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Effects of rainbow trout farming on water quality around the sea farms in the south of the Caspian Sea

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ABSTRACT

The purpose of this study was to investigate the physical and chemical factors of seawater to determine the water quality index around two marine farms of rainbow trout in the south of the Caspian Sea. Each farm had four floating polyethylene cages with a final fish harvest of 60 tons. The water sampling was performed in January and March 2014 as well as May and August 2015 from around the cages (close: cage shade, 50 m and 100 m; distant: 1000 m) in three geographical directions: east, west, and south. The water quality parameters including pH, temperature, transparency, salinity, electrical conductivity (EC), total dissolved solids, dissolved oxygen, and nutrients (nitrogen and phosphorus compounds) were determined. The results of the analysis of variance of data at both farms showed that changes in physical and chemical parameters of water had only significant differences at the time of sampling ($p < 0.05$). The highest value of variance in the principal component analysis (PCA; 30.23% from 84.75%) was related to EC, temperature, salinity, total nitrogen, pH, and organic phosphorus. Iran Surface Water Quality Index (IRWQISC) at near and far distances from farms was determined to be moderate (40-55). The main reasons for this result can be attributed to the small-scale and short fish farming period along with the hydrological conditions of the region.

Keywords: Caspian Sea; Marine aquaculture; Physical and chemical factors; Water Quality Index.
Article type: Research Article.

INTRODUCTION

Increasing human population along with food needs due to the limitations of the use of freshwater resources in the world has caused human attention to provide the required protein to the water resources of the seas and oceans (Tidwell & Allan 2001; Pillay & Kutty 2005). Freshwater shortage in Iran has always been a factor limiting the development of agriculture, industry and even the society (Masoudiyan 2006). Thus the future of aquaculture development in Iran depends on the sea and the use of salt water, and in this way there are various ways, including fish farming in sea cages (Pillay & Kutty 2005). The sea cage fish farming is mainly in the coastal strip, but since coastal waters are affected by land and sea, they have high dynamic changes and cause huge problems for farmers (Miki *et al*. 1992). Aquaculture activities in cages can affect the ecology of the sea (Nabavi *et al*. 2011). Pollution, degradation of sensitive coastal habitats, threats to biodiversity of aquatic organisms and significant economic and social damage must be balanced against its significant benefits. In other words, the balance between food supply and environmental damage of this type of production must be considered (Craig 1999). Therefore, in different countries, strict regulations are set for these areas to prevent environmental damage. In Scotland and Chile, for example, farmers have been pushed offshore to minimize the adverse effects of cage farming (Duff 1987; Alvial 2013). Nowadays, any type of aquaculture development requires an Environmental Impact

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Assessment (EIA; Pittenger *et al*. 2007). The EIA program in marine environments is carried out with the two objectives of licensing and minimizing any possibility of adverse environmental impacts on large-scale marine farms (over 5 hectares or 1000 floating cages). The full EIA program does not apply to most aquatic products in the world as these aquaculture products are often done on a small scale and as a routine activity. Therefore, it is necessary to adapt to the regional conditions of these studies. Under such circumstances, the EIA becomes the Strategic Environmental Assessment (SEA), which is a new concept for the region. In SEA review, water quality parameters are monitored (FAO 2009). The cage fish farming does not have a long history in Iran, so the existing laws and regulations are derived from leading countries. Thus, the existing guidelines of the Veterinary Organization of Iran (Iran Veterinary Organization 2017) are fully in line with the guidelines of the Food and Agriculture Organization (FAO) and the United Nations Development Program (UNDP 1989) regarding the criteria for selecting fish farming in nautical cages in Asia. Methods for assessing the environmental impact of aquatic products vary depending on the type of rearing system. In the fish farming system in cages, the physical and chemical properties of water, sediment and benthic organisms are mainly studied (FAO 2009; Phillips *et al*. 2009). The study of physical and chemical properties and determination of water quality index is one of the most important monitoring aspects of environmental impacts in the fish farming system in sea cages (Carr & Neary 2008; Kho 2016). The water quality has a great impact on the health and quality of the environment, so it is necessary to identify the source of pollution in order to eliminate pollution (Adeleke *et al*. 2014). The physicochemical parameters for measuring water quality include dissolved oxygen, pH, turbidity, salinity, temperature, suspended solids, and nutrients including ammonia, nitrate, nitrite, silica and orthophosphate (Kho 2016; Zidani *et al.* 2020; Fallah *et al.* 2021; Omidi & Shariati 2021; Fatih Ali *et al.* 2021; Alewi *et al.* 2022). The water quality measurement is often defined using the Water Quality Index (WQI), which is useful for simplifying, reporting, and interpreting complex information obtained from any water body (Rubio-Arias *et al*. 2012; Sanchez 2007). This index is used to understand water quality issues by integrating complex data and creating a number that describes the overall body of water quality (Usman *et al*. 2018; Zhang *et al*. 2020). Therefore, the present study was conducted to investigate the physical and chemical factors of sea surface water in fish farms in order to determine the water quality index around two rainbow trout farms in the central region of the Southern Caspian Sea.

MATERIALS AND METHODS

Area and sampling stations

This study was carried out in two offshore farms named Klargostar Niko and Samamgostar Shomal, which are located at a distance of 20 km from each other and at a depth of 30 m in the southern region of the Caspian Sea. These two farms were located at a distance of 3200 m and 5500 m from the shore, respectively (Fig. 1). In each farm, 20 tons (80,000 pieces of rainbow trout fry weighing an average of 250 g) were introduced to the cages in December 2014. After a 5-month rearing period, 60 tons of fish (with an average weight of 800 g) were harvested from the cages. The water sampling was performed in January, March and May in the rearing period and in August outside the rearing period in 2015 from around the cages (nearby: cage shade, 50 m and 100 m; long-haul control: 1000 m) in three Geographical directions (east, west and south) (Kalantzi *et al*. 2013), (Figure 1).

B A

Fig. 1. **A**: Location of fish farms in sea cages (A: klargostar Niko, B: Samamgostar Shomal) and **B**: Sampling stations in relation to the location of cages in three directions: east, west and south.

Sampling and analysis of samples

Water sampling was performed to determine the physical and chemical factors from each station (by mixing three samples from depths of one meter below sea level, middle layer of 10 m and depth of 20 m) using a Rottner device. Physical and chemical factors of the examined water included temperature (Water T.), transparency (Trans.), Turbidity (Turb.), Salinity (Sal.), pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD_5), ammonium ion (+ NH_4), nitrite (NO_2-), nitrate (NO_3-), mineral phosphorus (P inorg), total nitrogen (TN), total phosphorus (TP), mineral nitrogen (Ninorg), organic phosphorus (P org) and organic nitrogen (N org) that were measured with a mercury thermometer, disk suction plate, Russian electrosolymer device, WTW320 device, Hatch device, Winkler method, Fanat method, Bern Schneider and Robinson method, cadmium reduction column method, mourning correction method, Valderma method, computational method and Wetzel and Link method respectively (Water and Wastewater Standard 2007; Sapozhnikov *et al.* 1988; Wetzel & Likens 1991; APHA 2005; Eaton *et al*. 2007).

Calculation of water quality index

In this study, the quality of seawater around fish farms was determined by calculating the Iranian surface water quality index (IRWQISC)[1] using the parameters: biochemical oxygen demand (BOD_5), nitrate, dissolved oxygen (DO), electrical conductivity (EC), ammonium, total phosphate, turbidity, total hardness and pH using the following formula:

$$IRWQI_{SC} = [\prod_{i=1}^{n} I_i^{W_i}]^{\frac{1}{\gamma}}$$

$$\gamma = \sum_{i=1}^{n} W_i$$

where Wi: i parameter weight, Ii: quality index value for the i parameter of the ranking curve, n: number of water quality parameters.

Table 1. Iran Surface Water Quality Index ($IRWQI_{SC}$).

Status WQS	Value $IRWQI_{SC}$
Very good	>85
Good	70.1-85
relatively good	55.1 -70
Medium	45 -55
Relatively bad	30-44.9
Bad	15-29.9
Too bad	<15

Statistical processing and data analysis

In order to record information, descriptive statistics and the statistical analysis of data, Excel 2010 and SPSS statistical program version 20 were used. Kolmogorov-Smirnov test was used to check the normality of data distribution. At first, the data were analyzed by F-test and one-way statistical analysis of variance at the 5% level. The means were compared with Duncan's multiple range tests. Multivariate test based on several invisible random quantities (or factor) was used to classify the data between different variables (NIST / SEMATECH 2010; Simeonov *et al*. 2001). Thereafter, the data adequacy test was performed under Kaiser-Meyer-Olkin Test (KMO), and the probability of correlation between parameters was performed under Bartlett test (Raftery 1993). Then for the principal component analysis (PCA), the method of Varimax factor period, special values and component conversion matrix table was used (Pradhan *et al*. 2009; NIST / SEMATECH 2010; Zhang *et al*. 2020).

RESULTS AND DISCUSSION

Statistical studies showed that some of the physical and chemical factors of seawater at the location of the cages were only significantly different at the time of sampling ($p < 0.05$). There was not a logical order in the impact of fish farming on the environment at both farms and the geographical direction, and distance from the farm did not

[1] Calculation of water quality index of Iran (Department of Environment, 2020: https://www.doe.ir)

cause significant differences in water parameters ($p > 0.05$). In addition, this study exhibited that the significant difference in both farms was only based on sampling time ($P < 0.05$), the results which were found through the multivariate test with respect to dependent variables (distance from cage, geographical direction and sampling time). So, the parameters of each fish farm were compared by integrating the direction and distance at the time of sampling for better data analysis (January, March, May and August; Table 2).

Table 2. Physical, chemical and water parameters (mean ± standard error) around rainbow trout farming cage in the southern Caspian Sea region (2015-2016).

Parameters	January	March	May	August
Water T(ºC)	12.10 ± 0.01^{d}	13.97 ± 0.02^{c}	17.23 ± 0.03^{b}	30.04 ± 0.03^{a}
Trans (m)	8.42 ± 0.13^{c}	5.92 ± 0.09^{d}	9.43 ± 0.18^{a}	8.02 ± 0.11^{c}
Turb (NTU)	4.73 ± 0.13^{c}	6.76 ± 0.06^{a}	5.56 ± 0.13^{b}	3.38 ± 0.22^{d}
Sal (PSU)	10.79 ± 0.01^{b}	10.80 ± 0.04^{b}	10.60 ± 0.02^{c}	11.21 ± 0.01^{a}
pH	8.81 ± 0.01^{a}	8.37 ± 0.01^{a}	8.48 ± 0.04^{a}	8.43 ± 0.01^{a}
DO (mg L^{-1})	8.54 ± 0.16^{a}	8.36 ± 0.18^{a}	8.43 ± 0.35^{a}	8.97 ± 0.22^{a}
EC (ms cm^{-1})	18.38 ± 0.02^{c}	18.46 ± 0.02^{b}	18.11 ± 0.03^{d}	19.05 ± 0.01^{a}
TDS(g L^{-1})	9.19 ± 0.01^{b}	9.22 ± 0.01^{b}	9.06 ± 0.02^{c}	9.51 ± 0.01^{a}
NO_2^- (µg L^{-1})	2.63 ± 0.20^{a}	3.61 ± 0.27^{a}	3.76 ± 0.15^{a}	15.48 ± 8.83^{a}
NO_3^- (µg L^{-1})	112.07 ± 4.69^{b}	134.72 ± 4.6^{ab}	106.75 ± 1.48^{b}	153.01 ± 19.07
NH_4^+(µg L^{-1})	67.52 ± 2.65^{a}	71.32 ± 2.75^{a}	82.89 ± 3.75^{a}	73.56 ± 10.18^{a}
Norg (µg L^{-1})	629.29 ± 12.51^{c}	779.08 ± 1.12^{a}	723.19 ± 2.68^{b}	751.87 ± 24.03^{ab}
Ninorg (µg L^{-1})	182.23 ± 4.57^{b}	209.64 ± 6.25^{ab}	193.40 ± 4.47^{b}	242.05 ± 27.30^{a}
Ntotal (µg L^{-1})	811.52 ± 12.85^{c}	988.73 ± 14.01^{a}	916.58 ± 19.29^{b}	993.92 ± 15.89^{a}
Pinorg (µg L^{-1})	16.71 ± 0.92^{c}	24.21 ± 0.82^{a}	21.97 ± 0.48^{b}	20.33 ± 1.24^{ab}
Porg (µg L^{-1})	10.19 ± 0.96^{c}	18.48 ± 0.99^{a}	14.81 ± 0.82^{b}	18.36 ± 1.31^{a}
Ptotal (µg L^{-1})	26.90 ± 1.56^{c}	42.70 ± 1.23^{a}	36.78 ± 0.81^{b}	35.69 ± 2.35^{ab}

Note. The Latin letters represent a significant difference in each row among the sampling times in the cage setting area under Duncan's multiple range test ($p < 0.05$).

The physico-chemical factors were examined among different variables by multivariate statistical method (KMO = 0.75, $p < 0.05$ in Bartlett test). In this study, the five main components, accounting for 84.75% of the total variance (period) were the components that remained in the analysis and included alterations (Table 3).

Table 3. Contribution of variance and principal component analysis (PCA) of physicochemical factors of water in the period of rainbow trout farming in cages (2014-2015).

The main components	Participation in variance	Accumulated share rate of variance of principal components
1	30.23	30.23
2	21.37	51.60
3	14.38	65.98
4	11.10	77.08
5	7.67	84.75

In the main component analysis of the data of physical and chemical factors of water, the parameters such as EC, temperature, salinity and total nitrogen exhibited the highest variance among the main components at 30.23% of the total 84.75% (Table. 4). The water quality index around the cage location was determined in two ways, including near the cage (cage shade and distances of 50 and 100 m) and far from the cage (distance 1000 m) at different sampling times. The results showed that there was no significant difference between the two fish farm at close and far distances from the cage ($p > 0.05$). Of course, the calculated values of water quality index by sampling time in both centres in August were higher than in other periods, exhibiting a significant difference ($p < 0.05$), however, the water quality status of the sampling area during the period based on Iranian Surface Water Resources Quality Index (IRWQIsc) was in average condition (Table 5). Each of the two farms in the present study had four cages, hence considering small-scale aquaculture. Although EIA surveys focus almost entirely on large-scale projects, such surveys raise awareness of the environmental issues related to aquaculture in the region and lead to better management of the marine environment (Phillips *et al*. 2009). There will always be environmental alterations due to the effects of fish farming in cages, unless the density of farmed fish and the morphometric and hydrological conditions of the area play a controlling role according to the degree of degradation of these effects. For example, the amount of water mixing in large bodies of water plays an important role in reducing the abovementioned effects (Beveridge 1984; Grigorakis & Rigos 2011; Plavan *et al*. 2012; Gorlach-Lira *et al*. 2013; Price & Morris 2013). The effects of caged fish farming on water quality usually first appear in the amounts of turbidity, dissolved oxygen, organic matter, nitrogen and total phosphorus (Huang 1998; Guo & Li 2003). If the location of the cage is chosen correctly, these effects will decrease after a distance of 30 m from the cages (Price & Morris 2013). Since soluble nutrients such as nitrogen and phosphorus are readily available to larger phytoplankton and algae (Troell *et al*. 2009) and are rapidly absorbed, they may increase the phytoplankton biomass around the cage (Olsen & Olsen 2008).

Table 4. Matrix and variance of the main components of the water physical and chemical factors during the period of rainbow trout farming in cages (2015-2016).

Parameter	The main components				
	1	2	3	4	5
EC (ms cm^{-1})	0.815	-0.422	0.018	-0.251	-0.252
TDS (g L^{-1})	0.808	-0.410	0.024	-0.279	-0.238
Water T. (ºC)	0.801	-0.322	-0.057	-0.229	0.263
Sal (PSU)	0.780	-0.361	0.024	-0.297	-0.166
Ntotal (µg L^{-1})	0.686	0.197	-0.336	0.532	0.085
pH	-0.619	-0.443	0.374	-0.218	-0.166
Porg (µg L^{-1})	0.558	0.539	-0.102	-0.321	0.120
Pinorg (µg L^{-1})	0.308	0.797	0.022	-0.108	0.067
Turb (NTU)	-0.314	0.775	0.002	0.285	-0.279
Ptotal (µg L^{-1})	0.514	0.765	-.0052	-0.259	0.111
NH_4 (µg L^{-1})	0.161	0.604	0.496	-0.370	0.233
Norg (µg L^{-1})	0.314	0.106	-0.854	0.281	0.032
Ninorg (µg L^{-1})	0.554	0.137	0.716	0.378	0.079
NO_3 (µg L^{-1})	0.540	-0.025	0.568	0.480	-0.057
DO (mg L^{-1})	0.160	-0.410	-0.423	0.239	0.394
NO_2 (µg L^{-1})	0.349	-0.263	0.388	0.588	0.097
Trans. (m)	-0.277	-0.268	0.181	-0.145	0.846

Table 5. The effects of fish farming on sea water quality index (IRWQIsc) and water quality status (WQS) around the location of cages in two offshore farms in the Southern Caspian Sea (2015-2016).

Cage establishment area	Sampling period	close to the cage	away from the cage (1000 m)	Water quality status
Klargostar Niko	January	46.39^{b}	47.09^{b}	Medium
	February	46.93^{b}	46.37^{b}	Medium
	March	46.80^{b}	46.96^{b}	Medium
	May	50.82^{a}	51.03^{a}	Medium
Samamgostar Shomal	January	46.27^{b}	46.69^{b}	Medium
	February	45.91^{b}	46.75^{b}	Medium
	March	46.08^{b}	46.71^{b}	Medium
	May	49.51^{a}	50.32^{a}	Medium

Note. The Latin letters represent a significant difference in each column among the sampling times in each cage setting area under Duncan's multiple range test ($p < 0.05$).

In the comparative study of physicochemical parameters of water in two fish farms under the multivariate test, only the turbidity in Samam Gostar North farm was determined to be higher than Clargester Niko. However, the trend of turbidity alterations in different sampling periods was similar in both farms and observed to be independent of the distance from the cage and geographical directions to the location of the cage. Therefore, in general, physicochemical factors did not display a significant difference in the effects of distance and different geographical directions in the two study areas around the floating cages ($p > 0.05$), however, by distance from the cage in a number of nutrient parameters, a limited decreasing trend was observed. A review of the sources shows that these alterations are usually more intense in the shadow of the cage up to a distance of 50 m, and the parameter alterations in different directions concerning to the cage are affected by the general flow of water at the cage location (Phillips *et al*. 2009; Kalantzi *et al*. 2013), consistent with the results of this study. The general flow of water in the southern region of the Caspian Sea is from north to south and from west to east, and is also affected by local winds. The average annual speed of water flow in the southern region is higher than 10-15 cm per second. This current in the central region of the southern parts (i.e., Tonekabon City, Mazandaran Province) fluctuating from the sea level by a flow of 26 cm per second to a depth of 30 m was about 7 cm per second. This flow has been reported in the range of the two studied farms from the sea level to a depth of 8 m to be 18-26 cm sec^{-1} (Zaker *et al*. 2011). Therefore, alterations in the water physical and chemical factors affected by fish farming in the cage were expected to be greater at close distances and in the south and east directions, however this did not happen.

On the other hand, it is not possible to accurately measure some parameters during the rearing period. For example, the measurement of dissolved oxygen in water exhibits a temporal, spatial, daily and seasonal complexity and is in association with rearing conditions, area, rate of alteration, water flow and hydrographic conditions of the area (Wu 1995; Johansson *et al*. 2007). In this study, it was found that alterations in the water physical and chemical parameters were mainly a function of sampling time (different months), since the measured values and the trend of alterations are consistent with seasonal changes in the southern coast of the Caspian Sea in recent years (Farabi *et al*. 2017). The factor analysis of physical and chemical parameters around fish farms, including temperature and total nitrogen compounds (affected by mineral nitrogen) in main component 1 and total phosphorus (inorganic and organic) in main components 1 and 2, are the effective parameters by a total of 51.6% of the total variance. Noteworhty, temperature, salinity, TN, EC and TDS, which are in the main components 1, are completely affected by the coastal areas in the Caspian Sea and are related to seasonal alterations. These data are consistent with data from previous years in these areas (Farabi *et al*. 2017). So it can not be concluded that the alterations in these parameters were affected by fish farming in these areas. Zhang *et al*. (2020) reported studies on the water quality parameters around marine fish farms in 2018. The results of their studies on the effects of seasonal alterations were in agreement with the present study. It may seem that in the principal component analysis (Table 4), fish farming resulted in a relative increase in nutrients. However, it is more likely to increase nutrients due to physicochemical properties and water currents, substrate dynamics or as a result of the local nutritional process due to a significant elevation in nutrients outside the fish farming period (Table 2; Hakanson 1986; Ola & Hall 1994). The amount of nitrogenous nutrient compounds was higher outside the growing season (August). It is possible that when the thermal layering of water fails, nutrients and other compounds deposited in sediments or deeper layers from rearing cages are returned to the water column (Venturoti *et al*. 2014). In this study, the surface water quality index was determined based on the standard of the Iranian Environmental Protection Organization ($IRWQI_{SC}$) around the cage at close distances (shade, 50 m and 100 m) and away from the cages (1000 m). The water quality conditions of the region outside the sampling season in January ($p > 0.05$) and especially in August ($p < 0.05$) exhibited a more favourable situation than in the rearing period (March and May). However, in the whole period, the water quality of the study area was classified as average (medium). This is due to the general conditions of the Southern Caspian region and the lack of small-scale aquaculture. Nevertheless, cage aquaculture is typically involved in hypereutrophic conditions, whether on a small or larger scale. However, it is very difficult to verify the role of aquaculture in relation to its effect on eutrophication, especially in marine areas (Mente *et al*. 2006). Therefore, in this study, minor alterations were observed due to fish farming in the physical and chemical parameters of water around the sea cage, many of them were affected by seasonal changes. This result is similar to some of the results obtained in small-scale marine fish farms around the world. For example, Demirak *et al*. (2006) identified the main changes in the physicochemical parameters of water around the European bass (*Dicentrarchus labrax*) in the Gulf of Gulluk in the Aegean Sea as a result of seasonal pattern changes in environmental impacts. In addition, in some other studies, minor alterations were observed due to the effect of the fish cage farming on water quality (especially nutrients; Nash *et al*. 2001; Soto & Norambuena 2004; Tlusty *et al*. 2005; Rensel *et al*. 2007). In general, no clear and orderly alterations were observed due to the direct effect of fish farming around the cages, similar to resulta of Zanatta *et al*. (2011) and some other studies (Santos *et al*. 2009) on small-scale marine fish farms. In this scale of farms, no significant alteration was observed in the amount of nutrients between near and far distances from the cages. In this and other similar studies, the fish culture have not influenced water quality yet, since these impacts were not sufficient in short fish farming times or small-scales farming to deteriorate the ambient environment. However, in any case, fish farming can rise the nutrients in the environment.

CONCLUSION

This result can be attributed to the small scale of the fish farm, the hydrological conditions of the area, the short length of the rearing period, the placement of the cages at a suitable depth of the sea and most importantly the existence of abundant flows and currents, especially in the different directions of the study area. In addition, the studied farms experienced their first rearing period, so the environment was able to receive nutrients from fish farming on an existing scale and, therefore, the ecosystem structure was not altered in these areas. Obviously, further studies will be needed. In order to reduce the cost of environmental monitoring for marine fish farmers, it is recommended that assessment of the environmental impact of caged fish farming be carried out on large-scale farms or on farms with several periods of continuous aquaculture activities.

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