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# Assessment of water quality in Iran's Anzali Wetland, using qualitative indices from 1985, 2007, and 2014

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**Abstract** In the present study, the water quality of the Anzali Wetland, located southwest of the Caspian Sea in Iran, was compared for the years 1985, 2007, and 2014, using a weighted arithmetic mean function (National Sanitation Foundation Water Quality Index: $NSFWQI_a$), a weighted geometric mean function ($NSFWQI_m$), and the Oregon Water Quality Index (OWQI). To that end, nine water quality parameters [pH, turbidity (TURB), temperature (T), dissolved oxygen (DO), nitrate ($NO_3$), total solids (TS), phosphate ($PO_4$), biological oxygen demand ($BOD_5$), and fecal coliforms (FC)] were analyzed at eight selected stations. According to the proposed classification for water quality indices (higher value (0–100), better water quality), the Wetland water quality was classified as the mean values of the three indices for the three sampled years, as follows: $NSFWQI_a$ (13.72, 12.81, 12.07); $NSFWQI_m$ (63.049, 52.388, 49.108); and OWQI (26.867, 14.477, 15.53). The values of $NSFWQI_a$, $NSFWQI_m$, and OWQI for the western

stations were better than for the other stations in the region over the 29-year span of investigation; however, the remainders of the stations' values were very poor. Because wastewaters discharged from industrial and agricultural areas are more concentrated in the eastern part of the Anzali Wetland, the eastern stations of the Wetland showed lower water quality compared to the central and western stations. The water of the Anzali Wetland has different quality classes according to the aggregation methods employed. It is concluded that when evaluating water quality of aquatic ecosystems, several indices should be used to obtain more comprehensive results.

**Keywords** Water quality indices · $NSFWQI_a$ · $NSFWQI_m$ · OWQI · Anzali Wetland · Iran

## Introduction

Wetlands tend to purify incoming pollutants in several ways, such as via biogeochemical reactions, phytoremediation, bioremediation, and sedimentation (Davis 1995; USEPA 1995). All over the world, tragically, aquatic ecosystems are being destroyed (Jin et al. 2009). An overview throughout Iran's wetlands shows that most have been lost because of land cover changes, poor management, boating, dam building, and introducing non-native species such as plant and

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fish (Gorgizade et al. 2014). Iran is located in the dry belt of the world, and water reserve for consumption is an important national issue (Nemati et al. 2009). In addition, increasing population from industrial and agricultural activities near the water resources has decreased water quality (Nasirian 2007). With increasing water scarcity, water quality will decline, which can reduce water supply for different usages, including drinking water, agriculture, and industries, especially in semi-arid and arid regions. Thus, the quality and quantity of water are closely interrelated, which together can limit water availability and usage (Peters and Meybeck 2014). The water quality of ecosystems is determined based on physicochemical and biological factors (Sargaonkar and Deshpande 2003). Using appropriate indices is one of the most important ways to acquire information on water quality trends (Dwivedi and Pathak 2007). Using indices to assess ecosystem health and to inform the general public and decision makers about the situation of an ecosystem can be helpful in monitoring programs (Nasirian 2007; Simoes et al. 2008). Indices enable the creation of benchmarks to help determine management strategies when attempting to improve water quality (Rickwood and Carr 2009).

To date, various aggregation methods have been used to calculate water quality indices. For example, Liou et al. (2004) summarized various types of aggregation methods for the calculation of water quality and presented many examples of their applications. The National Sanitation Foundation Water Quality Index (NSFWQI) was one of the first water quality indices to be developed (Brown et al. 1970); it calculates nine water quality parameters and aggregates them through a weighted arithmetic mean function (NSFWQI$_a$). Subsequently, McClelland (1974) created a weighted geometric mean function (NSFWQI$_m$), and found it more sensitive than the weighted arithmetic mean function in showing changes in the individual variables. Finally, use of the Oregon Water Quality Index (OWQI) has been proposed to improve the weighted arithmetic and weighted geometric mean formulae (Dojlido et al. 1994; Cude 2001). The variables used in all three indices do not include pollutants, but rather levels of essential aquatic conditions, listed in the next section. In recent years, the Anzali Wetland, one of the most important wetlands of Iran, has faced an increasing number of point and nonpoint sources of

pollution. Charkhabi and Sakizadeh (2006) reported that eutrophication and a high burden of industrial effluents and domestic sewage has pushed the Anzali Wetland to the verge of complete collapse. Consequently, the water quality of the Wetland has declined drastically. The objective of this study was to compare the current condition of the wetland (2014) with those in 1985 and 2007, using NSFWQI$_a$, NSFWQI$_m$, and OWQI.

One of the most important advantages of the present study is providing baseline data for future investigations. Without baseline data, ecological risk assessment of water quality parameters and water quality management of wetlands is not possible.

## Materials and methods

### Study area

The Anzali wetland (37°24′N, 49°22′E) is located in northwestern Iran along the southern shores of the Caspian Sea (Zamani-Ahmadmahmoodi et al. 2013) (Fig. 1). The Wetland is internationally known as an important area for birds, and was registered as a Ramsar site in June 1975. The wetlands have been identified as an "Important Bird Area" by BirdLife International (Evans 1994). It has also been added to the Montreux Record of wetlands being degraded by human activities, technological development, or pollution. In recent years, the Wetland has been deteriorating due to the inflow of wastewater, solid waste, and sediment from its encompassing environment (Ayati 2003). As mentioned above, the Anzali Wetland is now being continually subjected to several severe stresses, such as industrial and agricultural activities, exotic species, eutrophication, and sedimentation, which have gradually destroyed the Wetland (Sakizade 2003).

### Sample collection and preparation

Water samples were collected (2014–2015) from eight stations in the Wetland, namely Nahang Rogha, Sorkhankal, Pirbazar, Siadarvishan, Hendkhaleh, Nokhaleh, East (Sheyjan), and West (Abkenar) (Fig. 1). Table 1 provides the locations of the stations. At each station, samples were collected every 45 days from March 2014 to March 2015, using three
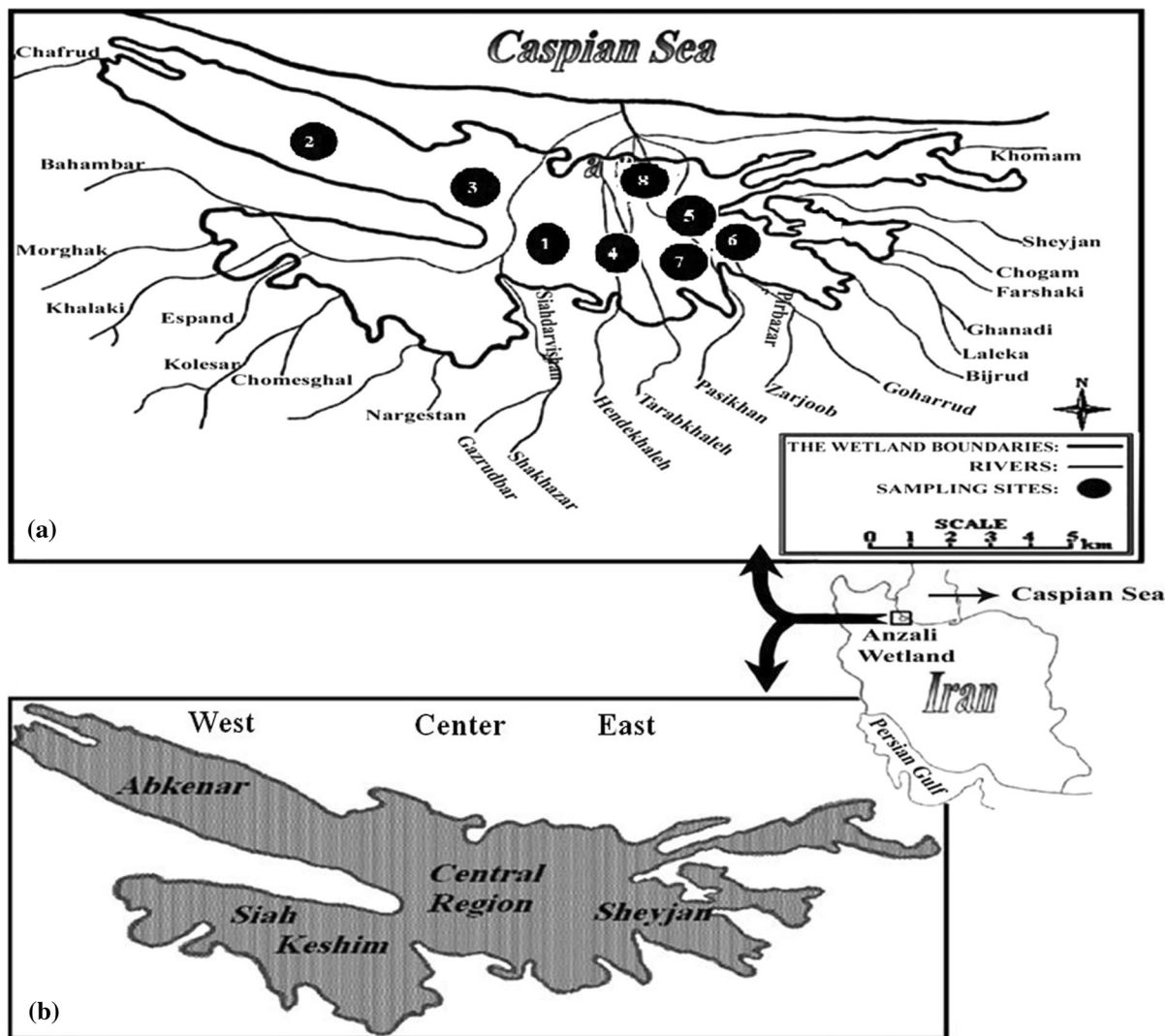
**Fig. 1** Map of Anzali Wetland and sampling locations (**a**), and their parts (**b**)

**Table 1** Location of eight stations in the Anzali Wetland

| Number | Station | X | Y | Location |
|---|---|---|---|---|
| 1 | Hendkhaleh | 4140191 | 363170 | Central |
| 2 | Western part of Wetland (Abkenar) | 4145240 | 358977 | Western |
| 3 | Siadarvishan | 4144411 | 360645 | Western |
| 4 | Sorkhankal | 4140191 | 360903 | Central |
| 5 | Eastern part of Wetland (Sheyjan) | 4142686 | 367652 | Eastern |
| 6 | Pirbazar | 4140646 | 367413 | Eastern |
| 7 | Nokhaleh | 4140676 | 367267 | Eastern |
| 8 | Nahang Rogha | 4147399 | 364257 | Central |

replicates. Water samples (1000 ml) were collected separately at each sampling site using polyethylene bottles. In addition, an extra bottle of water was taken by the same method at each collection, in order to examine the concentration of dissolved oxygen in each station. The pre-washed bottles were rinsed with

sample water thrice on site before collecting the sample water. The water samples were then brought to the laboratory and stored in a dark cool room (4 °C) until the analyses were completed (Bahar et al. 2008). Water quality data for the years 1985 and 2007 were obtained from the Department of Environment (DOE) of Iran.

Analytical procedures

All parameters were analyzed according to standard procedures (APHA 1992). The method of analysis of each parameter is mentioned in parentheses. The measurements of pH (4500-H.B, field measured), turbidity (2130-B, field measured with DRT-15 in NTU units), temperature (2550-B, field measured) and dissolved oxygen (4500-O, Winkler method) were carried out in the laboratory immediately after sample collection. Other parameters such as 5-day biological oxygen demand (BOD$_5$) (5210-A), fecal coliform bacteria (9221 E), nitrate (4500-B.C), total solids (2540 B), and phosphates (4500-P.E) were analyzed after transferring the samples to the laboratory. Fecal coliform bacteria test was performed immediately and other parameters were analyzed in the first 24 h after sample collection. The analytical procedures in water quality analysis were the same for 1985, 2007, and 2014.

Water quality indices (WQIs)

With the NSFWQI, an internationally recognized WQI, values were obtained by multiplying the respective weight factor by an appropriate quality value for each water quality variable. This index is presented in two forms: with a weighted arithmetic mean function (NSFWQI$_a$) (Eq. 1), and a weighted geometric mean function (NSFWQI$_m$) (Eq. 2) (Brown et al. 1970; McClelland 1974). This WQI consists of nine water quality variables, listed here with their respective weight factors: dissolved oxygen (0.17), fecal coliform bacteria (0.16), biochemical oxygen demand (0.11), pH (0.11), temperature change (0.10), phosphates (0.10), nitrates (0.10), turbidity (0.08), and total solids (0.07). The weight factors had been designated according to the importance of the water quality variables to overall quality. In NSFWQI$_m$, a weighted mean is used to combine the respective values of these water quality variables to obtain an

overall index ranging from 0 to 100. According to this calculated index, the water quality is then assigned to one of five possible categories, i.e., excellent, good, fair, bad, or very bad (Table 2) (Dojlido et al. 1994; Mitchell and Stapp 2000). With the Oregon Water Quality Index (OWQI), an unweighted harmonic square mean formula is derived (Eq. 3). The parameters covered in this method are temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, ammonia and nitrate nitrogen, total phosphorus, total solids, and fecal coliform bacteria (Cude 2001).

$$NSFWQI_a = \sum SI_i W_i \qquad (1)$$

$$NSFWQI_m = \prod SI_i W_i \qquad (2)$$

$$OWQI = \sqrt{\frac{n}{\Sigma 1/SI2}} \qquad (3)$$

where WQI is water quality index, n is number of parameters, SI$_i$ is subindex I, and W$_i$ is the weight given to subindex I. Finally, after calculating the three mentioned water quality indices, the water quality of Anzali Wetland was compared based to these indices from 1985, 2007, and 2014.

Statistical analysis

The normality of data was checked by Kolmogorov–Smirnov test. One-way ANOVA test was used to determine any significant differences among mean

Table 2 Classification of water quality indices

| WQI value | Rating of water quality |
|---|---|
| National sanitation foundation water quality index (NSFWQI) | |
| 91–100 | Excellent water quality |
| 71–90 | Good water quality |
| 51–70 | Medium water quality |
| 26–50 | Bad water quality |
| 0–25 | Very bad water quality |
| Oregon water quality index (OWQI) | |
| 90–100 | Excellent water quality |
| 85–89 | Good water quality |
| 80–84 | Fair water quality |
| 60–79 | Poor water quality |
| 0–59 | Very poor water quality |

values of water quality indices in the years 1985, 2007, and 2014. Subsequently, the Duncan multiple range test was performed if significant differences were found in ANOVA. Differences were considered significant at p values <0.05. All statistical analyses were performed using the statistical package from SPSS Inc., released 2007 (SPSS for Windows, Version 16.0, Chicago, SPSS Inc.). All data were reported as mean ± SE (standard error).

## Results and discussion

Table 3 provides summarized statistical analysis of the water quality parameters measured in the sampling stations of the Anzali Wetland in 1984, 2007, and 2014. Raw data of individual water quality parameters cannot supply some information about water quality conditions, so use of water quality indices can be more useful. Water quality indices are not only source of information that is brought to bear on water related decisions, but also many activates such as assessment, utilization, treatment, resource allocation, public information, and environmental planning are all served by indices as well (Abbasi and Abbasi 2012).

Figure 2 shows the mean value of $NSFWQI_m$ in the three most important parts of the Anzali Wetland during 1985, 2007, and 2014. The $NSFWQI_m$ index at all stations during 1985 was in the range 13.10–14.37. Overall, the mean values of $NSFWQI_m$ showed higher levels in 1985 compared with 2007 and

2014 (11.71–13.79 and 11.63–12.87, respectively). In addition, the mean values of $NSFWQI_m$ showed higher levels in 2007 compared to those of 2014. The results of $NSFWQI_m$ showed that the water quality of the Anzali Wetland is gradually declining. The mean value of $NSFWQI_a$ is displayed in Fig. 3 for 1985, 2007, and 2014. The $NSFWQI_a$ index at all stations during 1985 was in the range of 54.08–70.63. As with the previous indices, the mean values of $NSFWQI_a$ showed higher water quality levels in 1985 than in 2007 and 2014 (47.45–64.18 and 37.95–57.87, respectively). Figure 4 shows the mean values of the OWQI index at all stations. These values also showed a decline, from 16.71–49.73 to 11.70–16.53 and 11.77–21.24, in 1985, 2007, and 2014, respectively. The mean values of the $NSFWQI_a$, $NSFWQI_m$, and OWQI are provided in Table 4.

The $NSFWQI_m$ index values, 1985, 2007, and 2014, all stations across demonstrate that the various regions of the Anzali Wetland have remained in the qualitative category "very bad". However, according to the classification presented in Table 2, the Wetland water quality had been of "moderate" quality during 1987 and 2007, and of "bad quality" in 2014. Nevertheless, on the OWQI index also, for 1985, 2007, and 2014, the Anzali Wetland water quality was "very bad". Taking the values of the indices overall, the water quality of the stations in the western region was better than in the other areas, according to all three indices, $NSFWQI_m$, $NSFWQI_a$, and OWQI. In general, based on the classification of indices in Table 2 and the values of Figs. 2, 3, and 4 by individual index,

Table 3 Summary of statistical analysis of the parameters measured in the sampling stations of the Anzali Wetland in 1984, 2007, and 2014

| Parameter | n | 1985 (Mean ± SE) | 1985 (Min–Max) | 2007 (Mean ± SE) | 2007 (Min–Max) | 2014 (Mean ± SE) | 2014 (Min–Max) |
|---|---|---|---|---|---|---|---|
| pH | 24 | 7.98 ± 0.06 | 7.17–9.23 | 7.75 ± 0.07 | 6.8–8.66 | 8.12 ± 0.08 | 7.46–9.02 |
| Turbidity (NTU) | 24 | 20.92 ± 4.26 | 3.2–117.14 | 15.34 ± 4.07 | 0.1–93.1 | 37.21 ± 6.7 | 8.02–250.5 |
| Temperature (°C) | 24 | 18.23 ± 1.02 | 8.4–29 | 21 ± 1.39 | 12–31 | 18.32 ± 1.2 | 8.4–30 |
| Dissolved oxygen (mg/l) | 24 | 7.69 ± 0.4 | 2.81–12.1 | 6.89 ± 0.47 | 10.5–0.58 | 8.49 ± 0.45 | 3.9–16.2 |
| $BOD_5$ (mg/l) | 24 | 3.29 ± 0.32 | 0.89–10.56 | 20.4 ± 1.33 | 8–41 | 43.3 ± 5.96 | 9.05–150.08 |
| Nitrate (mg/l) | 24 | 0.22 ± 0.03 | 0.11–0.8 | 0.6 ± 0.1 | 0.024–1.9 | 4.22 ± 0.29 | 2.71–12.6 |
| Total solids (mg/l) | 24 | 507.32 ± 52.91 | 1589–167 | 661.6 ± 71.91 | 125–1800 | 1536.1 ± 291 | 172.8–6221 |
| Phosphates (mg/l) | 24 | 0.09 ± 0.02 | 0.01–0.7 | 0.66 ± 0.08 | 1.84–0.03 | 0.39 ± 0.09 | 0.04–2.82 |
| Fecal coliform (MPN/ 100 ml) | 24 | 7.67 ± 1432.9 | 100–7452 | 17,957 ± 1173 | 3–24,000 | 38,656 ± 1412 | 3–240,000 |

**Fig. 2** Values of
$NSFWQI_m$ (Mean ± SE) in
1985, 2007, and 2014 [East
(n = 72), Center (n = 72),
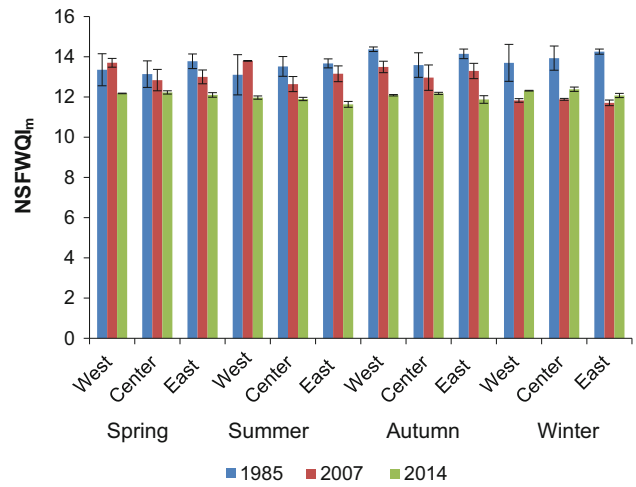and West (n = 48)]



**Fig. 3** Values of $NSFWQI_a$
(Mean ± SE) in 1985, 2007,
and 2014 [East (n = 72),
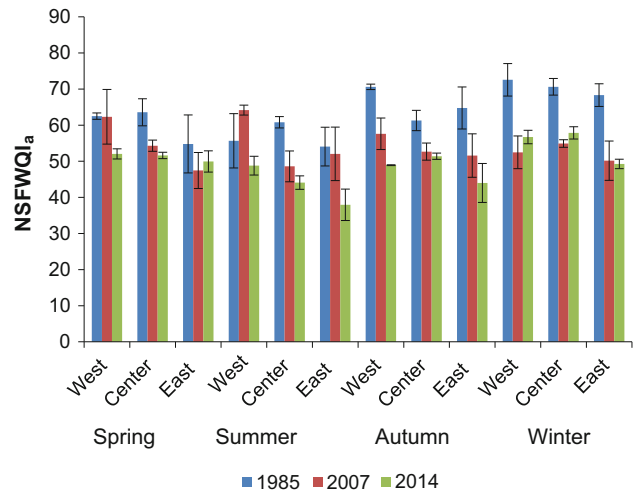Center (n = 72), and West
(n = 48)]



**Fig. 4** Values of OWQI
(Mean ± SE) in 1985, 2007,
and 2014 [East (n = 72),
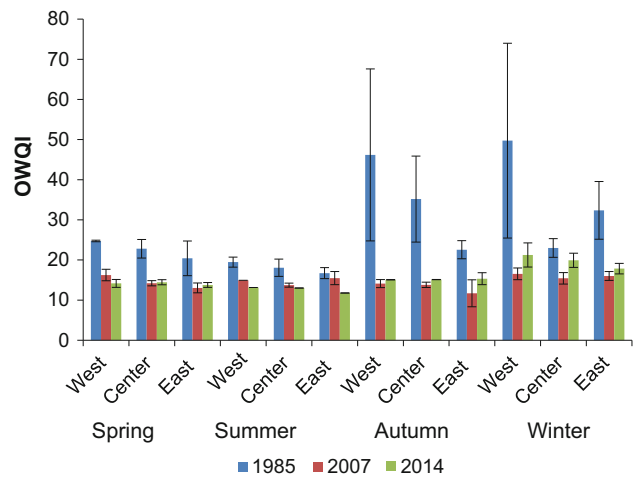Center (n = 72), and West
(n = 48)]

**Table 4** Comparison of mean value of water quality indices (Mean $\pm$ SE, n = 24)

|  | 1985 | 2007 | 2014 |
| --- | --- | --- | --- |
| NSFWQI$_m$ | $13.72 \pm 0.141^c$ | $12.81 \pm 0.147^b$ | $12.07 \pm 0.044^b$ |
| NSFWQI$_a$ | $63.049 \pm 1.56^a$ | $52.388 \pm 1.38^a$ | $49.108 \pm 1.16^a$ |
| OWQI | $26.867 \pm 2.63^b$ | $14.477 \pm 0.43^b$ | $15.53 \pm 0.53^c$ |
| F value | 208.2 | 743.6 | 769.6 |
| p value | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |

Different letters indicate statistical significance (Duncan, $p < 0.05$)

the stations of the western regions had better status in 1985, 2007, and 2014 in terms of NSFWQI$_m$ and NSFWQI$_a$, while the eastern and central regions have the lowest values of these indices in these years. According to Fig. 4, in terms of OWQI, the lowest value is related to the eastern and central regions of the Wetland, while the highest value belongs to the western region during these years. Based on the results of water quality indices shown in Figs. 2, 3, and 4, there were occasions when water quality did not show a gradual decline from 1985 onwards. However, based on the results of individual water quality parameters presented in Table 3, and the comparison of mean value of water quality indices in Table 4, water quality of the Wetland showed gradual decrease from 1985 to 2014. This may be because of the small sample size, but when the whole of the data were examined, better results were achieved.

In general, human activities and land use changes in a region have a major influence on parameters of water quality (Boyacioglu and Gunduz 2005). Using the NSFWQI, Clayton (2009) associated the decreased quality of the Pearson River water in New Zealand to environmental factors and to the discharge of wastewater into the river. There are numerous rivers around the Anzali Wetland. Passing through the city of Rasht, the Zarjoob and Goharrood Rivers join and form the Pirbazar River, situated east of the Wetland. The majority of the large industrial polluting units are within the basin of the Zarjoob and Goharrood Rivers (the eastern part of the Wetland), and their wastewater finds its way to the Anzali Wetland through these two rivers (Fig. 1). Furthermore, the wastewater produced by rice farms during spring and summer are among the Wetland's polluting agents. The leachate of urban wastes of Anzali Port, discharged within the Wetland range, join the Zarjoob River together with surface

waters, finally reaching the eastern part of Anzali Wetland, after pouring into the Pirbazar River.

Based on the study by Gatot and Sumiharni (2011), the NSFWQI water quality index is on the whole considered to be the best water quality index, suitable for monitoring and evaluating surface waters such as rivers, lakes, ponds, and reservoirs. Generally, BOD$_5$ and fecal coliform bacteria are the main water quality subindices that reflect the effect of anthropogenic activities on water quality (Nemati et al. 2009). In addition, the water quality of the Wetland declines in the summer because of increased nitrate and phosphate concentrations from fertilizer use in farmlands. Overall, based on the values of Figs. 2, 3, and 4 by individual index, the water quality of the stations in summer (dry season) decreased compared to winter (wet season) in 1985, 2007, and 2014, especially in terms of OWQI.

Our results agree with the conclusion reached by Srebotnjak et al. (2012): "No single widely accepted method has emerged and, furthermore, all currently used indices are restricted in their applicability and scope, because each author adopted different indicators, weights, and subindices". Certainly the water of the Anzali Wetland has different quality classes according to diverse aggregation methods (Eqs. 1–3). However, the selection of an aggregation method is an essential step to surveying and describing the state of a given body of water. Alobaidy et al. (2010) compared water quality of Dokan Lake in Iraqi Kurdistan in1976 and 2000 with 2008 and 2009. Their results showed that the water quality of the Lake decreased gradually over the period from good to poor. The most important issue to be addressed in the structure and functions of subindices and their summing is the problem of ambiguity and darkness area.

The existence of an ambiguity area in an index signifies that the general index represents a poor environmental state without any of its subindices having reached the poor stage. Similarly, the darkness issue occurs when at least one of the indices does reveal poor environmental conditions, but the general index does not indicate such conditions. Regarding NSFWQI, two summing functions have been presented for calculating the index. The linear weight sum function has the problem of darkness, and thus the weight multiplication function (NSFWQI$_m$) was proposed (Landwehr and Deininger 1976). Curves and determination of subcriteria in the OWQI index, as in the NSFWQI, have advanced, based on the opinions of experts, as a function of logarithmic transformation. The difference with NSFWQI is that the parameters of the effects are equally important (Brown et al. 1970; Cude 2001), and based on results, all stations were classed in the "very bad" water quality category. That all eight parameters have equal weight in the calculation of OWQI is the shortcoming of this index. Because of the equal weights of the eight parameters, the low value in one or two subindices can decrease the value of the OWQI. Compared to the index NSFWQI, the OWQI has less efficiency. Since the NSFWQI index considers a specific weight for every parameter, and these weights are incorporated in the calculation of the NSFWQI index (Brown et al. 1970; Landwehr and Deininger 1976), this is a more appropriate index to assess water quality in the Anzali Wetland. Razdar et al. (2008) and Ahmadzadeh et al. (2013) conducted similar studies on the Anzali Wetland in years of 2007 and 1995–2002 respectively, and their results showed that water quality of the Wetland could then be classified into the "good" and "medium" classes. The reasons for getting different results with our study are that the first study was conducted in 10 stations with positions very different from the stations in our study, and the second study was conducted in 14 stations located on influent rivers to the Wetland, not in the Wetland itself.

## Conclusion

Because of discharging wastewaters from industrial and agricultural areas that are more concentrated in the eastern part of the Anzali Wetland, the eastern stations of the Wetland displayed lower water quality compared to the central and western stations. Based on the results of this study, it is concluded that, when evaluating water quality of the Anzali Wetland, several indices should be used to obtain more comprehensive and accurate results. The results of the NSFWQI$_m$, NSFWQI$_a$, and OWQI indices generally indicated that most stations, over the 29-year period, were positioned in the very worst class. The results also reveal that the number of point and nonpoint sources of pollution must be controlled, in order to restore the water quality of this Wetland.

**Compliance with ethical standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** The research does not involved human participants, and involved animals.

## References

Abbasi T, Abbasi SA (2012) Water quality indices. Elsevier, Amsterdam

Ahmadzadeh T, Akbarzade A, Javid AR (2013) Study water quality Anzali wetland, using WQI index. 2nd national conference conservation and planning of environment, pp 1–13

Alobaidy AHMJ, Abid HS, Maulood BK (2010) Application of water quality index for assessment of Dokan Lake ecosystem, Kurdistan region, Iraq. Water Resour Prot 2:792–798

APHA (1992) Standard method for examination of water and wastewater, 18th edn. American Public Health Association, Washington

Ayati B (2003) Investigation of sanitary and industrial wastewater effects on Anzali Reserved Wetland (final report). Report presented to MAB-UNESCO by Environmental Engineering Division. Tarbiat Modares University

Bahar MM, Ohmori H, Yamamuro M (2008) Relationship between river water quality and land use in a small river basin running through the urbanizing area of Central Japan. Limnology 9:19–26

Boyacioglu H, Gunduz O (2005) Application of factor analysis in the assessment of surface water quality in Buyuk Menderes river basin. J Eur Water 10:43–49

Brown RM, McClellan NI, Deininger RA, Tozer RG (1970) A water quality index—do we dare? Water Sew Works 117(10):339–343

Charkhabi A, Sakizadeh M (2006) Assessment of spatial variation of water quality parameters in the most polluted branch of the Anzali wetland, Northern Iran. Pol J Environ Stud 15:395–403

Clayton M (2009) Water Quality Analysis of Pearson Creek: Comparison of Pearson Creek Water Quality since Discharge of Effluent Lagoon Water, 5/15/2009

Cude C (2001) Oregon water quality index: a tool for evaluating water quality management effectiveness. J Am Water Resour Assess 37(1):125–137

Davis L (1995) A handbook of constructed wetlands: a guide to creating wetlands for agricultural waste, domestic wastewater, coal mine drainage and stormwater in the mid-atlantic region. Vol. 1: general considerations. Natural Resources Conservation Service. United States Environmental Protection Agency, Washington, DC

Dojlido JR, Raniszewski J, Woyciechowska J (1994) Water quality index applied to rivers in Vistula River Basin in Poland. Environ Monit Assess 33:33–42

Dwivedi SL, Pathak V (2007) A Preliminary Assignment of Water Quality Index to Mandakini River. Chitrakoot. Indian Journal of Environmental Protection 27(11):1036–1038

Evans MI (1994) Important bird areas in the middle East. BirdLife International, Cambridge

Gatot E, Sumiharni S (2011) Proposing water quality index calculation method for indonesian water quality monitoring program. Int J Eng Sci 2(2):2086–3799

Gorgizade A, Marzouni MBN, Haghighifard J, Rafiei M, Esmaeili M (2014) Water quality evaluation of Bamdezh wetland using combination of NSFWQI and geographic information system. Int J Adv Biol Biomed Res 2(5):1454–1467

Jin G, Elits K, Kelley TR, Webb JW (2009) Preliminary water quality assessment of Spunky Bottoms restored wetland. J Environ Sci Health Part A 44:235–243

Landwehr JM, Deininger RA (1976) A comparison of several water quality indexes. J Water Pollut Control Fed 48(5):954–958

Liou SM, Lo SL, Wang SH (2004) A generalized water quality index for Taiwan. Environ Monit Assess 96(1):35–52

McClelland NI (1974) Water quality index application in the Kansas River Basin. U.S. Environmental Protection Agency, Region 7. Kansas City, Missouri

Mitchell MK, Stapp WB (2000) Field manual for water quality monitoring, 12th edn. Kendall/Hunt, Dubuque

Nasirian M (2007) A new water quality index for environmental contamination contributed by mineral processing: a case study of Amang (Tin Tailing) processing activity. J Appl Sci 7(20):2977–2987

Nemati M, Ebrahimi E, Mirghaffary N, Safyanian A (2009) Water quality assessment in an arid region using a water quality index. Water Sci Technol 60(29):2319–2327

Peters M, Meybeck M (2014) Water quality degradation effects on freshwater availability: impacts of human activities. Water Int 22(2):185–193

Razdar B, Ghavidel A, Zoghi MJ (2008) Study water quality Anzali wetland, using WQI index. In: Proceedings of the national conference, sustainable development patterns, water management, pp 465–457

Rickwood CJ, Carr GM (2009) Development and sensitivity analysis of a global drinking water quality index. Environ Monit Assess 156(1–4):73–90

Sakizade M (2003) Investigate and identify sources of pollution sources in the Shahrood basin in Guilan. Tehran University, Thesis for a master's degree

Sargaonkar A, Deshpande V (2003) Development of an overall index of pollution for surface water based on a general classification scheme in indian context. Environ Monit Assess 89(1):43–67

Simoes FS, Moreira AB, Bisinoti MC, Gimenez SMN, Yabe MJS (2008) Water quality index as a simple indicator of aquaculture effects on aquatic bodies. Ecol Ind 8(5):476–484

Srebotnjak T, Carr G, Sherbinin A, Rickwood C (2012) A global water quality index and hot-deck imputation of missing data. Ecol Ind 17:108–119

USEPA (1995) Ecological restoration: linking restoration practices to water quality parameters. Technical Report No. EPA 841-F-95-007. United States Environmental Protection Agency, Washington, DC. http://www.epa.gov/OWOW/NPS/Ecology/chap3.html. Accessed 19 Sept 2002

Zamani-Ahmadmahmoodi R, Esmaili-Sari A, Mohammadi J, Bakhtiari AR, Savabieasfahani M (2013) Spatial distribution of cadmium and lead in the sediments of the western Anzali wetlands on the coast of the Caspian Sea (Iran). Mar Pollut Bull 74:464–470