Environ Earth Sci (2010) 59:1397–1407
DOI 10.1007/s12665-009-0126-1

ORIGINAL ARTICLE

Water quality variability and eutrophic state in wet and dry years in wetlands of the semiarid and arid regions

J. Nouri · S. A. Mirbagheri · F. Farrokhian · N. Jaafarzadeh · A. A. Alesheikh

Received: 31 July 2008 / Accepted: 21 February 2009 / Published online: 13 March 2009
© Springer-Verlag 2009

Abstract Wetland ecosystems are particularly vulnerable due to flow of nutrients from the surrounding watershed. The study was performed in the Shadegan wetland, a Ramsar-listed wetland located in the south-west of Iran at the head of the Persian Gulf. The wetland plays a significant hydrological and ecological role in the natural functioning of the northern Gulf. The proposed wetland has different water quality characteristics in wet and dry years of study during 1994–2006. To determine the variables, sampling was carried seasonally for each year at six stations. The results indicate that wetland in wet years had high concentrations of nitrate and silicate, leading to oligo–meso eutrophic conditions. Wetland in dry years had high phosphate concentrations, resulting in meso-eutrophic conditions. Forcing functions, such as climatic patterns, water residence time, reduce runoff and increasing density of wastewaters from the surrounding urban, agricultural and industrial area are probably the main variables that explain the observed patterns.

Keywords Water quality · Eutrophication · Wetlands · Shadegan wetland

J. Nouri · F. Farrokhian (✉)
Department of Environmental Management,
Graduate School of the Environment and Energy,
Science and Research Branch,
Islamic Azad University, Tehran, Iran
e-mail: fz.farrokhian@yahoo.com

S. A. Mirbagheri
Department of Civil Engineering,
K.N. Toosi University of Technology,
Tehran, Iran

N. Jaafarzadeh
Department of Environmental Health, School of Health,
Ahwaz Jondishapour Medical Sciences University,
Ahwaz, Iran

A. A. Alesheikh
Department of Geometrics Engineering,
K.N. Toosi University of Technology,
Tehran, Iran

Introduction

Wetland ecosystems are particularly vulnerable to eutrophication because freshwater enters these areas via rivers which are highly susceptible to pollution from urban, agricultural and industrial wastewater (Fetter 1994). Traditionally, studies on wetland eutrophication have focused on point sources of nutrients, such as rivers and wastewater treatment plants (Richardson and Jorgensen 1996). Decreasing of water quality can lead to unhealthy ecosystem conditions as reported for other wetland (Boynton et al. 1982; Malone et al. 1986; Verity 1987; Kemp and Boynton 1992; Malone 1992; Patrico et al. 2004; Xu et al. 2005). Nitrogen has been particularly important among these nutrients, because it is considered a limiting nutrient for primary production in wetland ecosystems (Nixon and Pilson 1983). Increased productivity and standing stocks at vegetation can be resulted from nitrogen which may be considered as a pollutant factor (Nouri et al. 2008). Phosphorus is generally the limiting element due to its affinity to calcium carbonate and rapid precipitation in the form of apatite (Fourqurean et al. 1993). Elevated P concentrations are a major concern for the quality of surface waters, in particular with respect to eutrophication (Casey and Clarke 1979; Heathwaite et al. 1996; Brookes et al. 1997; Environment Agency 1998). Low flows during drier periods, with a limited ability to dilute point source loads, with sluggish flows promote algal growth and eutrophication (Smith et al. 2005). Urbanization, intensive agriculture, aquaculture and industrial, promotes some undesirable changes in wetland systems. These problems are increasing in developing countries that lacking the appropriate technology for the implementation of wastewater treatment systems, promote nutrients discharges to the wetland ecosystems, generating eutrophic conditions. Sima and Tajrishy (2006) described a framework for determining environmental water allocations for Shadegan wetland. Essential components of a wetland's water regime include the quantity of water, and the timing, duration and frequency of inundation (McCosker 1998). The hydro period of wetland's surface and subsurface water is like a hydrological signature of each wetland type. It is unique to each type of wetland, and its constancy from year to year ensures a reasonable stability for that wetland. The hydro period is an integration of all inflow and outflows of water, but it is also influenced by physical features of the terrain and by proximity to other bodies of water (Mitsch and Gosselink 2000). Hydrological droughts characterized by the reduction in wetland storage, lowering of groundwater levels and decrease in flow discharge may occur over 1 year or over several years, and often affect large areas. The results of previous study showed that water quality in Shadegan wetland has been diminished, probably due to decreasing run off and increasing pollution in Shadegan wetland (Sabzalizadeh and Amirineia 2003). This study attempts to determine the water quality conditions and eutrophic status during wet and dry years in Shadegan wetland, where it is listed by the Ramsar Convention.

Materials and methods

Study area

Shadegan wetland is the largest wetland in southwestern Iran, and the 34th largest of 1,201 designated Ramsar Convention (23 June 1975) in the world. It is the largest coastal wetland in the Persian Gulf (30° 30′N 048° 30′). It is an extensive delta on the border with Iraq, forming part of the largest lowland in Iran, and composed of the floodplains of major rivers draining 11.5 million ha. Shadegan wetland is supplied by fresh water from Jarrahi (90%) and Karun (10%) rivers, local rainfall, and by tidal influxes of sea water from the Persian Gulf. The wetland is bordered by salt flates, rice fields, date palms and human settlements. Shadegan wetland was placed on the Montreux Record in 1993 because of chemical pollution from the Iran–Iraq war. This wetland is altered by pollutants from upstream or local runoff. Autumn and winter rains in the Zagros Mountains cause extensive flooding throughout the delta, creating a vast complex of shallow lagoons with extensive sedge marshes. These dry out gradually during the long, hot summer, and the entire area may be completely dry by the end of the summer. The water level is higher following spring floods, but drains into the Gulf. Shadegan wetland located in arid and semi-arid region and some years encountered to low water. In spite of the vast and high potential, there are little previous scientific studies in Shadegan wetland (Fig. 1).

Samplings

Six stations were sampled at each year once during each season, between wet years and dry years, from 1994 to 2006. In each station, in situ temperature (°C), salinity and dissolved oxygen (mg/L) were measured with an YSI-85 multi-probe. Due to the lack of water column stratification in wetland, surface samples were collected with a data flow IV system (Madden and Day 1992). The sampled water was stored and refrigerated at 4°C for later laboratory analysis. All samples were collected between 08:00 and 12:00 h local time. Water quality analysis included ammonium (NH_4^+) using the phenol–hypochlorite method (Solórzano 1972), nitrite (NO_2^-) with the sulfanilamide method and reduction of nitrate (NO_3^-) to nitrite was using a cadmium–copper column. Phosphorus, as soluble reactive phosphorous (SRP), was measured with the mixture of reagents technique (Solórzano and Sharp 1980), and soluble reactive silica (SRSi) was measured using the blue-molybdenum method (Strickland and Parsons 1972). Sima and Tajrishy (2006) calculated wetland environmental water requirements monthly. The annual mean was calculated (230 MCM) by using of their study (Farrokhian 2008). In the present study, according to this calculated annual mean, the years with more and less than 230 MCM water volumes classified as wet and dry years, respectively.

Data analysis

With the objective of evaluating significant differences between wet and dry years for all water quality variables, data were analyzed using a one-way non-parametric ANOVA, with the years and seasons as main factors (Zar 1997). Several multivariate classification and ordination analytical tools were used to extract, interpret or reveal structures that otherwise would be overlooked or misinterpreted (Green and Vascotto 1978). As wetland often show environmental gradients, a classification analysis was performed to distinguish areas with similar water quality conditions, by placing the object in groups, first by the similarity measure, and then by the grouping algorithm

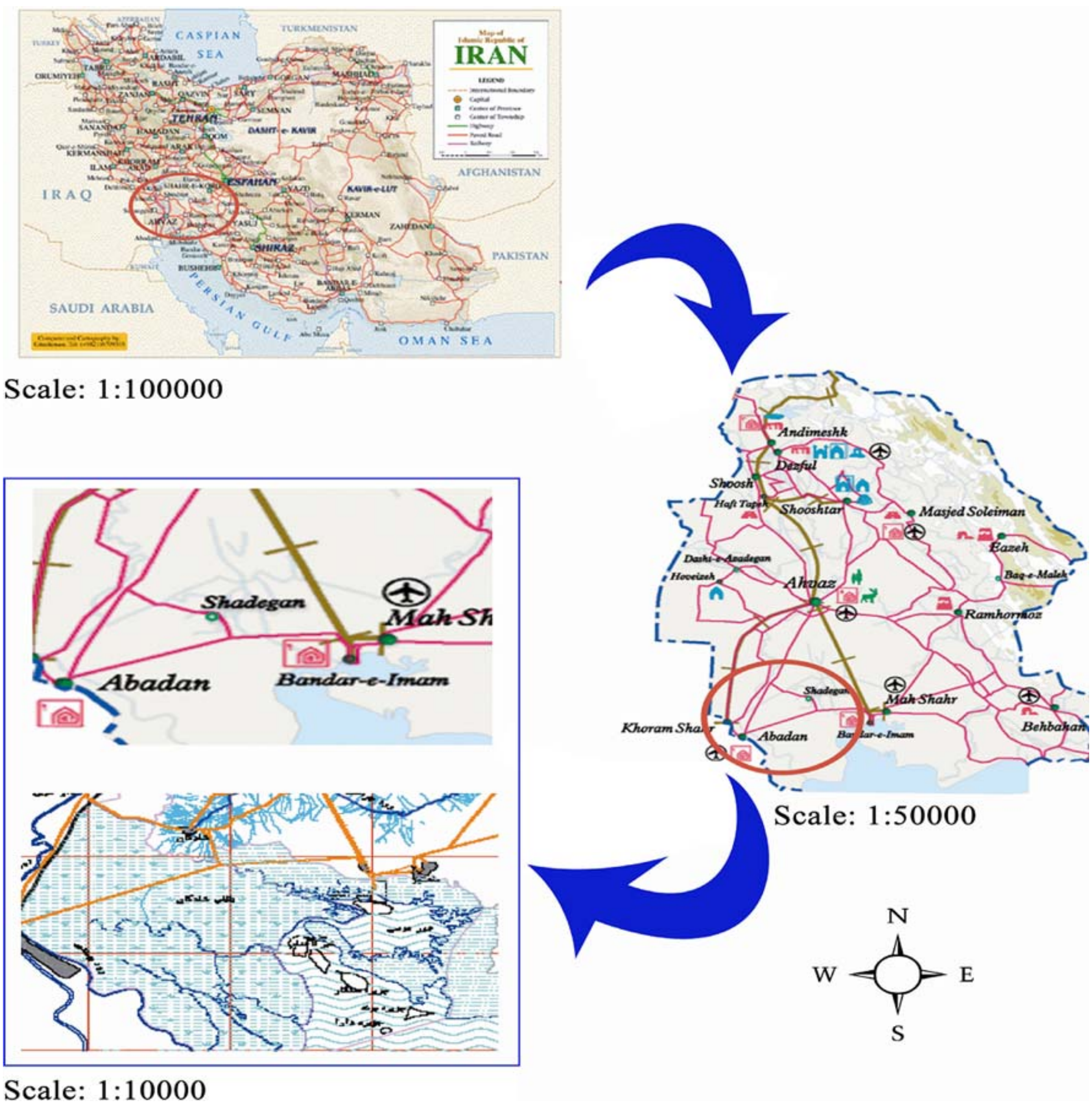


Fig. 1 Geographic location of the study area along with the Shadegan wetland

(Legendre and Legendre 1998). The similarity analysis was performed using the PRIMER software package developed at the Plymouth Marine Laboratory (Clarke and Warwick 1994). The variability and the differences between wet and dry years TSI were presented by Arc-view GIS modeling.

Trophic state index

Wetland is enriched with nutrients from natural and anthropogenic sources; therefore, to evaluate water quality in this context between wet years and dry years, it was necessary to use an indicator, the trophic state index (TSI), for each nutrient. Carlson's index is one of the more commonly used trophic indices, and is the trophic index used by the Unites States Environmental Protection Agency (EPA, 2007). The Carlson trophic state index is useful for assessing changes in trophic status over time. A wetland would be classified as oligotrophic with a TSI below 30, mesotrophic with a TSI between 40 and 50, and eutrophic with a TSI between 50 and 60. A TSI index above 70 characterizes hypereutrophic lakes (Carlson and Simpson 1996) usually classified as being in one of three possible classes: oligotrophic, mesotrophic or eutrophic. According to the special conditions of the site, the droughts and increasing nutrients discharges would cause undesirable results. Therefore, it was concluded to apply the TSI to study the trophic state more carefully in the Shadegan region.

The index is relatively simple to calculate and to use:

$$\text{TSI (TP)} = 14.42\ \ln(\text{TP}) + 4.15$$

where

TSI (TP) = Carlson trophic state index (total phosphorus)
ln(TP) = natural logarithm (total phosphorus)

Kratzer and Brezonic (1981) used data from the National Eutrophication Survey on Florida lakes. This index is calculated using the formula:

$$\text{TSI (TN)} = 54.45 + 14.43\ \ln(\text{TN})$$

(Nitrogen values must be in units of mg/L) where

TSI (TN) = Kratzer and Brezonic trophic state index (total nitrogen)
ln(TN) = natural logarithm (total nitrogen)

Results

Spatial and temporal variation of water quality conditions

The average values of water quality characteristics in wet and dry years are presented in Table 1. The variance analysis showed significant differences ($p < 0.05$) between wet years and dry years and among the different seasons. Water temperature behavior was related to the seasonal pattern. In wet years, the highest mean temperature was 29.1°C during the summer season (station 5), while the lowest (15.9°C) was during the winter season (station 6). In dry years, the highest mean temperature occurred during the summer season (31.7°C, station 6), and the lowest during winter (13.3°C, station 2). The ANOVA showed significant differences ($p < 0.05$) between winter and autumn seasons, in wet and dry years. The highest mean salinity in wet years occurred during the spring season (12.5, station 3), and the lowest during the winter season (1.2, station 4) in dry years, the highest mean value in dry years occurred during the summer season (30, station 3), and the lowest during the winter season (1.3, station 6). The ANOVA showed significant differences ($p < 0.05$) between summer season in wet years and dry years. Dissolved oxygen showed a slight state of hypoxia (<2 mg/L) in station 5 (dry years); however, the mean values (Table 1) indicate general healthy conditions of the water column. Both wet and dry years showed similar season patterns with the highest average during winter season (>6.5 mg/L) while the lowest was registered during dry season (<3 mg/L). The ANOVA showed significant differences ($p < 0.05$) between summer and autumn season in wet and dry years (Table 1). Annual mean NO_2^- was greater in wet years than in dry years. During wet years, the highest NO_2^- concentrations was registered during the winter season (0.14 mg/L, station 5), and the lowest during the spring season (0.003 mg/L, station 2). In dry years, the highest mean value was registered during the winter season (0.093 mg/L, station 2), and the lowest during the summer season (0.0015 mg/L, station 2). The ANOVA showed significant differences ($p < 0.05$) between summer season

Table 1 Average values of water quality variables calculated annual and seasonally in wet and dry years in Shadegan wetland

Season	Year	Temperature (°C)	Salinity (ppt)	DO (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	NH_4^+ (mg/L)	SRP (mg/L)	SRSi (mg/L)
Annual	Wet years	22.5	4.7	5.7	0.030	5.17	1.32	0.02	1.99
	Dry years	21.6	8.1	5.4	0.020	3.68	1.23	0.08	1.54
	SD/years							*	
Spring	Wet years	24.7	6.5	6.6	0.010	4.46	1.03	0.01	1.85
	Dry years	26.1	7.9	7.5	0.016	4.03	1.56	0.07	1.72
	SD/years								
Summer	Wet years	27.5	5.7	5.5	0.023	4.23	0.94	0.02	1.32
	Dry years	28.5	16.9	3.5	0.004	1.23	0.49	0.11	0.43
	SD/years		*	*	*	*		*	*
Autumn	Wet years	19.9	3.1	4.1	0.028	6.80	2.25	0.03	1.29
	Dry years	14.2	4.0	4.1	0.021	6.66	2.05	0.06	1.61
	SD/years	*		*					
Winter	Wet years	17.7	3.3	6.5	0.058	5.18	1.06	0.01	3.49
	Dry years	17.7	3.5	6.5	0.040	2.81	0.84	0.08	2.40
	SD/years	*						*	

* Significant differences, SD ($p < 0.05$, one-way ANOVA)

in wet and dry years. The annual mean NO_3^- concentrations were similar in wet years and dry years (Table 1), and showed the same temporal pattern with high mean concentration during autumn (>6.5 mg/L), and the lowest during the summer season (4.2 mg/L wet years, 1.3 mg/L dry years). The ANOVA showed significant differences ($p < 0.05$), between summer season in wet and dry years (Table 1). The annual mean NH_4^+ concentrations were similar in wet years and dry years (Table 1), and showed the same temporal pattern with high mean concentration during autumn (>2 mg/L), and the lowest during the summer season (0.94 mg/L wet years, 0.43 mg/L dry years).The ANOVA showed no significant differences ($p > 0.05$) neither annually nor seasonally. In wet years, the highest mean annual SRP occurred during the autumn season (0.16 mg/L, station 6), while the lowest was observed during the spring season (0.004 mg/L, stations 2, 3 and 6). In dry years, the highest mean annual SRP occurred during the summer season (0.4 mg/L, station 4), while the lowest was observed during the spring season (0.0205 mg/L, station 2). The ANOVA showed significant differences ($p < 0.05$) annually, during winter and summer. The annual mean concentration of SRSi was different between years (Table 1); however, there were similar seasonal patterns of high values during winter season (3.5 mg/L wet years, 2.4 mg/L dry years) and lower in the summer season (1.3 mg/L wet years, 0.4 mg/L dry years). The ANOVA showed significant differences ($p < 0.05$) between summer seasons in wet and dry years. During wet years, concentrations of NO_3^- and SRSi increased, while in dry years, water temperature, salinity and SRP increased (Figs. 2, 3).

Trophic state index

The trophic state index regarding TP showed different behavior in wet and dry years. In wet years, stations 1, 2 and 5 were oligotrophic while the 3 and 4 were mesotrophic and in dry years, wetland was eutrophic. For TN, the TSI in wet years, wetland was eutrophic and in dry years, stations 1, 3 and 6 were mesotrophic while stations 2, 4 and 5 were eutrophic (Figs. 4, 5, 6, 7).

Influence of nutrients on each other

Correlation matrices enabled the identification of relationships between nutrients. Therefore, correlation matrices were calculated for influence of nutrients on each other. Based on the correlation matrix obtained for nutrients (Table 2), in wet years, NO_3^- showed positive and little association with (NH_4^+), SRP and SRSi. However, NO_3^- showed negative and weak association with NO_2^-. NO_2^- showed positive and weak association with SRSi, but it showed the negative and little association with other variables. In dry years, NO_3^- had little and negative correlation with NO_2^-, SRP and SRSi, while NO_3^- had little and positive correlation with NH_4^+. In the years of drought, NO_2^- showed negative and moderate association with NH_4^+, so that it had negative and little correlation with SRSi and positive and little correlation with SRP. In the aquatic ecosystem, the major forms of nitrogen which were available to bacteria and plants were nitrate and ammonium (Goldman and Horne 1983). Denitrification ($NO_3^- \rightarrow NO_2^- \rightarrow N_2$) and nitrification ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$) repeatedly can be occurred and increasing of NO_3^- coincided with decreasing NH_4^+ or NO_2^- and vice versa.

In a study performed in Australia by Liaghati et al. (2003), the following criteria were obtained as; 0.60–1.00 = strong correlation; 0.50–0.59 = moderate; 0.40–0.49 = weak; 0.00–0.39 = little or no association.

The cluster analysis is an exploratory data analysis tool for solving classification problems. According to the water quality variables, six stations were classified using the cluster analysis (Figs. 8, 9). In the wet years, stations 1 and 2 were close to each other had the most similarity and station 3 had similar quality with them in the less degree. Also in wet and dry years, stations 4 and 5 had the most similarities with each others in the water quality. In dry years, stations 1 and 6 and also stations 2 and 3 had high similarity with each other in the water quality.

Discussion and conclusion

Wetland water quality fluctuations are due to different factors such as water temperature, sunlight intensity, evaporation rate and rainfall patterns. Shadegan wetland is also vulnerable to eutrophication due to variations in water quality over different years. The differences observed in water quality between wet and dry years indicate that drought and agricultural activities and perhaps physical processes, such as water residence time, are key factors that play an important role in promoting changes in the trophic status. Agricultural waste is one of the sources of nitrate, ammonium and SRP and thus plays an important role in the water quality of wetland. Nitrate and silicate showed peaks in wet years in winter and autumn seasons. High ammonium and nitrate showed that agricultural waste was the main source of nutrients to the system. Spatially, the gradients observed in wetland are related to the balance of water volume and the physical and chemical characteristics of the water inputs. Biogeochemical processes such as productivity, organic matter decomposition and nitrification/denitrification in specific locations of system, are related to water residence time, and affecting water quality. The changes in water quality of wet and dry years were

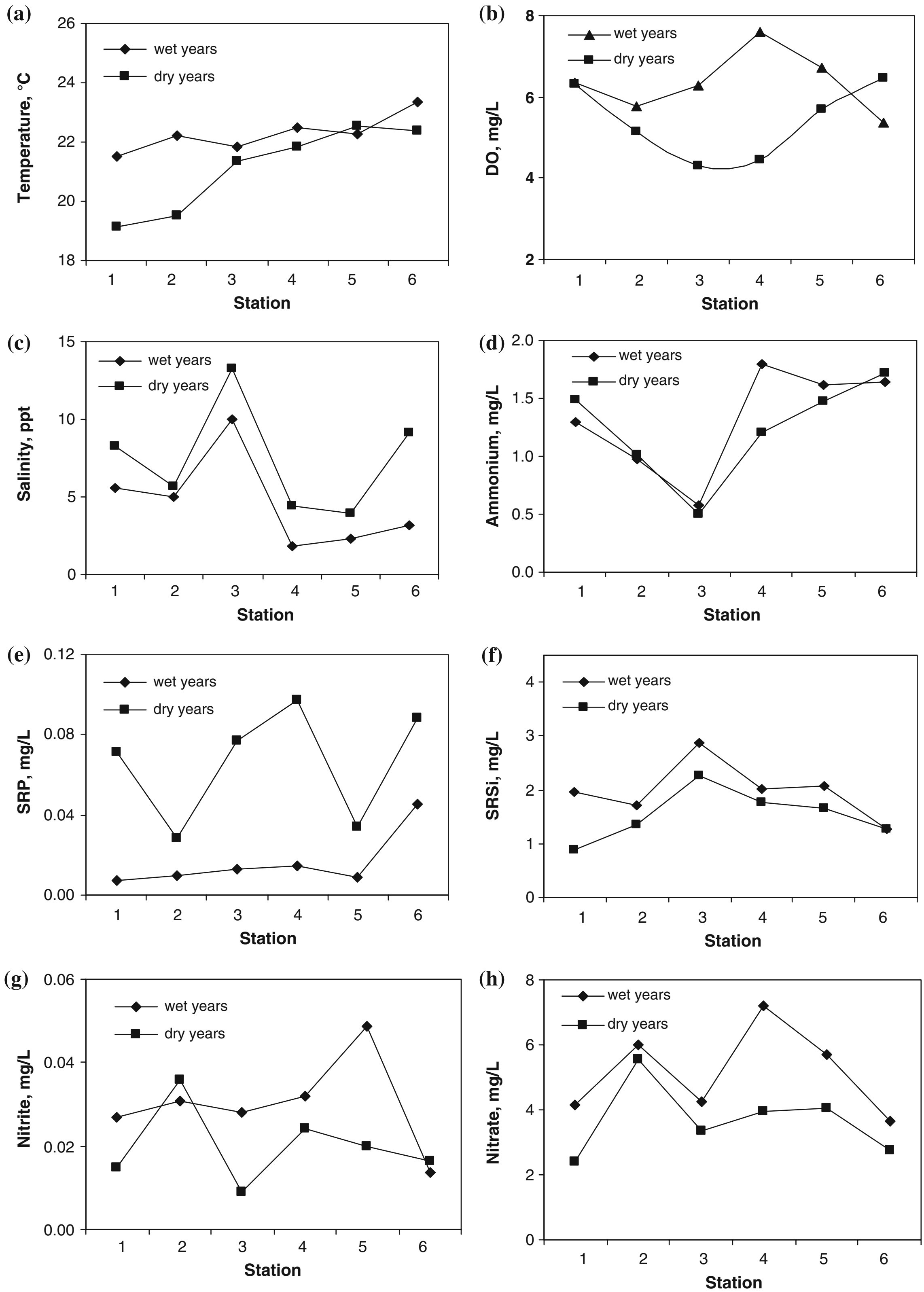


Fig. 2 Spatial variation of mean concentration of temperature (**a**), dissolved oxygen (**b**), salinity (**c**), ammonium (**d**), SRP (**e**), SRSi (**f**), nitrite (**g**) and nitrate (**h**) in wet and dry years (Shadegan wetland)

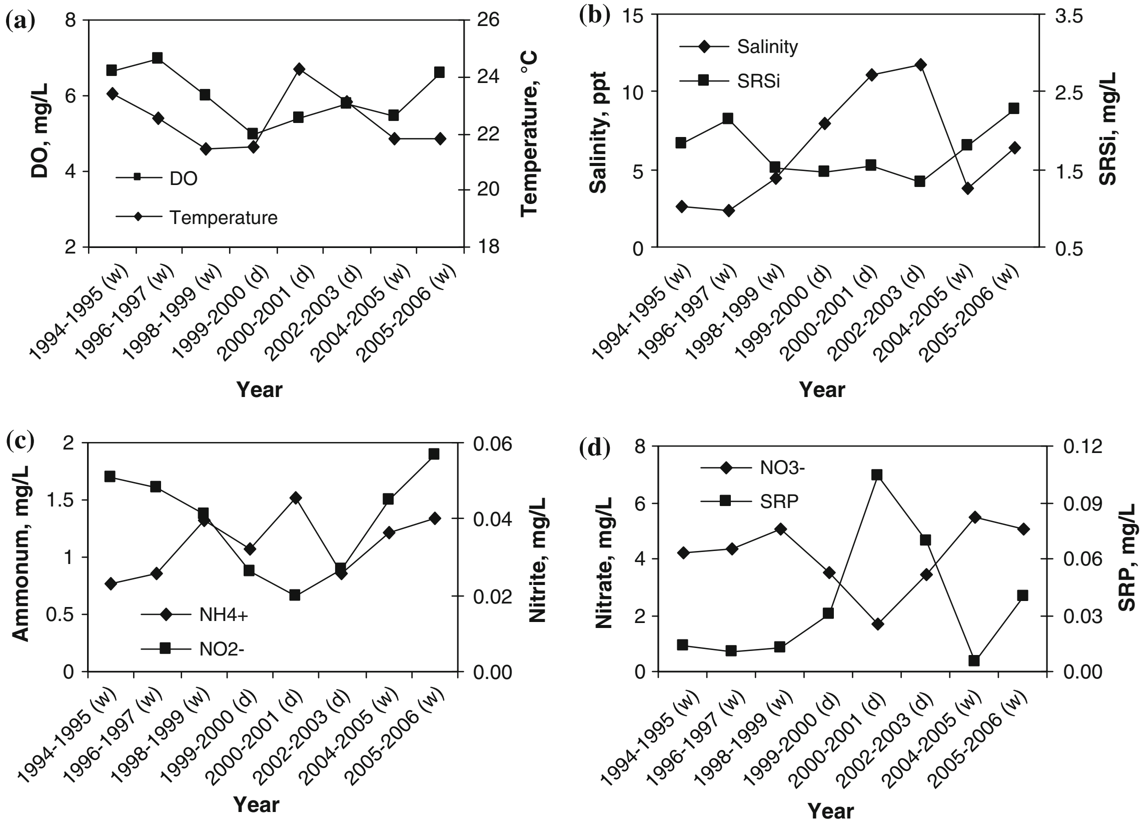
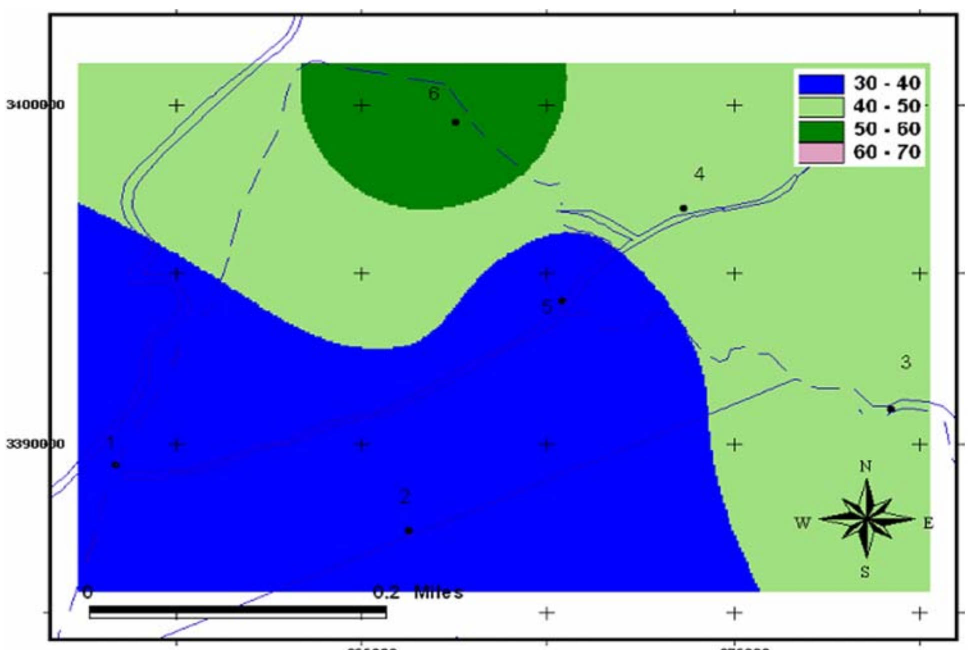


Fig. 3 Annual variation of mean concentration of DO and temperature (**a**), salinity and SRSi (**b**), ammonium and nitrite (**c**), nitrate and SRP (**d**) in Shadegan wetland. *w* Wet, *d* dry

Fig. 4 Trophic state index (TP) in wet years



related to nutrient inputs such as phosphorus especially orthophosphate ions and nitrate. In Shadegan wetland, the high nitrite and silicate concentrations during the wet years could be related to the polluted water inputs from the agricultural, industrial and municipal wastewaters, while in dry years, high temperature, salinity and SRP could be

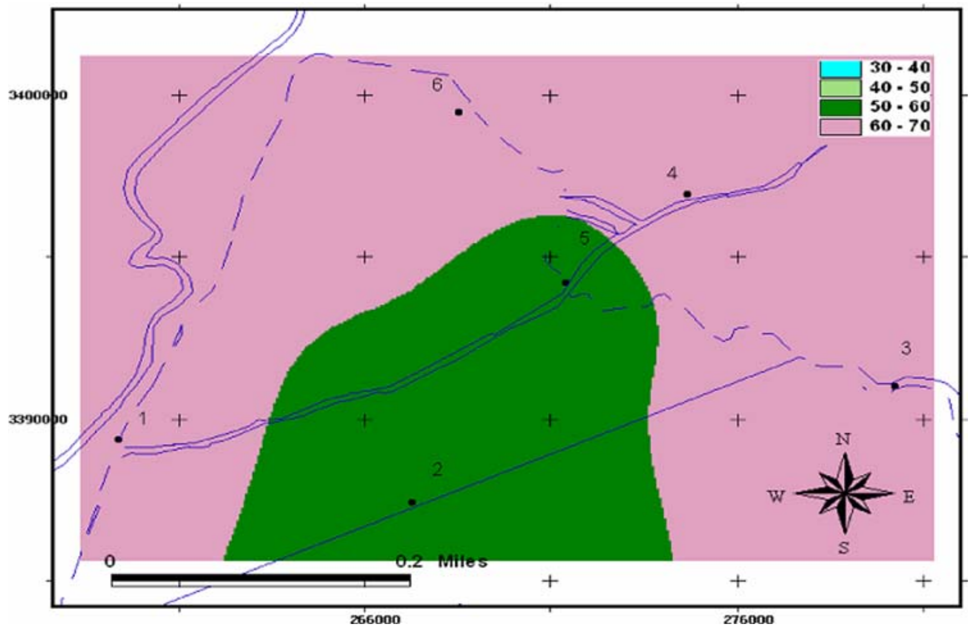


Fig. 5 Trophic state index (TP) in dry years

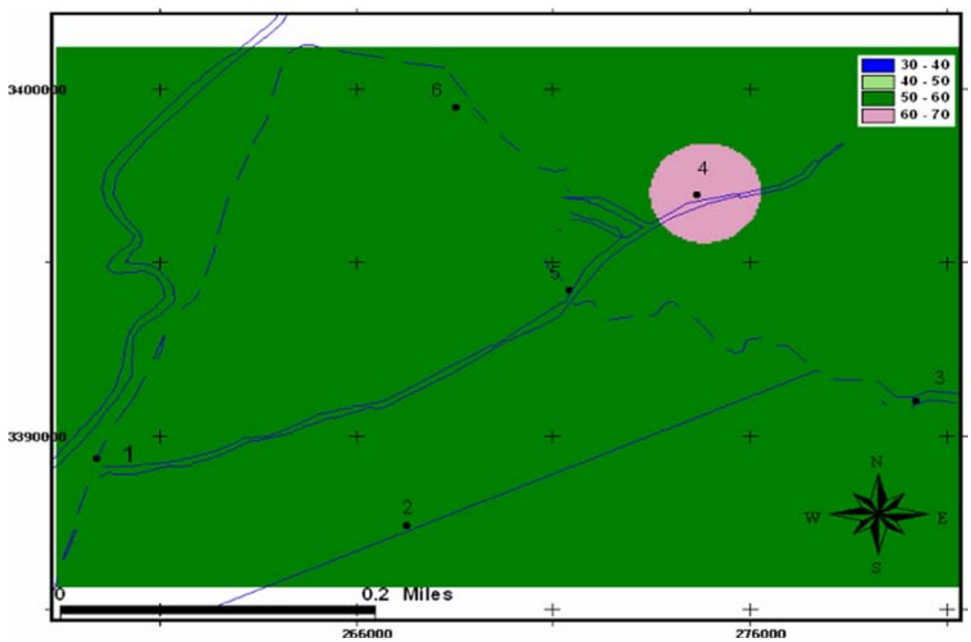


Fig. 6 Trophic state index (TN) in wet years

related to low rainfall, high evaporation, water residence time, organic matter decomposition and water inputs polluted through human activities. The oscillation in water discharge had vital effect on the physico-chemical properties of the Shadegan wetland (Farrokhian et al. 1997). In spite of the spatial and temporal variability observed in the water quality of wet and dry years, it was possible to determine similarities and differences in the water's physical and chemical characteristics among sampling stations that made wetland zoning possible. Wetland was divided into three areas that included similar stations; in wet years, stations 1, 2 and 3 located in the south part of the study area close to each other had similar water quality. Also, in wet and dry years, stations 4 and 5 which were under the influence of Jarrahi River discharge had the most similarities with each others; these stations were located in the north part of the study area. In dry years; stations 1 and 6 were close to each other and affected by the water quality changes from Karun River and for the waste water of sugarcane development plants had the high similarities. The stations 2 and 3 in the years of drought, which were impressed by the Persian Gulf, had high similarity in the

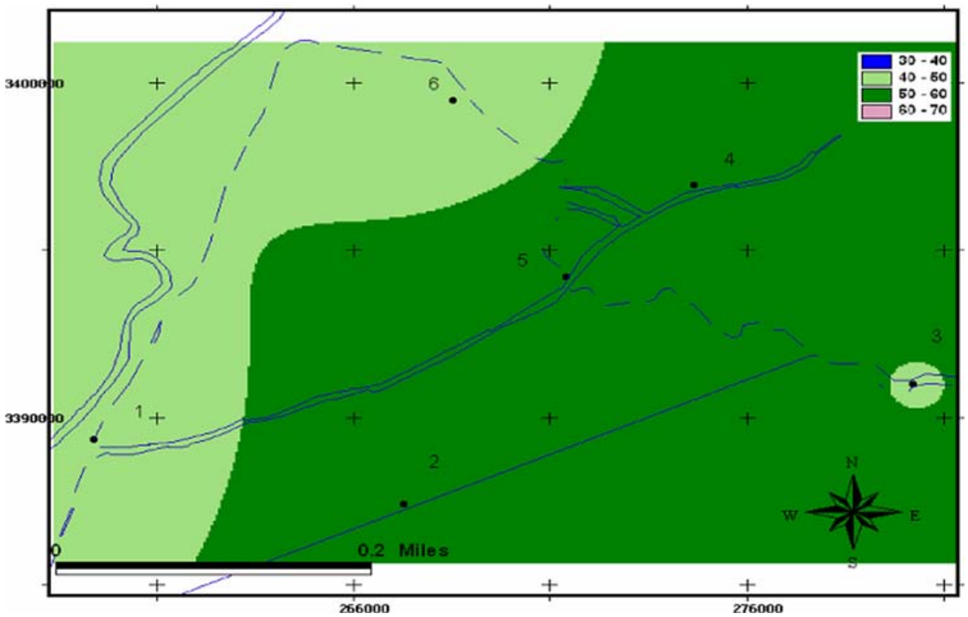


Fig. 7 Trophic state index (TN) in dry years

Table 2 Correlation matrix for nutrients in wet and dry years in Shadegan wetland

Variable	Year	NO_3^-	NO_2^-	NH_4^+	SRP	SRSi
NO_3^-	Wet years	1				
	Dry years	1				
NO_2^-	Wet years	−0.44	1			
	Dry years	−0.08	1			
NH_4^+	Wet years	0.26	−0.08	1		
	Dry years	0.14	−0.5	1		
SRP	Wet years	0.044	−0.05	0.04	1	
	Dry years	−0.026	0.22	−0.1	1	
SRSi	Wet years	0.3	0.43	0	0	1
	Dry years	−0.07	−0.08	0	0.25	1

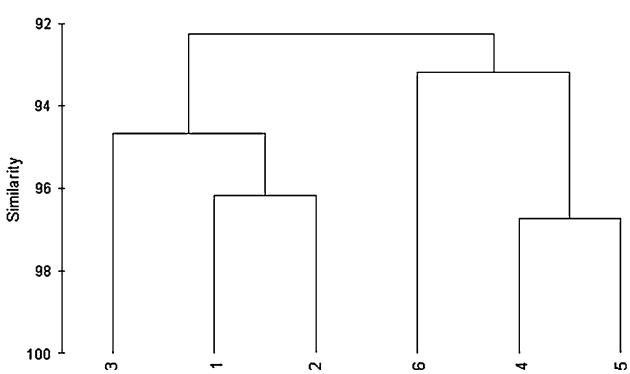


Fig. 8 Classification analysis (clusters) according to water quality variables in wet years

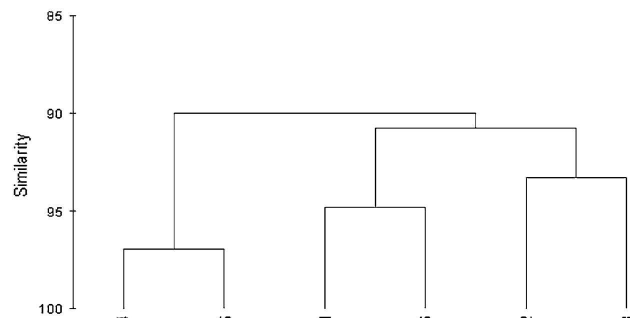


Fig. 9 Classification analysis (clusters) according to water quality variables in dry years

water quality. Water quality of stations in each area can vary seasonally and annually as a result of hydrological variability. This behavior of increasing and decreasing the size of these areas is a basic characteristic for estimating the conservation status of these types of ecosystems and could be useful as a vulnerability indicator. The major findings in this study, with respect to TN concentrations indicated that wetland in wet years showed an eutrophic behavior, while in dry years was mesotrophic and eutrophic. Regarding SRP, wetland in wet years was divided to three areas that included oligotrophic, mesotrophic and eutrophic while in dry years was only eutrophic. Increasing nutrient loadings and the higher water residence time in dry years promote these differences, driving wetland to long-term eutrophic conditions.

According to the recent ecological observations in the Shadegan wetland, descending trend in biotic condition, especially in high-value endemic fish species have been found from 1994 to 2006. In dry years, due to drought condition and nutrient enrichment, in spite of increasing in number of phytoplankton, phytobenthic and macrobenthic animals, species composition were changed and number of dominant fish species was decreased while tolerant species were increased. Therefore, management strategies should be designed to restore wetland's water quality and biological communities that have been damaged by anthropogenic pressures. In order to understand the processes related to water quality and eutrophication trends in Shadegan wetland, a methodological approach has been followed in this study, which gives a base for developing an integrated approach for the management of Shadegan wetland with high seasonal and spatial variability.

Acknowledgments The authors would like to thank Mrs. Sabsalizade and Dr. Dehghan Medise for their assistances throughout the analysis; Dr. Hemmadi for the analysis of hydrological data; Mrs. Akbari for her assistance in GIS modeling preparation and finally Graduate School of the Environment and Energy, Science and Research Branch, IAU for its valuable support during this research study.

References

Boynton WR, Kemp WM, Keefe CW (1982) A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production. In: Kennedy VS (ed) Estuarine comparisons. Academic Press, New York, pp 69–90

Brookes PC, Heckrath G, de Smet J, Hafman G, Vanderdeelen J (1997) Losses of phosphorus in drainage water. In: Tunney H, Caton OT, Brooks PC, Johanston AE (eds) P loss from soil and water. CAB International, Wallingford, pp 253–271

Carlson RE, Simpson J (1996) A coordinator's guide to volunteer lake monitoring methods. North American Lake Management Society. pp. 96

Casey H, Clarke RT (1979) Statistical analysis of the nitrate concentrations from the River Frome (Dorset) for the period 1965–1976. Freshw Biol 9:91–97

Clarke KR, Warwick RM (1994) Change in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Laboratory, Plymouth, p 144

Environment Agency (1998) Environmental issues series: aquatic eutrophication in England and Wales—a proposed management strategy. Environment Agency, Bristol

Farrokhian F (2008) Providing a model of water quality management for Shadegan Wetland. PhD thesis. Islamic Azad University, Science and Research Branch, Tehran, Iran

Farrokhian F, Savari A, Imandel K, Abbaspour M, Riazi B (1997) Chemical quality of Shadegan wetland. J Environ Stud 23(19): 13–24. http://dbase.irandoc.ac.ir

Fetter CW (1994) Applied hydrogeology. Prentice-Hall, Englewood Cliffs

Fourqurean JW, Jones RD, Zieman JC (1993) Processes influencing water column nutrient characteristics and phosphorus limitation of phytoplankton biomass in Florida Bay, FL, USA: inferences from spatial distributions, Estuarine, Coast. Shelf Sci 36:295–314

Goldman CR, Horne AJ (1983) Limnology. McGraw-Hill, New York, p 464

Green RV, Vascotto GL (1978) A method for analysis of environmental factors controlling patterns of species composition in aquatic communities. Water Res 12:583–590

Heathwaite AL, Johnes PJ, Peters NE (1996) Trends in nutrients. Hydrol Proc 10:263–293

Kemp WM, Boynton WR (1992) Benthic-pelagic interactions: nutrients and oxygen dynamics. In: Smith DE, Leffler M, Mackiernan G (eds) Oxygen dynamics in the Chesapeake Bay: a synthesis of research. Maryland Sea Grant College, College Park, MD. pp 149–221

Kratzer CR, Brezonic PL (1981) A Carlson-type trophic state index for nitrogen in Florida lakes. Water Res Bull 17:713–715

Legendre P, Legendre L (1998) Numerical ecology, 2nd edn. Elsevier, Amsterdam, p 853

Liaghati T, Preda M, Cox M (2003) Heavy metal distribution and controlling factors within coastal plain sediments, Bells Creek catchment, southeast Queensland, Australia. Environ Int 29:935–948

Madden C, Day J (1992) An instrument system for high speed mapping of chlorophyll and physico-chemical parameters. Estuaries 15(3):421–427

Malone TC (1992) Effects of water column processes on dissolved oxygen, nutrients, phytoplankton, and zooplankton. In: Smith DE, Leffler M, Mackiernan A (eds) Oxygen dynamics in the Chesapeake Bay: a synthesis of research. Maryland Sea Grant College, College Park, MD. pp 61–112

Malone TC, Kemp WM, Ducklow HW, Boynton WR, Tuttle JH, Jonas RB (1986) Lateral variations in the production and fate of phytoplankton in a partially stratified estuary. Mar Ecol Prog Ser 32:149–160

McCosker RO (1998) Methods addressing the flow requirement of wetland, riparian and floodplain vegetation. In: Arthington AH, Zalucki JM (eds) Comparative evaluation of environmental flow assessment techniques: review of methods, pp 47–65

Mitsch WJ, Gosselink JG (2000) Wetlands, 3rd edn. Wiley, New York

Nixon SM, Pilson MEQ (1983) Nitrogen in estuaries and coastal marine ecosystems. In: Carpenter EJ, Capone DG (eds) Nitrogen in the marine environment. Academic Press, New York, pp 411–458

Nouri J, Danekar A, Sharifipour R (2008) Evaluation of ecotourism potential in the northern coastline of the Persian Gulf. Environ Geo 55:681–686

Patrico J, Ulannowicz R, Pardal MA, Marques JC (2004) Ascendancy as an ecological indicator: a case study of estuarine pulse eutrophication. Estuar Coast Shelf S 60:23–35

Richardson K, Jorgensen BB (1996) Eutrophication: definition, history, effects. Coast Estuar Stud 52:1–20

Sabzalizadeh S, Amirineia S (2003) Study on some physical and chemical characteristic of Shadegan marsh. Iranian J Fish Sci 12: 47–53. http://www.braincoad.com/Introduction/tigrisriverbasin.htm

Sima S, Tajrishy M (2006) Water allocation for wetland environmental water requirements: the case of Shadegan Wetland, Jarahi Catchment, Iran. ASCE, USA

Smith RMS, Evans DJ, Wheater HS (2005) Evaluation of two hybrid metric conceptual models for simulating phosphorus transfer from agricultural land in the river enborne, a lowland UK catchment. J Hydrol 304:366–380

Solórzano L (1972) Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol Oceanol 14(5):799–801

Solórzano L, Sharp JH (1980) Determination of total dissolved phosphorus and particulate phosphorus in natural waters. Limnol Oceanol 25(4):754–758

Strickland JDH, Parsons TR (1972) A practical handbook of seawater analysis. Fish Res Board Can Bull 167:107–112

United States Environmental Protection Agency (2007) Carlson's trophic state index. Aquatic biodiversity. http://www.epa.gov/bioindicators/aquatic/carlson.html

Verity PG (1987) Factors driving changes in the pelagic trophic structure of estuaries with implications for the Chesapeake Bay. In: Lynch MP, Krome EC (eds) Perspectives on the Chesapeake Bay: advances in estuarine science. Publ. No. 127. Chesapeake Bay Research Consortium, Gloucester Point, VA, pp 35–56

Xu LF, Zhao ZY, Zhan W, Zhao SS, Dawson RW, Tao S (2005) An ecosystem health index methodology (EHIM) for lake ecosystem health assessment. Ecol Model 188:327–339

Zar JH (1997) Biostatistical analysis. Prentice-Hall, Englewood Cliffs