

Spatial-Temporal Modeling of Qualitative Parameters and Land Use Status in Anzali International Wetland Using GIS Technique

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ABSTRACT

Aims Monitoring and zoning of water resources are one of the important principles in environmental planning and management. Therefore, considering the issues raised and the importance of Anzali wetland monitoring, the assessment of effective factors in zoning (GIS) along with TSI p, TSI n, and NSFQI indices and the study of land use effects justifies the necessity of this study.

Materials & Methods In this study, physicochemical parameters of water (phosphate, total nitrogen and total dissolved solids, dissolved oxygen, acidity, electrical conductivity, and BOD5 properties) and water quality indicators (TSI p, TSI n, and NSFQI) were modeled using GIS interpolation functions. To determine the effect of land use, the partial and Pearson correlations coefficient were used.

Findings According to zonation maps of annual mean values of qualitative parameters, the lowest dissolved oxygen content was in the eastern part of the wetland, the highest electrical conductivity, as well as BOD5 observed in the center of the north, in the east and north of the wetland, respectively. A survey of the total phosphate zonation map revealed the increasing trend from west to east of the wetland. The partial correlation analysis showed that the electrical conductivity, acidity and total dissolved solids were directly affected by inputs and effluent from the land use ($p < 0.05$; $p < 0.01$).

Conclusion Based on the coefficient of determination, about 70% of the pollution derived from the use of wetlands surrounding and entering wastewater from agricultural fields, industrial and urban.

Keywords Anzali Wetland; Partial Correlation; Buffer; Water Quality Index; Interpolation

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Introduction

Population growth, development of cities, and human activities, including over-exploitation of natural resources, the land surface has undergone significant changes over the last few decades, leading to land use changes that in turn affects the quality of surface water [1]. Having healthy water resources is fundamental for conserving environment and country development. Surface waters are more susceptible to contamination than other waters [2]. Today, The Geographic information system (GIS) is considered as a powerful tool for monitoring natural resources, especially water resources. The GIS technique makes it possible to monitor water resources more easily and cost-effective [3]. GIS provides appropriate opportunities for full analysis of spatial data, and effective applications for survey of land cover/use and their changes in environmental, hydrology, agriculture, forestry, and geography and urban management [4, 5]. Today, most natural waters are exposed to contamination and got polluted. Knowledge of the quality status of surface and underground waters with the use of water quality indicators such as National Sanitation Foundation Water Quality Index (NSF) and Trophic State Index (TSI) allows using obtained information along with the management solutions that would minimize natural resource damage. Using GIS and remote sensing technology to control and monitor the quality of surface water and underground water is very cost effective [6, 7].

By qualitatively zoning, the process of surface water quality changes would be determined at any time, place, and condition. It is possible to save time and money by removing stations with the same qualitative status and when the qualitative conditions are varied or critical, new stations could be established [8]. Geostatistical methods are used to investigate the trend of changes and zoning using the Geographic Information System (GIS) [9]. GIS and geostatistical are highly capable of surveying the spatial distribution and zoning of pollutants and assessing the origin and source of surface water pollution. Geostatistical methods have a significant performance in estimating uncertain points. The use of the estimator can be a decision support system and as a circle of environmental impact assessment cycle and effectively help decision makers [10]. Anzali International Wetland life during the last few decades, due to

the increase in the flow of agricultural, domestic and industrial waste decline in Caspian Sea surface has been endangered by the growth and spread of plants such as reed and *Azolla* SP. The Anzali Wetland is now on the Montreux blacklist of wetlands, according to that Iran is obliged to restore the wetland and prevent it from ecological changes [11]. So far, several studies have been done on modeling and zoning of aquatic ecosystems affected by land use and related statistical analyses. These include the studies of Arbuckle and Downing, Sliva and Williams, Tong and Chen, Woli *et al.*, Ren *et al.*, Hassler, Ahearn *et al.*, Newall and Walsh, Pijanowski *et al.*, Martin *et al.*, Liu *et al.*, Oladele and Abdulrafiu, and Samadi [12-24]. Therefore, considering the issues raised and the importance of Anzali wetland monitoring, the assessment of effective factors in zoning (GIS) along with TSI p, TSI n and NSFQI indices and the study of land use effects justifies the necessity of this study.

Materials and Methods

Study of area

Anzali wetland situated in the southern coast of Caspian Sea in Guilan province, Anzali located in 36°55' to 37°32' N and 48°45' to 49°42' E (Figure 1). An important feature of Anzali wetland is the presence of abundant macrophyte aquatic plants that has the largest wetland area. The maximum absolute temperature in July is 36.8°C and the minimum absolute temperature in February is -11.4°C and the average annual temperature is 16°C. The water temperature is between 2 and 11°C in the winter and is typically 2 degrees below the air temperature [25].

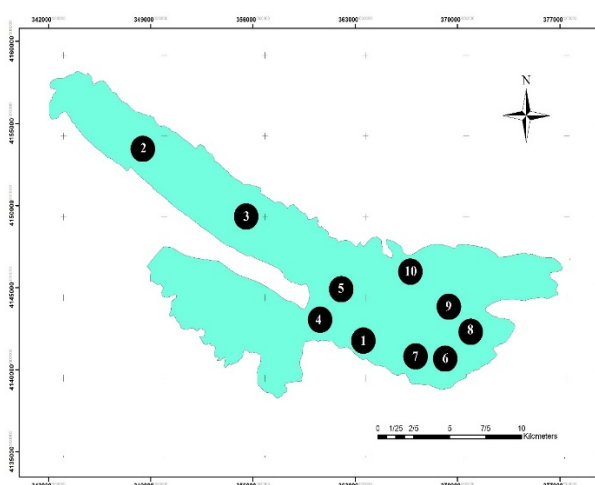


Figure 1) Position of the wetland and station in the map

Sampling for determining qualitative parameters (phosphate, total nitrogen, total dissolved solids, dissolved oxygen, acidity, electrical conductivity, and BOD₅) was done in order to design modeling, and zoning the studied indices throughout four seasons in 2014 at 10 stations. Table 1 and Figure 1 show the position of the stations. The analysis of water parameters was performed according to the APHA standard [26]. After sampling the parameters physicochemical and inserting them into the ArcGIS 10.2 software, the most suitable interpolation methods for each parameter used for spatial modeling of parameters and quality indices. The Pearson correlation was used to evaluate changes, impacts, and role of each parameter. In addition, the wetland status was zoned using the GIS environment based on TSI p, TSI n, and qualitative indexes of NSFQI. See trophy and water quality and trophy indicators for available resources [27, 28] to learn more.

Table 1) Geographical coordinate of the stations studied Anzali Wetland International

Station	X	Y
1 Hendkhaleh	49 ° 27' 14"	37 ° 23' 54"
2 Westen of Wetland (Abkenar)	49 ° 24' 20"	37 ° 26' 35"
3 Westen of Wetland (Mah-rooze)	49 ° 24' 35"	37 ° 26' 36"
4 Siadarvishan	49 ° 25' 29"	37 ° 26' 9"
5 Sorkhankal	49 ° 25' 42"	37 ° 23' 53"
6 Nokhaleh	49 ° 30' 1"	37 ° 24' 12"
7 Eastern of Wetland	49 ° 30' 15"	37 ° 25' 17"
8 Outlet of Eastern Wetland	49 ° 29' 26"	37 ° 25' 26"
9 Pirbazar	49 ° 30' 7"	37 ° 24' 11"
10 Under the bridge of Anzali Port	49 ° 27' 54"	37 ° 27' 48"

Figure 2 shows the land use map prepared in 2013 [29]. In order to investigate the effect of land use on the water quality of the wetland, 500 meters of buffers were collected from the point of pollutants and surrounding the wetland caused by land use (0-500 meters of buffer probability of the highest contamination, and the buffer of 2000-30000 probability of the least contamination). Initially, the Pearson correlation coefficient of annual quality index with buffers was used to determine the type and extent of the spatial time span of land use waste utilization on the pollution status of Anzali

wetland. Finally, the partial correlation coefficient was used to determine the effective parameters in this regard. All statistical analyzes and charts were made using SPSS 22 and Excell 2013 software, respectively.

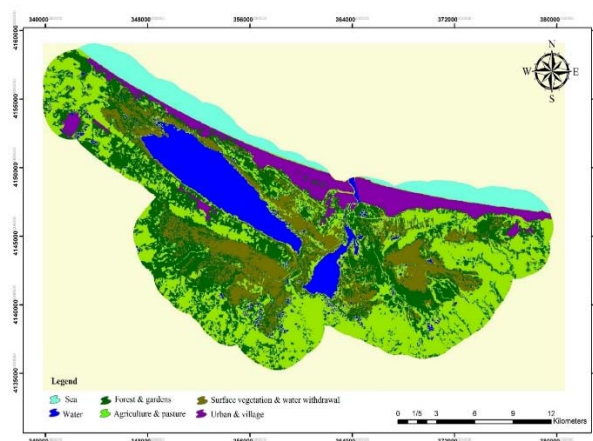


Figure 2) Land use map of Anzali Wetland in 2013 [29]

Findings

In order to evaluate the effectiveness of various deterministic and geostatistical methods, the most suitable method was selected. This is achieved by comparing Root Mean Square Error (RMSE) and Mean Biase Error (MBE) for each method. Validation results presented the most appropriate method for each parameter, and TSI p, TSI n, and NSFQI, along with the values of the statistics in Table 2.

Table 2) Validation Results of appropriate interpolation deterministic and geostatistical methods Study Parameters

Evaluation criteria Parameter	RMSE	MBE	The most appropriate method
TSIp	10.37	0.04	Ordinary Kriging
TSIn	2.06	0.004	Universal Kriging
NSFWQI	3.23	-0.044	Ordinary Kriging
Total phosphate (mg/L)	0.59	0.01	Universal Kriging
Total Nitrogen (mg/L)	1.07	0.039	IDW
Total Dissolved Solids (mg/L)	373.7	-0.011	Simple Kriging
Dissolved Oxygen (mg/L)	1.40	0.03	Simple Kriging
Acidity	2.48	0.01	Simple Kriging
Electrical conductivity (μ/cm)	591.67	0.009	IDW
BOD5 (mg/L)	35.7	-2.37	Simple Kriging

Raster maps Physical and chemical parameters of water, including phosphate and total nitrogen, total dissolved solids, and dissolved oxygen, acidity, electrical conductivity and Biochemical Oxygen Demand (BOD₅), TSI_p, TSI_n, and NSFQI indices based on the annual average of stations according to the appropriate methods is modeled in Figure 3.

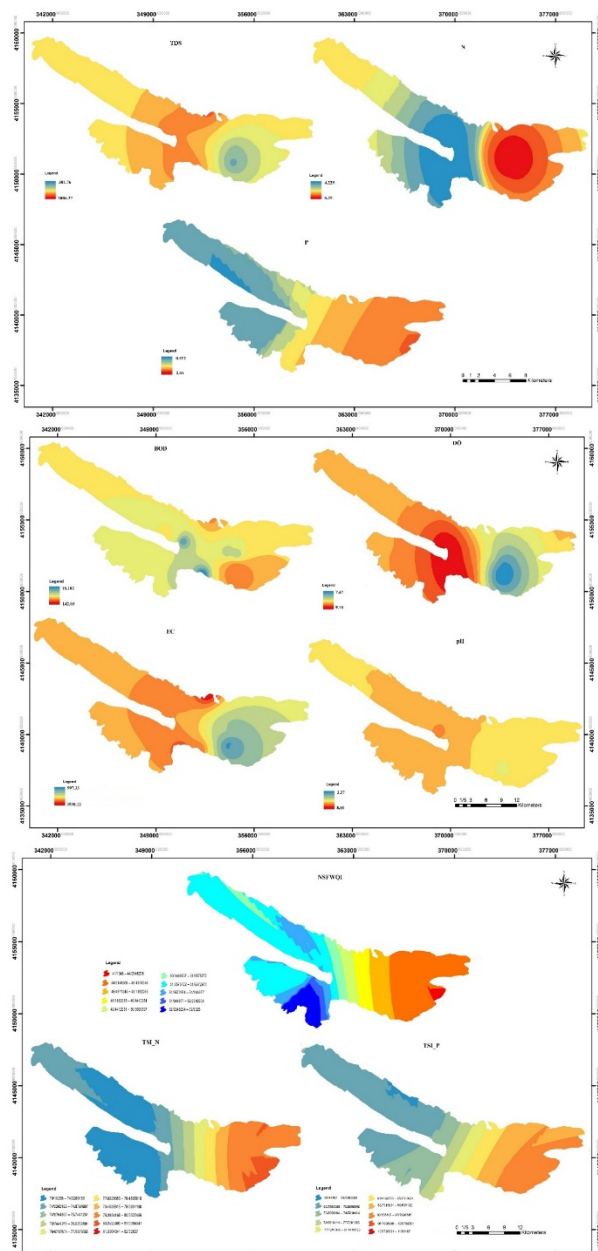


Figure 3) Zoning parameters and quality indices of Anzali wetland in 2014; **A)** N, phosphate, TDS; **B)** acidity, BOD₅, dissolved oxygen, electrical conductivity; **C)** quality indices

Table 3 summarizes the annual mean values of qualitative parameters. Also, in Diagram 1, the average annual values of the studied indices for each station are reported. For better

investigation, at first, the correlation between the different parameters of the studied water was calculated using Pearson correlation. The results were presented in Table 4. Then, in Table 5, Pearson correlation values are presented between the parameters and the studied indexes. The results indicate a significant difference in some of the parameters involved in water quality with different indices.

Table 3) Annual Physicochemical Parameters of Anzali International Wetland

Parameter	Value
Total phosphate (mg/L)	0.45±0.02
Total Nitrogen (mg/L)	5.18±0.23
Total Dissolved Solids (mg/L)	1470.39±195
Dissolved Oxygen (mg/L)	8.34±0.36
Acidity	8.11±0.07
Electrical Conductivity (μ/cm)	2298.3±352
BOD ₅ (mg/L)	45.16±4.25

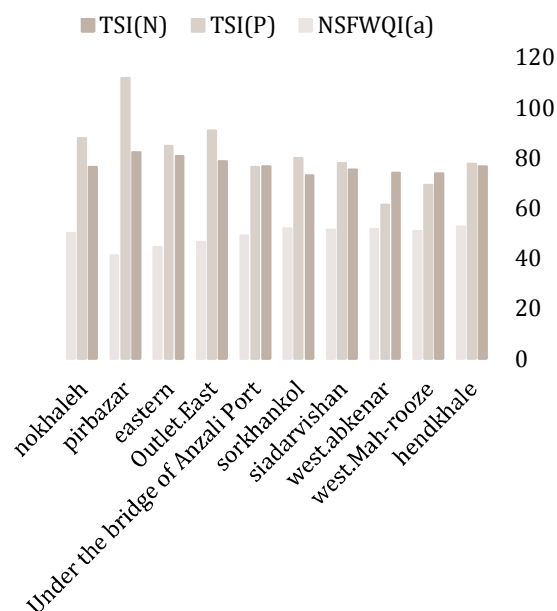


Diagram 1) Average annual values of quality and trophic indices at different stations

Table 4) Correlation coefficient between Water Quality Parameters

	EC	pH	TDS	DO	BOD ₅	TN	P
EC	1						
pH	0.460**	1					
TDS	0.9**	0.460**	1				
DO	-0.276	0.016	-0.275	1			
BOD ₅	-0.139	-0.089	-0.139	-0.277	1		
TN	0.261	0.244	0.261	-0.118	-0.137	1	
P	0.020	-0.046	0.020	-0.279	-0.205	0.301	1

*Correlation at the level of 0.05; ** Correlation at the level of 0.01.

Table 5) Pearson correlation coefficient of different parameters and NSFWQIa and TSI p and TSI n indices

	EC	pH	TDS	DO	BOD ₅	TN	P
NSFWQI_a	0.531**	-0.286	-0.53**	-0.012	0.112	0.016	0.165
TSI p	0.388*	-0.013	0.388*	0.032	-0.079	-0.047	-0.339
TSI n	0.483**	0.021	0.483**	-0.134	-0.056	-0.080	-0.002

*Correlation at the level of 0.05; ** Correlation at the level of 0.01.

Discussion

Modeling of quality parameters and indicators

According to the zoned maps, the annual mean values of the quality parameters (Figure 3- a, b), the lowest dissolved oxygen content was in the eastern part of the wetland, the highest electrical conductivity placed in the center to the north, the highest BOD₅ observed in the east and north of the wetland, and the lowest BOD₅ determined in the distance center to the south. Also, based on the total dissolved solids mapping, the boundary between the center and the southeast of the wetland is the lowest. The study of acidity map indicates that most wetland areas have high pH (alkaline). This trend extends further from the center to east. Based on the total nitrogen zonation map, both eastern and western parts of the wetland, respectively, were observed the highest and the lowest total nitrogen value in the center zone. Survey of the total phosphate zonation map revealed the increasing trend from west to east of the wetland. Electricity conductivity is more common in the vicinity of agricultural land [30]. Based on the zoned map (Figure 3a, b), an increase in dampness and agriculture and rice fields seen from east of the wetland towards the west, which is the reason of high electrical conductivity in the west of wetland. Also, the high correlation between total dissolved solids and electrical conductivity also confirms our data (Table 4). Investigation of zoning maps indicates that total dissolved solids in Anzali wetland have been increasing in recent years due to the continuous flow of urban and agricultural influents into the wetland and the growth of floating and immersed plants in the wetland. The results of high correlation with electrical conductivity and quality indices indicate an increase in a load of organic solvents from contaminating sources in recent years (Tables 4 and 5).

The relative increase in acidity in this study might be due to the entry of urban wastewater and agriculture into the wetland. Agricultural pesticides and fertilizers, like the geological

status of the watershed, are one of the sources of pH changes [31, 32]. According to Newall and Walsh studies in 2005, increasing urban and agricultural use can be one of the reasons for the relative increase in pH over the past years [19]. The correlation results show the highest correlation of pH with dissolved solids and electrical conductivity (Table 4). According to the zoning maps, the highest BOD₅ is in the eastern part (Pirbazar), and then in the northern part of the wetland (Under the bridge of Anzali Port). Because the Zarjoob and Gohar Rood Rivers cross the city of Rasht and the entrance of all industrial, domestic and hospital wastewater to The Pirbazar River, it is one of the most polluted rivers in Gilan province. Although due to the large distance, it passes to some extent Self-purification is carried out, the volume of contamination is high [30]. The station of under the bridge of Anzali Port is a region in which all the waters entering the sea through wetland from this point. On the other hand, this part is very contaminated due to the traffic of motorized boats and the entrance of the city of Anzali. According to the modeling maps, phosphate and total nitrogen have increased in recent years, which indicates an excessive nutrient load of Anzali wetland. Considering the significant correlation between electrical conductivity and total dissolved solids with qualitative and trophic indices (levels of 0.01 and 0.05), it can be confirmed that the amount of organic matter in the wetland has increased (Table 5).

Modeling of TSI p and TSI n indicators also showed an incremental trend of indicators from the west to the east part of the wetland in one year (Figure 3c). In relation to the modeling of the NSFWQI index, since, based on the structure of this indicator, the closer to 100, the water is of better quality, so it is seen that the opposite of the trophic index, the distance from the eastern part of the wetland to the numerical value of this index, which means that the west of the wetland has a better water quality status. Meanwhile, it should be noted that this index has its own color

scheme, which is visible in Figure 3 (blue indicates good quality and red is poor water quality). According to Diagram 1 and the zoning map (Figure 3c), among the stations, respectively, the Pirbazar and the eastern wetland had the lowest NSFWQI index. The reason of this is the concentration of industrial activities in the Pirbazar watershed and the entry of the entire sewage system in Rasht and the agricultural wastewater in its area [33]. According to Diagram 1 and zoning map (Figure 3c), the average values of the trophic index in 2014, based on the concentration of phosphate and nitrogen concentration in most stations, indicate eutrophic conditions tend to hypertrophic within the wetland. Based on the average trophic index, the highest index value was estimated in terms of phosphate concentration in Pirbazar and Nokhaleh, and the lowest in the west (Abkenar) region. Also, in assessing the average trophic index in terms of nitrogen concentration, the highest value of the indicator was measured in the Pirbazar and the lowest was measured in Sorkhankal. Generally, this trend shows a strong development of the eutrophication process of the wetland during the studied years. Fifty-four percent of the catchment area of the wetland belongs to the forest and rangelands. As a result, the litter and humus of the forest floor are entering the wetland as the most important external source of surface runoff from the rain [34]. Also, household sewage, adjacent residential areas, food wastewater, and livestock farms that enter the wetland-related intestines without any treatment, have a high share in the aggravated Anzali wetland eutrophication trend [35].

According to the studies, the extension of the wetland, various applications in the area and the resulting organic and non-organic input into the wetland are the most important reasons for the intensification of the eutrophication process. In this regard, three major sources of nutrients include fertilizers used in the agricultural sector, household wastewater and animal waste [36]. According to Table 5, the correlation significance (at levels of 0.05 and 0.01) parameters such as total dissolved solids, electrical conductivity with qualitative and trophic indices, in addition to the relationship between these parameters, indicate the quality of the wetlands and their impact on Anzali wetland contamination. As shown in Table 5, the relationship of these parameters with the

NSFWQIa qualitative index is negative (parameter increase leads to a decrease in water quality and index) and, on the other hand, is positively correlated with trophic indices and can be due to the direct relationship between these factors and eutrophication.

Modeling the effect of land use

Based on prepared buffers and adjacent areas around the wetland, correlation, and coefficient of determination of quality and trophic indices values with buffers (intervals) were used to determine the type and extent of spatial effects of wastewater on the pollution status of Anzali wetland. Table 6 shows the correlation and coefficient of the determination of quality and the trophic indices value of Anzali wetland with the proximity of land use. Accordingly, the significant correlation between quality and trophic index is -0.948, -0.8887, and 0.633. According to Table 6 and the coefficient of determination for these indicators, about 70% of pollution is due to the use of wetlands and wastewater from agricultural, industrial, and urban wastewater entering the wetland.

Table 6) Spatial correlation of quality and trophic status index value of Anzali wetland with land use waste

	Correlation with the proximity of wastewater	Coefficient of determination (%)
NSFWQI	-0.948**	72.9
TSI p	-0.887*	78.6
TSI n	0.633*	77.7

*Correlation at the level of 0.05; ** Correlation at the level of 0.01.

Hubbard *et al.* argued that California's river water quality was heavily contaminated with the development in agricultural activities [17]. Ahearn *et al.* explores the relationship between land use and water quality in state California in the USA, and concluded water quality of the rivers in the state influenced by the development of industry, land use change, especially agricultural development, and livestock activities and led to water quality degradation [18]. Since the values of the quality parameters of the wetlands are influenced by the interactions between the physiochemical processes, the results of the partial correlation coefficient for further study and determining the effective parameters on the quality of the wetland affected by the land use distances are given in Table 7.

Table 7) Partial spatial correlation of Anzali wetland quality parameters with land use waste

Parameter Qualitative Index	EC	pH	DO	TDS	N	P	BOD ₅
NSFWQI _a	0.973**	0.81*	0.976	-0.931*	-0.97	-0.66	-0.971
TSI _p	-0.328*	0.221**	-0.34	-0.192	0.987	0.316	-0.496
TSI _n	-0.951*	0.76*	-0.955	0.89*	0.947	0.745	-0.98

*Correlation at the level of 0.05; ** Correlation at the level of 0.01.

According to Table 7, the dissolved oxygen content, BOD₅, nitrogen and, total phosphate did not show a meaningful effect on the inputs of pollutants into the wetland by land use, which means that it is effective under natural environmental conditions and other parameters. These results were also obtained in Samadi's study. Samadi with using IRWQI and GIS techniques, the spatial and temporal effects of land use and pollution of Choghakhor wetland were modeled. Accordingly, the partial correlation coefficient of the qualitative index and the parameters of phosphate, nitrate and dissolved solids were -0.82, -0.64 and 0.62, respectively, due to pollution of agricultural and residential wastewater in the southern half and west of the wetland [24]. On the other hand, based on the partial correlation of Table 7, the electrical conductivity, acidity, and total dissolved solids are directly affected by inputs and effluent from the land use ($p < 0.05$; $p < 0.01$). Tong and Chen, using Spearman correlation coefficient, showed a positive correlation between total nitrogen and total phosphorus with residential, commercial, and agricultural uses and negative correlation with forest use in the United States watershed in the eastern shore of the Miami River, all of which the statistical significance was significant at 1% level [14]. Woli *et al.* in the effect of watershed land use on nitrogen load in two Shibetsu and Bekkanbeushi Rivers in Hokkaido of Japan have shown a positive and strong correlation between nitrogen of water and agricultural and urban and a negative correlation with forests and wetlands [15]. Martin *et al.* compared the relationship between land use temporal properties and concentrations of nutrient in 37 Michigan lakes in buffer zones in five time stages with the main components, multivariate regression, and classification and regression trees analyzed. The results showed that the increase in land use pollution caused an effect of 49% [21]. Arbuckle and Downing examined the effect of land use on the nitrogen and phosphorus of the lake, which was clearly influenced by agricultural activity. In this study,

based on multivariate regression analysis, in areas with more than 30% of rangelands, nitrogen, and phosphorus were lower, and areas where more than 90% of the arable land had significant levels of nitrogen and phosphorus [12]. To better explain the results of the regression between different buffers. Diagram 2 shows the regression of the model of the trophic index and the quality index of Anzali wetland with the proximity of land use. As can be seen, for the trophic index, with increasing distance of 500 meters from the pollutant inputs around the wetland, it is based on regression and decreases by about 70% depending on the coefficient of determination. In this regard, considering the structural content of the qualitative index, as far as users are concerned, the number of increments (desirable quality) is found. This study was also carried out in Samadi in 2016 and Samadi in 2015 [24, 37].

According to the source-sink theory, some land uses to play the role of the source of pollutants for water, and some role in receiving pollutants in water [38], thus, if the role of different types and combinations of land use and environmental factors are also identified in a watershed, so that they can enhance water quality management practices. Liu *et al.* in research using t-test and Pearson correlation and stepwise regression, showed that the relationship between land use and morphometric effects of lakes depended on the location of trophic conditions in lakes [22]. Based on the land use image (Figure 2), the highest percentage of land area in the wetland included agriculture and pasture, forests and gardens, vegetation and water withdrawal, water and city [29], which is inconsistent with the partial correlation results and correlation between the buffer (intervals) with the surrounding user (Tables 6 and 7). According to reports, 30 million cubic meters of urban and rural wastewater (domestic, hospital) annually enter the Anzali wetland basin without proper treatment [35]. According to the results of the present study, the effect of these issues on the parameters and qualitative indicators and the interaction of land use was significant, and since

the phenomenon of eutrophication follows a process of geometric development, its long-term sustainability is very disturbing and dangerous.

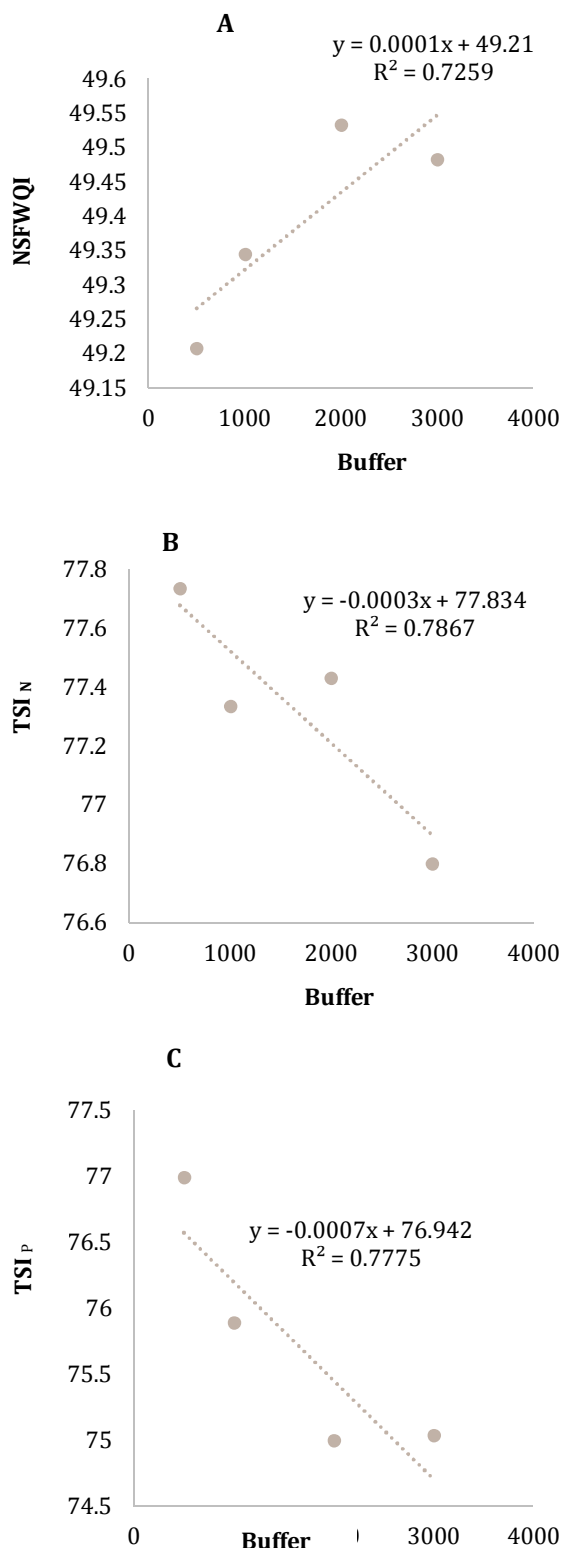


Diagram 2) Regression of quality and trophic models of Anzali wetland with land use in 2014. **A)** NSFQI; **B)** TSI_N; **C)** TSI_P

Conclusion

Quality management of the wetland in order to prevent, control, and reduce the quality problems requires identification of the amount and type of pollutants. In other words, water quality monitoring is helpful. This study showed that the use of GIS technique in environmental studies as an effective management tool could be very helpful in providing appropriate ways to identify and control the resources and pollutants in the wetland.

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