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RESEARCH PAPER

Cage Culture Potential and Site Selection Analysis in Seymareh Reservoir in Lorestan Province, Iran, Based on Boolean Logic Using Geographical Information System (GIS)

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Abstract

Data collection and field sampling for cage culture site selection at Seymareh reservoir in western Iran were conducted monthly from February 2022 at three stations and 15 depths, using 11 water quality factors. The most determinative factors were water temperature, dissolved oxygen, phosphorus, and nitrogen, respectively. The fish culture time frame is proposed to be December to April for rainbow trout and May to November for common carp. The fish weight for introduction to the cages is proposed as 100g and150g for rainbow trout and common carp, respectively. According to the acceptable dissolved phosphorus levels in the water and the predicted release of phosphorus from fish culture activities, the rainbow trout production capacity has been calculated to be 2467.44 tons/yr. The fish production strategy was proposed as the gradual increment of fish production over 4 years (25% per year) and continual assessment of the water quality to prevent any unwanted consequences on the water quality. Finally, according to the results, it was confirmed that the Seymareh reservoir is suitable for cage culture activities, and the optimum site selection was performed for fish cages and supplementary structures using available geographical raster data layers based on Boolean criteria in the GIS package.

Introduction

We are witnessing an increasing need for animal protein o from aquatic origin (FAO, 2024). Aquaculture in Iran is a growing industry experiencing development in terms of species diversity and techniques (Ghorbanzadeh & Sedghpoor, 2024). Lorestan province is considered one of the main centers for fish production, especially trout culture in Iran (Ghorbanzadeh & Sedghpoor, 2024). Lorestan province is located in a water-rich region in the middle of the Zagros Mountains, and the dam-building industry is developing in this province. New methods and tools for site selection and development of aquaculture activities, like GIS-based methods that integrate various data, including field data and geographical information, are being widely developed (Megrey & Editors, 2009). These methods can provide more accurate and desirable results with fewer biases for aquaculture purposes. Land suitability assessment (LSA) for aquaculture site selection via an integrated GIS-DANP multi-criteria method in Lorestan province in Iran is a good example of using a new tool for aquaculture development (Ghobadi et al., 2021). GIS-based modeling was used to locate potentially suitable sites for aquaculture development in the Lake Tana basin, Northwest Ethiopia (Assefa & Abebe, 2018). In a GIS-based approach for delineating suitable areas for tilapia fish cages in Lake Victoria, the researchers were able to accomplish the operation with high positional accuracy (Aura et al., 2021). In another study, a GIS-based multi-criteria evaluation (GIS-MCE) was used to improve site selection for cage culture in Mwanza Gulf, Lake Victoria (Mabula et al., 2023). GIS-based methods and multi-criteria approaches are widely used for aquaculture development in various aspects including: Site selection for shellfish aquaculture (Silva et al., 2011), Geographic information system in a multi-criteria tool for mariculture site selection in Azores archipelago - North Atlantic (Micael et al., 2015), site selection in marine aquaculture in Santa Catarina, Brazil (Vianna & Filho, 2018).

The reservoirs (dams) are considered a kind of artificial water resource for various purposes such as controlling surface water runoff, hydroelectric energy production, and providing agricultural and potable water. Their governing limnological principles are somewhat similar to those of natural lakes (Cooke et al., 2005; Kennedy, 2001). According to (ABFA, 2012), aquaculture activities in water bodies in Iran, especially cage culture activities in reservoirs, are only allowed in non-potable reservoirs. In this case, the Seymareh dam was designed and constructed for hydroelectric energy production and to support aquaculture in downstream areas. Most of the hydrological behaviors of the reservoirs are controlled by geographical, geomorphological, and geological conditions (Cooke et al., 2005). The aquatic ecosystem productivity is strongly controlled by the receipt of nutrients (Wetzel, 2015). Accordingly, one of the main environmental challenges in aquatic ecosystems is Eutrophication (Downing, 2014; Smith & Schindler, 2009). Eutrophication as a consequence of aquaculture activity is one of the determining factors for reservoir exploitation and site selection for aquaculture activities. The main causes of Eutrophication in natural waters are receiving various amounts of nutrients, including phosphorus and nitrogen, leaking from industrial and agricultural activities and urban sewage (Boqiang et al., 2012; Wei et al., 2020). Phosphorus is one of the key factors to investigate the carrying capacity, water quality studies in limnology, and especially in aquaculture (Kazemi-Seighali et al., 2021). Accordingly, there are various global and regional standards and regulations for aquaculture activities in natural water bodies (Sharifian & Sahafi, 2016; Williams, 1980; Woynarovich et al., 2011).

Supplying animal protein, especially from aquatic resources, as one of the main issues in food security management, is facing three major challenges, including the lack of freshwater resources, the lack of food, and environmental issues (Abdolhay et al., 2019). The increasing sea pollution, the severe decrease of marine fisheries resources, and the increasing demand of human societies have caused the failure of the marine fisheries industry to ensure marine protein supply (FAO, 2022), and these issues attract managers and decision-makers' attention to developing aquaculture activities in reservoirs and other artificial water resources (Rezanezhad et al., 2013). Despite the various benefits of cage culture, including the productivity of non-potable water resources, Relative simplicity of implementation, and Low fixed costs, there are some disadvantages, i.e., changing the production regime of the natural water resource (Das et al., 2009). Accordingly, the present study was carried out to investigate the feasibility and site selection of cage culture development in the Seymareh reservoir using water quality analysis and the Geospatial Information System (GIS).

Materials and Methods

Seymareh reservoir is a double-arched concrete dam on the common border of Lorestan and Ilam provinces (Iran). It was constructed to produce hydroelectric energy and control the Seymareh River basin's surface runoff. In this study, three sampling stations were selected. The UTM coordinates of the stations are S1 (Z38-702116E-3688377N), S2 (Z38-700371E-3690255N) and S3 (Z38-689624E-3695009N). The depth of the lake at each station was 80, 70, and 60 meters in Stations S1, S2, and S3, respectively (Figure 1). Sampling was performed monthly for 12 months from March 2022 until March 2023 at 15 depths in each station using a 2-liter Ruttner Water Sampler with a scaled connector rope. In this study, a total of 11 water quality indicators were investigated including water temperature, Dissolved Oxygen, pH, Total Dissolved Solids (TDS), Electric Conductivity (EC), Total Ammonia Nitrogen, Nitrate, Total Nitrogen, Phosphate, Total Phosphorus, and Secchi disk depth according to the standard methods for inland waters analyzes (Rice et al., 2012). This study was designed in two basic steps: 1- evaluation of the Feasibility of aquaculture (cage culture) in the reservoir according to the key water quality parameters as mentioned in previous section, and 2- site selection for Cage establishment according to the most important site selection criteria (Beveridge, 2004; Cardia & Lovatelli, 2015) based on Boolean logic embedded in GIS package. According to the first step, the reservoir was evaluated for cage culture activities, and even the potential fish production was calculated according to total phosphorus (Bureau & Cho, 1999; Downing et al., 1990).

The total Phosphorus produced through aquaculture activities in the reservoir was calculated using the formula;

$$P_r = 1000\left[P_w\left(P_f \times FCR\right)\right]$$

$P = P_r \times F_l$ (Dodds & Whiles, 2019).

Total phosphorus produced from aquaculture activities was calculated;

$$P\,{}^{mg}/_{l} = \frac{P}{V}$$

Where P_r: Total Phosphorus (gr) released from fish food per one metric ton fish production. P_w: Phosphorus loss from fish food (%) P_f: Phosphorus content of fish food (g/kg) the average value is 15.5 (g/kg) (Shadnoush & Pirali, 2016). FCR: Feed conversion ratio, P: Total amount of phosphorus released into the reservoir .F_l: Fish load, V: Reservoir Volume

In this study, the feed profile information on the feed packages provided by local fish food producers (food ingredients table) was used as the reference for calculations. Accordingly, the Protein, Phosphorus, and crude protein obtained as 45, 1.55, and 37-50 percent, respectively, and the feed FCR was 1.2. The average Phosphorus fixation in fish body and Phosphorus leakage were considered as 23 and 77 (g/kg LWG) (Live Weight Gain), respectively, based on (Bureau & Cho, 1999). Based on field observation, there were 30 polyethylene and 13 traditional active trout cages on the reservoir. As the average fish load in each cage was 10 tons, the total standing crop was calculated as 430 tons. The area of the reservoir, based on the analysis of the shape file in ArcMap 10.8, was 32800000 m^2. Based on the DEM file analysis of the reservoir using Surfer software, the area and average depth were calculated as 130.5 km^2 and 28 m, respectively. The caring capacity of the reservoir for rainbow trout based on total Phosphorus was calculated as

$$\Delta[P] = [P]_f - [P]_i$$

Where, Δ[P]: the capacity of the reservoir to accept phosphorus (mg/l), $[P]_f$: acceptable Phosphorus in the reservoir water (mg/l) and [P]i: current Phosphorus concentration in the reservoir (mg/l).

Site Selection Using Boolean Logic

Boolean logic refers to a form of algebra where the values of the variables are the truth values (also called Boolean values): "true" and "false," often denoted as "1" and "0", respectively, in computer calculations or operations. The term "Boolean" comes from the 19th-century English mathematician George Boole, who was the first person to define an algebraic framework for working with logical operations. This logic is one of the simplest and most widely used methods for decision-making, particularly in computer programs, which is supported by mathematical fundamentals. In Algebra, A Boolean expression is a combination of Boolean values and operators that yields another Boolean value. To evaluate these expressions, you must use Boolean algebra, which has rules for how to deal with Boolean values and operators. Boolean logic requires what are called operators to perform logical operations on Boolean values (0 & 1) (Radojevi, 2000; Zohuri & Moghaddam, 2017). The three basic Boolean operators are:

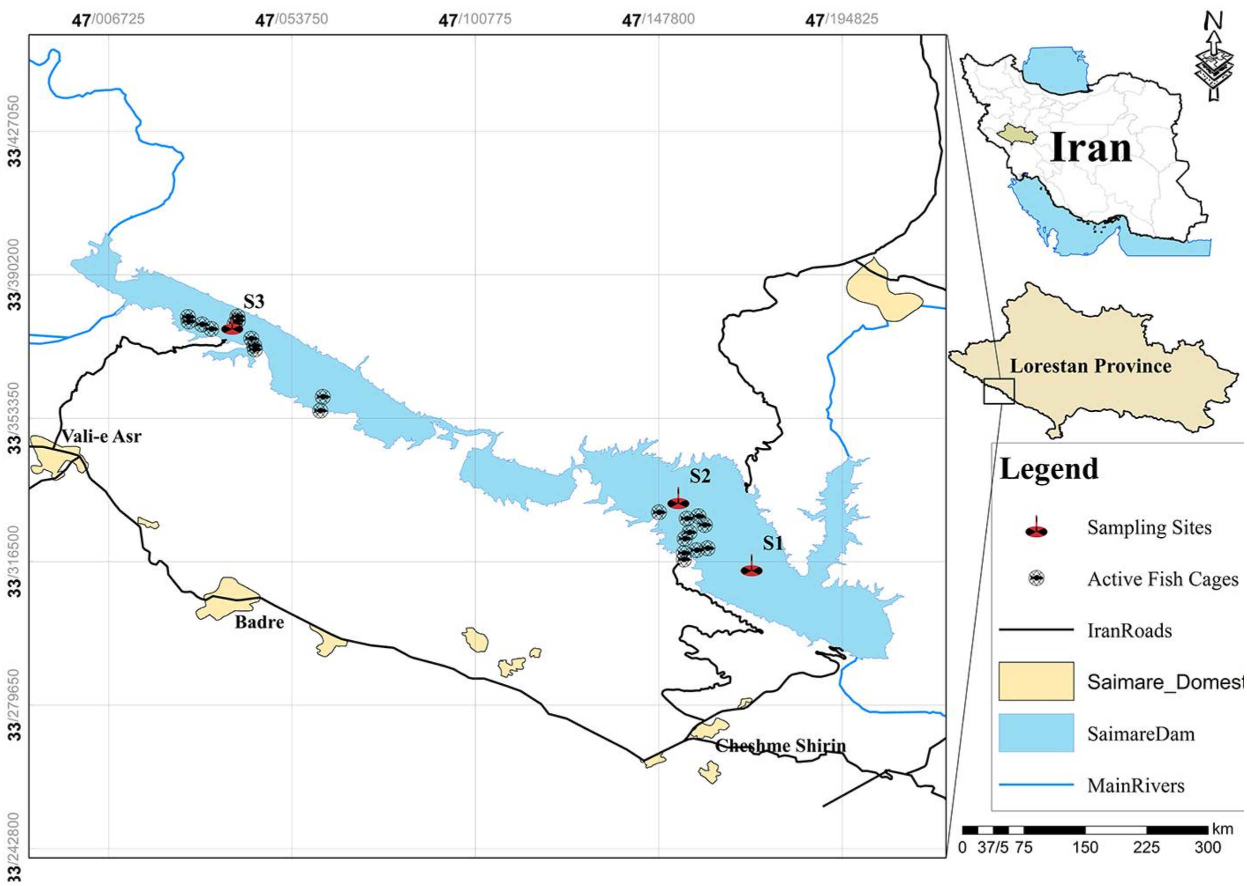

Figure 1. the map of the study area and sampling stations on the Seymareh reservoir.

- AND (conjunction): This operator returns true if both of its arguments are (1). For example, the expression "1 AND 1" will return (1).
- OR (disjunction): This operator returns (1) if at least one of the arguments is (1). For example, the expression "1 OR 0" will also return (1).
- NOT (negation): This operator takes one argument and inverts it, returning (1) if the input is (0) and vice versa. For instance, if "x" is a Boolean variable holding the value (1), then "NOT x" would equate to (0).

We assigned the Boolean values 1 and 0 to the presence and absence of conditions, respectively. The conditions that we used to evaluate the most proper sites for fish cages (1) were a minimum depth of 40m, a maximum distance from the reservoir shore of 200m, and the minimum distance from the dam structure of 500m, and the other situations were valued as (0). The Boolean conditions for supporting facilities site selection were: a minimum distance from the access road of 500m, a Land slope less than 30%, and a minimum distance from the dam reservoir of less than 400m (Cardia & Lovatelli, 2015; Das et al., 2009; Izadi et al., 2015). Based on the methodology, the information units of each layer are weighted as zero or one. All (0) values were ignored, and the conjunction of target criteria (1) values was considered as proper sites for fish cage establishment. In other words, membership in a set is either appropriate (1) or inappropriate (0), and there is no other situation. Finally, a combined map will be obtained that includes the Geometric location of all points with value (1) extracted from all digital layers and represents the most suitable geographical locations for cage culture facilities.

The digital data layers, including shapefiles of the reservoir, roads, waterways, residential areas, the positions of the existing cages on the reservoir, and sampling sites, were obtained using Google Earth Pro. The digital elevation Model (DEM) files with cell dimensions of 12.5 m were obtained from the EARTHDATA website (NASA, 2023). Spatial analysis was done based on Boolean Logic using GIS tools i.e., ArcGIS Desktop 10.8.1 and Surfer (Goldensoftware, 2022).

Results

The seasonal average values of nine water quality indicators of Seymareh reservoir are represented in (Figure 2). Chlorophyll a & b and, visibility depth were represented in (Figure 3). In this study, the ammonia concentration in the reservoir was less than the measurable range (<0.01 mg/liter).

The maximum and minimum surface water temperatures in Seymareh reservoir were 29.60°C in February and 12.13°C in August respectively. The maximum and minimum water temperatures at a depth of 6 meters were 26.77°C in July and 11°C in February, respectively. According to the results, the winter stillness was obvious, the thermal stratification was between 6 and 12 m, and the average summer thermocline depth was 9.75 m (Figure 2). The complete mixing process happened in the reservoir due to the wind during winter and spring.

The dissolved oxygen and oxycline diagram indicates the oxygen decrease related to the water depth. The surface dissolved oxygen in winter, spring, and autumn was more than 9 $^{mg}/_{l}$, and the decrease in oxygen content with increasing depth was obvious. The oxycline layer started at a depth of 6 m and ended at 15 m. Its thickness was different among seasons. A negative oxygen heterograde curve was observed in summer at 7-8 m. Oxygen concentrations at 2-4 m were comparatively higher than the surface water in April and May (Figure 2).

The pH showed a reduction pattern from the surface to the depth, with the highest surface pH in spring and summer. According to the observed values in different months and seasons, it is apparent that the pH shows its highest value at the sunlight penetration depth. Water pH dropped with increasing water depth, but never touched 7.1 (Figure 2).

According to the observed salinity, Seymareh water is categorized as freshwater. The highest and lowest surface waters EC were observed in February and August, respectively. Electric conductivity (EC) and total dissolved solids (TDS) were relatively constant at different depths. There was a significant regression between EC and TDS (Figure 4) in Seymareh reservoir

$$y = 5.1198\, X^{0.8477} \text{ } (R^2=0.91).$$

The highest and lowest Water transparency based on Secchi disk visibility depth were in February and June, respectively. Accordingly, the decrease in the Secchi disk visibility depth of Seymareh Dam corresponds to the peak of phytoplankton photosynthetic activity (Figure 3).

The amount of ammonia in this study was less than the measurable range (<0.01 mg/l). The highest and lowest total nitrogen and nitrate contents were observed in mid-summer and late winter, respectively. The most variation of nitrogen content was observed in the top 10 m. Nitrogen concentration started to increase from 15 m (Figure 2).

Total phosphorus and phosphate content in surface water in mid-winter and late summer showed the highest and lowest records, showing a slight increase from the surface to the depth (Figure 2).

According to the 0.027 mg/l average annual total phosphorus and 0.0067 mg/l estimated total phosphorus produced from rainbow trout production (430 tons) in active cages, it is estimated that 25.23% of the total phosphorus in Seymareh reservoir is produced from rainbow trout culture. Accordingly, the nominal capacity of increasing rainbow trout production and total production capacity in Seymareh reservoir were calculated as 2467.044 tons and 2897.044 tons, respectively.

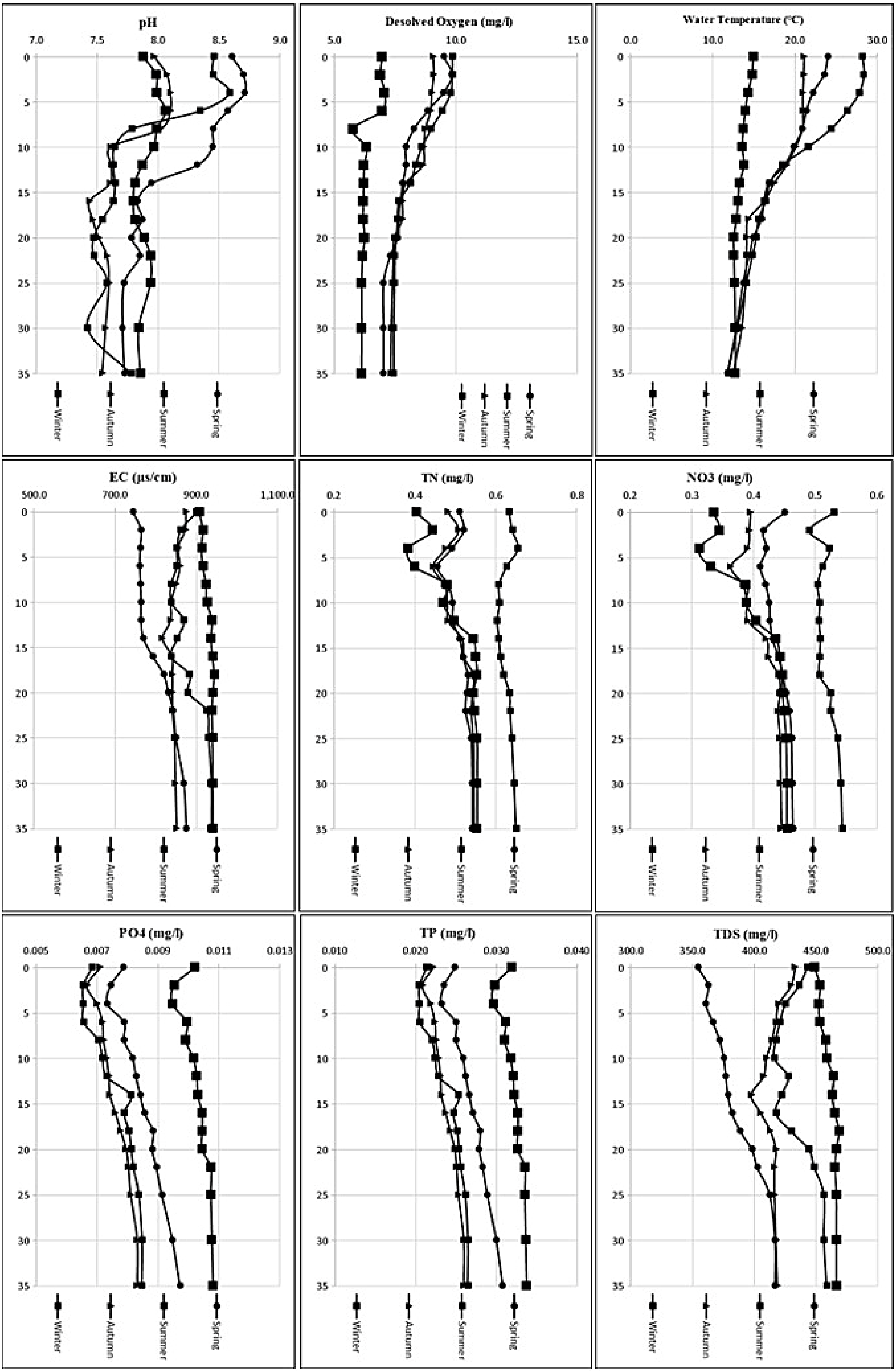

Figure 2. Seasonal average values of nine quality indicators from various depths of the Seymareh reservoir deep to 35 meters.

$$\mathrm{P_r} = 1000[0.77(15.5 \times 1.2)] = 14322\ \mathrm{g} = 14.322\ \mathrm{kg}$$

$$\mathrm{P} = 430 \times 14.322 = 6158.46\mathrm{kg} = 6{,}158{,}460\ \mathrm{gr}$$

$$V = 32800000 \times 28 = 918400000 m^3$$

$$P\ ^{mg}/_{l} = \frac{6158460}{918400000} = 0.0067\ ^{mg}/_{l} = 6.7\ ^{mg}/_{m^3}$$

$$\Delta[P] = 0.065 - 0.02656 = 0.03844$$

Nominal fish production in the reservoir: $\left(\frac{0.03844}{0.0067}\right) \times 430 = 2467.044\ \mathrm{ton}$

Total rainbow trout production: $2467.044 + 430 = 2897.044\ ^{\mathrm{Ton}}/_{\mathrm{year}}$

According to the available digital geographical layers (Figure 5), the three major effective factors on fish cage site selection, the intended digital raster maps were prepared in ArcGIS Software. Based on the topographic layer, the study area slope ranged as 0-81.5 degrees. The site selection operation for rainbow trout cages and supporting facilities was performed based on the obtained digital geographical layers (Figure 6).

Discussion

Water temperature is an important and effective physical factor in physiological activities like ammonia excretion (Khan & Mohammad, 2014; Stead & Laird, 2002). Considering the thermocline depth formation in 6-12 m depth from June to September, the high-water temperature in the epilimnion layer (>23℃), and the height of the fish cages of 6-8 m, it is apparent that rainbow trout culture in this period is impossible. In the other five months (December to April), the conditions are suitable for raising rainbow trout in the reservoir. Considering the short period of proper conditions for rainbow trout farming, it is proposed to use fingerling-size fish with at least 100g to start fish culture in Seymareh.

The high oxygen concentration in the surface layer can be due to high photosynthesis activities in this layer and direct oxygen exchange with the atmosphere. The appearance of the heterograde oxygen curve at a depth of 7-8 m can be due to the high level of nutrients and high temperature in this layer. A decrease in temperature and an increase in density, and simultaneously a lack of oxygen resulting from microorganisms and biochemical activities are the main

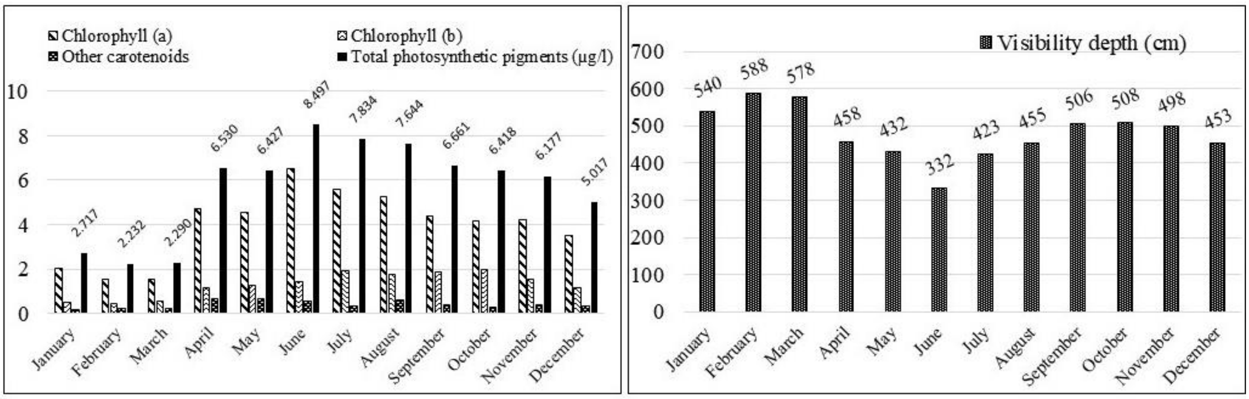

Figure 3. The monthly amounts of photosynthetic pigments (right) and the visibility depth of the Secchi disk (left) in Seymareh reservoir.

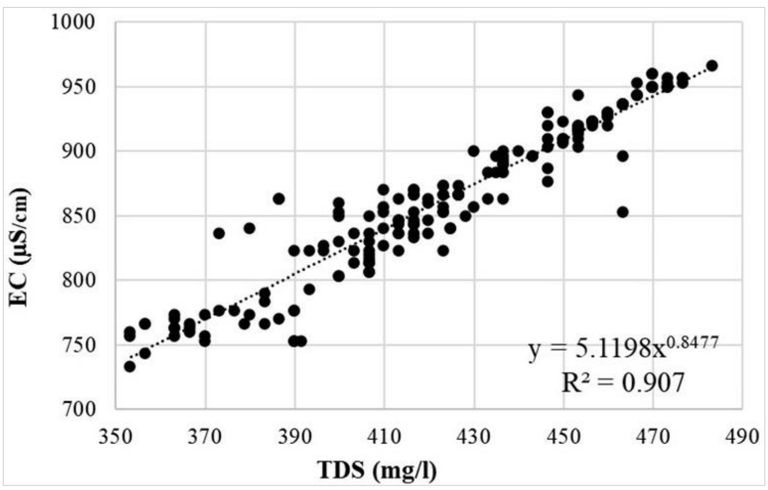

Figure 4. Regression diagram of TDS and EC in Seymareh reservoir.

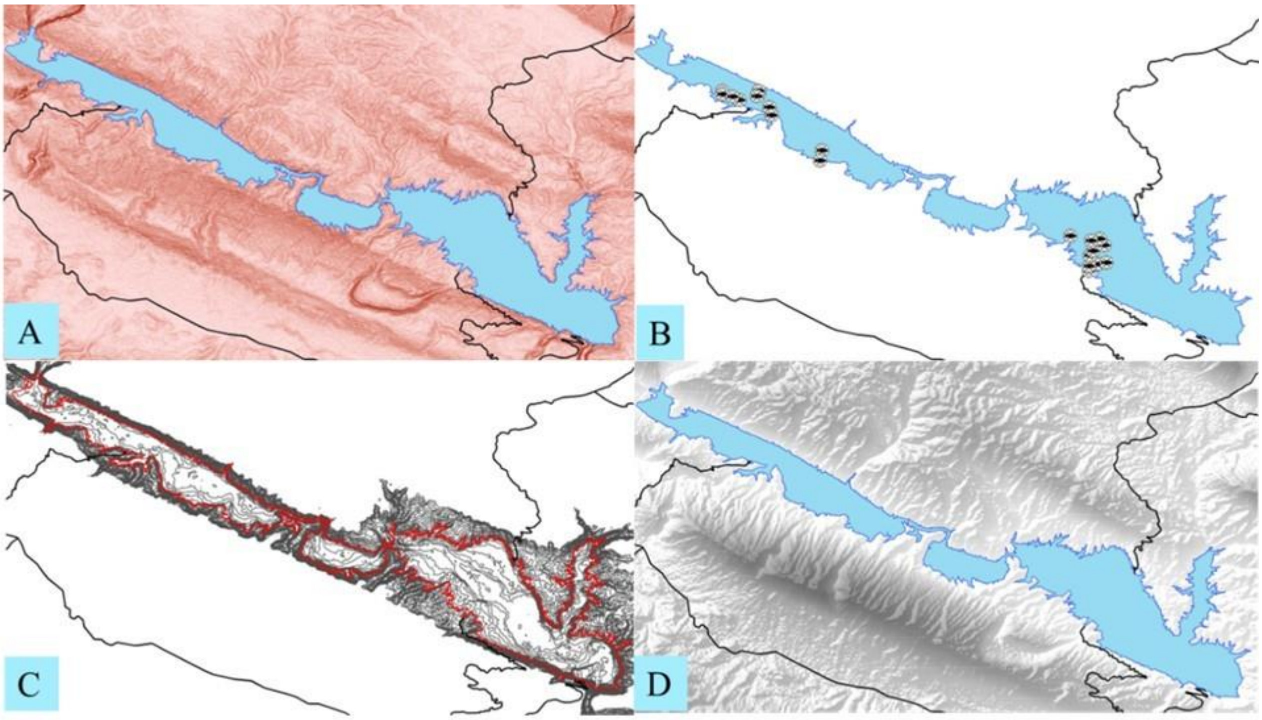

Figure 5. Geographical digital layers used for the rainbow trout cages and supporting facilities site selection in Seymareh reservoir. A: slope map of the area, B: location of the active cages in the reservoir, C: contour lines with 10-meter intervals, D: DEM of the area with a pixel size of 12.5 meters.

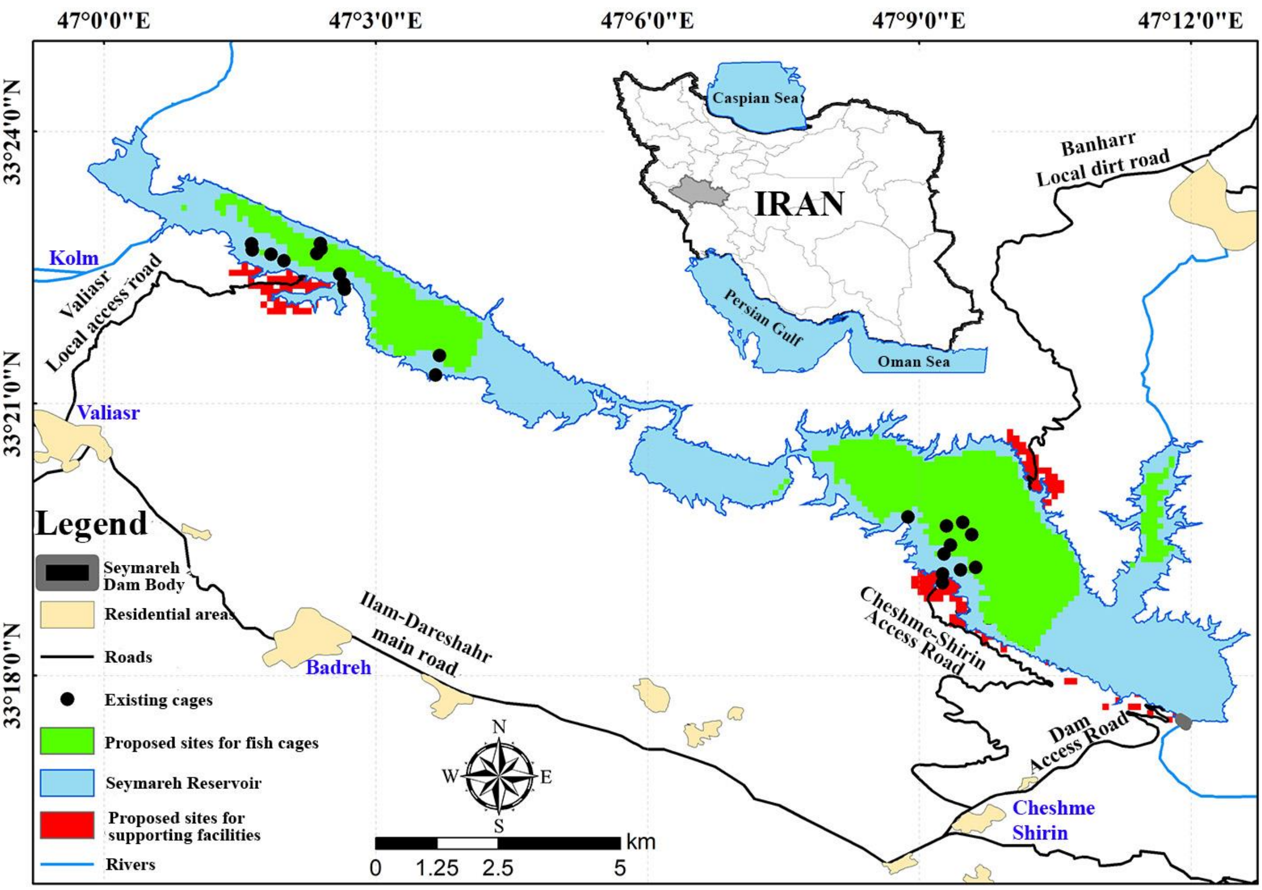

Figure 6. Site selection of fish cages and supporting facilities based on Boolean logic.

causes of heterograde oxygen curve formation in this reservoir. This is a serious threat to rainbow trout farming. The high oxygen content at a depth of 2-4 meters compared to the water surface at the beginning of spring can be due to the light-inhibition phenomenon in the surface layer, which inhibits phytoplankton growth (Dodds & Whiles, 2019).

Increasing photosynthesis will increase pH through Co_2 assimilation and $CaCO_3$ deposition. The deposited $CaCO_3$ can absorb Phosphorus, especially at high pH level (>9), removing it from the access of plants (Cooke et al., 2005). As a result, the high pH level at the photic layer, especially in Spring and summer, can be related to photosynthesis activities (Chapman, 1996; Cooke et al., 2005).

The observed annual fluctuations of EC were mainly due to increasing evaporation in the hot season and increasing rainfall in the cold season. Based on the significant relationship between EC and TDS, the TDS can be estimated by multiplying EC by 0.55-0.75 (Chapman, 1996; Selvaraj & Joseph, 2009). As the outlet of Seymareh reservoir was zero during the present study, and the water level decreased by 5 m, the impact of water evaporation on EC and TDS is acceptable. According to the available local reports (MOE, 2022), the average annual evaporation from Seymareh reservoir was 1814.01 mm. Another reason for the fluctuation of TDS and EC can be the increase in the load of suspended solids during the flood periods of the Seymareh River.

In this study, the intensity of upstream agricultural activities in spring and summer, the release of large amounts of urban and agricultural sewage containing various chemical fertilizers, as well as the land preparation for agriculture, and the reduction of the volume of water discharge to the reservoir, caused a sharp increase in nitrogen compared to other seasons. However, according to the national environmental standards, the maximum acceptable nitrate in natural waters for aquaculture activities is 45 ppm (MOF, 2012). Accordingly, there are no limits for aquaculture activities in Seymareh Reservoir. According to the results, agricultural activities, residential sewage, and the regional climate can be considered as the three main effective factors stimulating primary production in this reservoir. Based on the Ammonia content of the water, <0.02 ppm, Seymareh water is categorized as proper water for aquaculture purposes (MOF, 2012). Decreasing photosynthesis activities during winter and increasing water inlet due to seasonal floods are the main causes of increasing Phosphorus in the reservoir. The seasonal circulation in the lake escalated this phenomenon. Some authors noted that total phosphorus should be less than 0.025 ppm to prevent eutrophication in natural lakes (Nett et al., 2004). Based on the high amount of fertilizers discharging into the upstream river through agricultural activities, the total phosphorus content of the lake has reached 27 ppm, accordingly, the Seymareh reservoir was considered semi-eutrophic (Khan & Mohammad, 2014). According to the chlorophyll a and b content (5.3 µg/l), Seymareh reservoir is categorized as mesotrophic (Khan & Mohammad, 2014).

Conclusions

The results confirmed that the amounts of the main biogenic factors, P and N, are coincident with chlorophyll a and b. In conclusion, according to the results, the Seymareh reservoir has a good potential for cage culture, and it can be proposed to schedule fish production in the reservoir as follows: The proposed fish weight for introduction to the cages is 100g for rainbow trout in December, and harvesting the fish in April. The best weight for common carp fish seed is 150g from May to November. The total potential for fish production in the Seymareh reservoir was calculated as 2467.044 tons/year for rainbow trout. To prevent unexpected problems, reaching the maximum capacity of fish production and fish loading in the cages should be done gradually over four years (25% each year). Finally, two parts of the dam reservoir were suggested as the best areas for establishing rainbow trout breeding cages, and the best site for supporting facilities has been proposed.

Ethical Statement

All research processes were conducted using no biological specimens. According to the materials and methods, we did not use any harmful chemicals or operations that were harmful to the environment during this study.

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Author Contribution

First Author: Conceptualization, Methodology, Fieldwork, Laboratory works, Data Analysis, Writing - review and editing; Second Author: Data Curation, Formal Analysis, Investigation, Methodology, Writing - review and editing.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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