated map designed base on the different studied parameters by assuming the fix of sulfate and Mg ion limitations concerning the available water resources in the study area.

Table 5: The suitability percentages allocated for the coldwater aquaculture regarding the different studied parameters.

Parameter	suitability		
	suitable	moderately suitable	unsuitable
Na	100	0.00	0.00
K	100	0.00	0.00
Ca	95.50	3.80	0.70
Mg	100	0.00	0.00
Cl	100	0.00	0.00
SO_4^{2-}	100	0.00	0.00
HCO_3^-	54.80	45.20	0.00
Alkalinity	99.80	0.20	0.00
pH	94.30	5.70	0.00
TH	69.20	28.90	1.90
Salinity	100	0.00	0.00
DO	17.40	82.60	0.00
CO_2	54.00	41.20	4.80
T	0.00	100	0.00

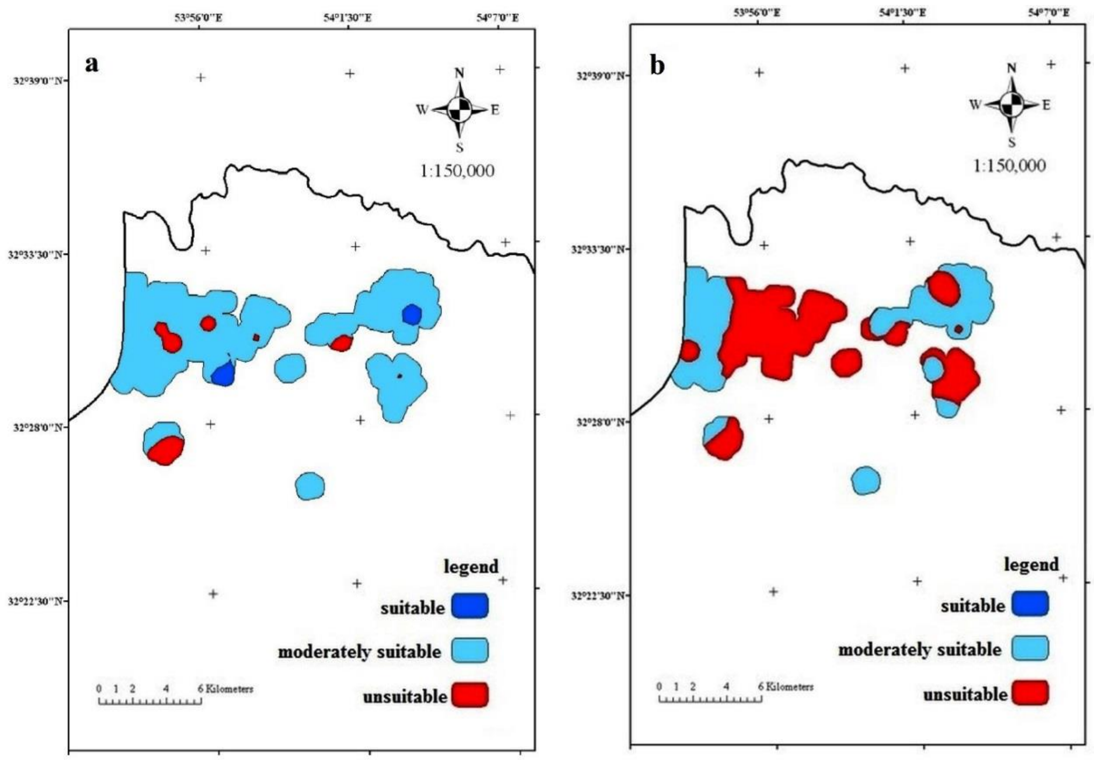

Figure 7: The final map of suitable regions for cold-water (a) and warm water fish culture (b).

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Fig. 6 shows that the study area will have little limitations in line with the soluble gases and water temperatures for warm-water fish. The temperature and soluble gases content of the wells' water will rapidly change in rearing tanks and improve the quality to meet the considered standards. Furthermore, there is a plausible water temperature reduction in some winter months, which can aggravate environmental conditions for the warm water fish.

Table 6 shows the percentage of suitable, relatively suitable, and unsuitable classes for the warmwater fishes. Regarding SO_4^{2-} and Mg, 99.2% and 55% of the study area was not suitable for warm water culture (Fig. 7b).

Table 6: The percentage of suitable, relatively suitable, and unsuitable classes for warm water fishes.

Parameter	suitability		
	suitable	moderately suitable	unsuitable
Na	8.90	74.3	16.80
K	100	0.00	0.00
Ca	10.30	85.2	4.50
Mg	0.00	45.0	55.00
Cl	0.40	92.7	6.90
SO_4^{2-}	0.30	0.50	99.20
HCO_3^-	54.80	45.2	0.00
Alkalinity	99.80	0.20	0.00
pH	94.30	5.70	0.00
TH	69.20	28.9	1.90
Salinity	72.50	27.5	0.00
DO	82.90	17.10	0.00
CO_2	79.70	19.60	0.70
T	100	0.00	0.00

Discussion

The mapping approach in the Arc-GIS software is considered as a common tool for the water quality monitoring towards the decision-making, correspondingly (Khalaf and Hassan, 2013; Chamanehpour *et al*., 2020). Furthermore, groundwater is the most desirable water source for aquaculture form the quantity and quality perspective, the lack of toxic pollutants, and unfavorable living organisms (Summerfelt, 2000).

Hanifi (2014) used the GIS to locate and prioritize the underground water resources of Sardasht City for the construction of rainbow trout farming ponds. According to the wide ranges of considered parameters, their results showed that out of a total of 208 water resources, 141 resources had the potential to be used for trout farming. In another study, in a qualitative mapping

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of water resources (Qanats) of Yazd province via GIS and geostatistic, Bari (2013) studied the feasibility using of these resources for farming rainbow trout (*Oncorhynchus mykiss*, Walbaum). The results showed that some of these water resources were qualitatively unsuitable for farming this fish. The results of the current study showed that the temperature of well water was not optimal for coldwater fish farming immediately after pumping, so the water resources can be categorized in the moderately suitable class concerning the output water temperature. Some parts of the study area were even unsuitable for coldwater fish farming in terms of the CO_2 content and need to use brief aeration. However, the assessment of groundwater quality in the Yazd-Ardakan Plain for agricultural purposes using the GIS showed that the water quality in 53.18% of the areas was suitable, 28.65% in average, and 18.17% in poor for irrigation (Eslami *et al*., 2018). According to these results, a suitable area for agriculture (north part of the area) can be considered for agri-aquaculture in the study area. Furthermore, the constraints due to the temperature and dissolved gases can be solved by the design of a simple aeration tower with reticulated plates.

However, it seems dissolved gases mainly DO and CO_2 are not practically as limiting factor in farming coldwater fish and this parameter can be recovered through simple ways. Regarding the high monthly air temperature fluctuations in the study area, ranging from 5 to 33°C, it appears that the growing season of these fish can be matched with the colder seasons of the year which causes to reduce the impact of ambient temperature on the local water resources and however the lessen of the dissolved oxygen, correspondingly due to increase of the ambient temperature resulting in an effect on the pond water temperature. Moreover, the aeration process accompanied by the use of some axillary equipment can alleviate the problem of lack of oxygen or increased CO_2 content.

Consequently, a high capability of the brackish underground water resources of these regions are admitted for inland saline aquaculture. From the rearing of warmwater fish perspective, 99.2% of the study areas would be unsuitable for the aquaculture. Jang *et al*. (2013) via integrating the spatial variability of water quality and quantity to probabilistically assess the groundwater sustainability for use in the aquaculture in the Pingtung Plain, Taiwan, indicated that the groundwater can be completely used for fish farming in 6.9% of aquifers, but should serve as a minor water resource for fish ponds in the 8.6% of aquifers. Additionally, the results illustrate that the quantity factors of groundwater are more critical compared with the groundwater quality for aquaculture in this area. Therefore, to achieve the goal of sustainable management of the groundwater resources for aquaculture, the conditions of spatial variability of groundwater quality and quantity parameters should be simultaneously considered.

The northern parts of Yazd-Ardakan plain were mainly more appropriate for the culture of coldwater fish. The major limitation for coldwater fish is water temperature that adversely effected on the dissolved oxygen. Therefore, it is highly recommended to consider the fish growing period in this region to coincide with the cold season and however using the aeration equipment to increase the dissolved oxygen content of pond water. Besides, the higher dissolved CO_2 content of water in the study area due to the inherent features of groundwater sources can be amended to meet the permissible level after pumping and/or aeration with the appropriate equipment. Thus, there was not much concern about the high CO_2content of well water in the study area. However, the reduction of water hardness and bicarbonate could have positive effects on the growth of coldwater fish in the study site, which should be considered. It was also found that the main limiting factor for the culture of warmwater fish was the high content of in the water resources of this region. Contrary to the coldwater fish, the temperature and dissolved gases of the water resources in these regions were not considered as the limiting agents for the culture of warmwater fish and they were appropriate in this sense.

As a conclusion, the recommendation of fish species (coldwater and warmwater) for this region was deeply depended on the applied aeration equipment in ponds. However, the obtained results from the present study could assist the researchers to develop their knowledge regarding the inland saline aquaculture, but more investigations are necessary to conduct identifying the exact eco-environmental burdens resulting in such plans.

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References

Aghazadeh, N. and Mogaddam, A., 2011. Investigation of hydrochemical characteristics of groundwater in the Harzandat aquifer, Northwest of Iran. *Environmental Monitoring and Assessment*, 176, 183-195. doi.org/10.1007/s10661-010-1575-4

Alizadeh, M. and Bemani, A., 2012. Environmental impact assessment of Tilapia (*Tilapia nilotica*) farming project in brackish water of Bafgh, Yazd. *Khoshkboom*, 2(**2**), 40-53 (in persion).

Bari, A.H., 2013. Feasibility study of rainbow trout *(Oncorhynchus Mikiss)* culture in flumes of yazd province, by using GIS. *New technologies in aquaculture development (Journal of Fisheries),* 7, 45-54.

Basheer, A., Elubid., Huang, T.H., Ahmed, E., Zhao, J., Elhag, M., Abbass, W. and M., Babiker, M., 2019. Geospatial distributions of groundwater quality in Gedaref State using geographic information system (GIS) and drinking water quality index (DWQI). *International Journal of Environmental Research and Public Health*, 16(**5**), 731. DOI:10.3390/ijerph16050731

Bemanikharanagh, A., Alizadeh, M. and Khanjani, M.H., 2018. Environment Impact Assessment (EIA) of Nile tilapia (*Oreochromis niloticus*) fish farming in some areas of Yazd Province. *Journal of Aquatic Ecology*, 7, 68-81.

Bora, M. and Goswami, D.C., 2017. Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam, India. *Applied Water Science*, 7, 3125-3135. DOI:10.1007/s13201-016-0451-y.

Boyd, C.E. and Pillai, V., 1985. Water quality management in aquaculture. CMFRI special Publication. 150 P.

Boyd, C.E., 1990a. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama.

Boyd, C.E., 1990b. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station, Auburn university. Alabama. 462 P.

Cassman, K.G., Wood, S., Choo, P., Cooper, H., Devendra, C., Dixon, J.A., Gaskell, J., Khan, S., Lal, R., and Lipper, L., 2005. Cultivated systems. In Ecosystems and Human Well-Being: Current State and Trends, Vol. 1. R. Hassan, R. Scholes and N. Ash, Eds. Island Press. Washington, DC.

Chamanehpour, E., hossein Sayadi, M. and Yousefi, E., 2020. The potential evaluation of groundwater pollution based on the intrinsic and the specific vulnerability index. *Groundwater for Sustainable Development*, 10, 100313. DOI:10.1016/j.gsd.2019.100313

Chithambaran, S., 2016. Desert aquaculture and environmental sustainability. Desert aquaculture and environmental sustainability. *Indian Journal of Marine Sciences*, 45, 1733–1741.

Commission, C.A., Programme, J.F.W.F.S. and Organization, W.H., 2007. Codex alimentarius commission: Procedural manual, Food and Agriculture Org.

Corner, R., Fersoy, H. and Crespi, V., 2020. Integrated agri-aquaculture in desert and arid lands-Learning from case studies from Algeria, Egypt and Oman. Food and Agriculture Org.

Costa-Pierce, B.A., 2002. Ecology as the paradigm for the future of aquaculture. Ecological Aquaculture: The Evolution of the Blue Revolution. Blackwell Science, Oxford, UK. pp. 339-372.

Dabbadie, L. and Mikolasek, O., 2017. Rice-fish farming in the Malagasy Highlands, twenty years after the FAO Projects.

De Silva, S.S. and Davy, F.B., 2010. Success stories in Asian aquaculture. IDRC, Ottawa, ON, CA.

Deutsch, C.V., and Journel, A.G., 1992. Geostatistical software library and user's guide. New York. 119 P.

Ernani, M.Z. and Gabriels, D., 2008. Detection of land cover changes using landsat data in the arid area of Yazd-Ardakan basin, Iran. Combating Desertification

Eslami, H., Almodaresi, S., Khosravi, R., Fallahzadeh, R., Peirovi, R. and Taghavi, M., 2018. Assessment of groundwater quality in Yazd-Ardakan plain for agricultural purposes using Geographic Information System (GIS). *Journal of Health*, 8, 575-86.

Fersoy, H. and Crespi, V., 2020. Regional Workshop on Integrated Agri-Aquaculture in Desert and Arid Lands. *FAO Aquaculture Newsletter*, (**61**), 23-23.

Fathizad, H., Ardakani, M.A.H., Mehrjardi, R.T. and Sodaiezadeh, H., 2018. Evaluating desertification using remote sensing technique and object-oriented classification algorithm in the Iranian central desert. *Journal of African Earth Sciences,* 145, 115-130. DOI:10.1016/j.jafrearsci.2018.04.012.

Fedoroff, N.V., Battisti, D.S., Beachy, R.N., Cooper, P.J., Fischhoff, D.A., Hodges, C., Knauf, V.C., Lobell, D., Mazur, B.J. and Molden, D., 2010. Radically rethinking agriculture for the 21st century. *Science,* 327, 833-834. DOI:10.1126/science.1186834.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. and Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. *Science,* 327, 812-818. DOI:10.1126/science.1185383.

Gutjahr, A., Bullard, B. and Hatch, S., 1997. General joint conditional simulations using a fast Fourier transform method. *Mathematical Geology,* 29, 361-389. DOI:10.1007/BF02769641.

Hanifi, R., 2014. Feaibility study of grounwater resources of west Azarbaijan province for farming salmon usng geographic information system (GIS)(Case study: Sardasht).

Jang, C.S., Liang, C.P. and Wang, S.W., 2013. Integrating the spatial variability of water quality and quantity to probabilistically assess groundwater sustainability for use in aquaculture. *Stochastic Environmental Research and Risk Assessment,* 27, 1281-1291. DOI:10.1007/s00477-012-0664-z.

Khalaf, R.M. and Hassan, W.H., 2013. Evaluation of irrigation water quality index IWQI for Al-Dammam confined aquifer in the west and southwest of Karbala city, Iraq. *International Journal of Civil Engineering IJCE*, 23, 21-34.

Lawson, T.B., 1995. Water quality and environmental requirements. *In* Fundamentals of Aquacultural Engineering, Springer. pp. 12-39.

Lazard, J., Baruthio, A., Mathé, S., Rey-Valette, H., Chia, E., Clément, O., Aubin, J., Morissens, P., Mikolasek, O. and Legendre, M.,

2010. Aquaculture system diversity and sustainable development: fish farms and their representation. *Aquatic Living Resources,* 23, 187-198. DOI:10.1051/alr/2010018.

Little, D.C. and Edwards, P., 2003. Integrated livestock-fish farming systems: the Asian experience and its relevance for other regions. Inland Water Resources and Aquaculture Service and Animal Production Service. *Food and Agriculture Organization, Italy*.

McDaid Kapetsky, J. and Aguilar-Manjarrez, J., 2007. Geographic information systems, remote sensing and mapping for the development and management of marine aquaculture. FAO Fisheries Technical Paper (FAO).

McIntyre, B.D., Herren, H.R., Wakhungu, J. and Watson, R.T., 2009. Executive summary of the synthesis report of the international assessment of agricultural knowledge, science and technology for development (IAASTD). In: McIntyre, BD, HR Herren, J. Wakhungu and RT Watson (eds.). Agriculture at a Crossroads. pp. 3-12.

McIntosh, D., Baldwin, T.K. and Fitzsimmons, K., 2003. Aquaculture development potential in Arizona: A GIS-based approach. *World Aquaculture-Baton Rouge,* 34, 32-36.

McLeod, D.R., Whitfield, D. and McGrady, M., 2002. Improving prediction of Golden Eagle (*Aquila chrysaetos*) ranging in western Scotland using GIS and terrain modeling. *Journal of Raptor Research,* 36, 70-77.

Meade, J.W., 1989. Water and health management. *In* Aquaculture Management. Springer. pp. 59-69.

Mehrjardi, R.T., Jahromi, M.Z. and Heidari, A., 2008. Spatial Distribution of Groundwater Quality with Geostatistics (Case Study: Yazd-Ardakan Plain) 1.

Nath, S.S., Bolte, J.P., Ross, L.G. and Aguilar-Manjarrez, J., 2000. Applications of geographical information systems (GIS) for spatial decision support in aquaculture. *Aquacultural Engineering,* 23, 233-278. DOI:10.1016/S0144-8609(00)00051-0.

Paramasivam, C.R. and Venkatramanan, S., 2019. An introduction to various spatial analysis techniques. In GIS and Geostatistical Techniques for Groundwater Science. pp. 23-30.

Pretty, J., 2008. Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 363, 447-465. DOI:10.1098/rstb.2007.2163.

Pueppke, S.G., Nurtazin, S. and Ou, W., 2020. Water and Land as Shared Resources for Agriculture and Aquaculture: Insights from Asia. *Water (20734441)*, 12(**10**). DOI:10.3390/w12102787.

Ravikumar, P. and Somashekar, R., 2017. Principal component analysis and hydrochemical facies characterization to evaluate groundwater quality in Varahi river basin, Karnataka state, India. *Applied Water Science*, **7**, 745-755. DOI:10.1007/s13201-015-0287-x.

Shi, G., 2014. Chapter 8–Kriging. Data Mining and Knowledge Discovery for Geoscientists. pp. 238-274.

Sullivan, K. and Crespi, V., 2018. Sharing Innovative, Water-Saving Agri-Aquaculture Experiences Across the Near East and North Africa. *FAO Aquaculture Newsletter*, (**58**), 28-30.

Summerfelt, R.C., 2000. Water quality considerations for aquaculture. Department of Animal Ecology. pp. 2-7.

Summerfelt, S.T., Vinci, B. and Piedrahita, R., 2000. Oxygenation and carbon dioxide control in water reuse systems. *Aquacultural Engineering*, 22, 87-108. DOI:10.1016/S0144-8609(00)00034-0

Zajdband, A.D., 2011. Integrated agri-aquaculture systems. *In* Genetics, Biofuels and Local Farming Systems, Springer. pp. 87-127.

Zweig, R.D., Morton, J.D. and Stewart, M.M., 1999. Water Source Quality for Aquaculture, A Guide for Assessment.The International Bank for Reconstruction and Development. 78 P.