Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Estimation of pollution load to Anzali Wetland using remote sensing technique

Maryam Navabian[1,2*], Majid Vazifehdost[1], Mehdi Esmaeili Varaki[1,2]

1. Department of Water Engineering, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran
2. Department of Water Engineering and Environment, Caspian Sea Basin Research Center, University of Guilan, Rasht, Iran

** Corresponding author's E-mail: Navabian@guilan.ac.ir*

ABSTRACT
To control pollution sources and prioritize the reduction strategies of pollution, estimating the pollution load and contributing to prevent entering the different pollution sources to the water resources is very important. To estimate the pollution load, detailed quantitative and qualitative information of pollutant is needed. However, ground-based measurement is very costly and time consuming. Instead, approaches based on remotely sensing techniques exhibits very high potential in determining the water quality parameters over an extensive area in a short time period. The aim of this study was to evaluate the possibility of applying remotely sensing data and hydrometric station data to estimate the pollution load entering Anzali Wetland. So that, the quality parameters including nitrate concentration, total dissolved solids, total suspended solids and orthophosphate in the entrance point of three important rivers leading to Anzali Wetland (Bahmbar, Siahdarvishan, and Pirbazar Rivers) was measured at the time of satellites overpassing over the period of November 2011 through August 2012. Pre-processing practices including radiometric and geometric corrections were performed on the Landsat images. Then multi-variable equations were derived for estimating the water quality parameters based on ground truth data and spectral reflections in the range of visible to middle infrared. After validating the accuracy of water quality parameters derived from Landsat satellite images (by statistical indices), the contamination loads of nitrate, total dissolved solids, total suspended solids and orthophosphate entering the wetland were estimated. To assay the contamination load of each parameter, the river discharges were multiplied by the concentrations of these parameters which derived from satellite images in the period of April 2012 through July 2013. The highest pollution load occurred during this period at the entrance of Siahdarvishan River into Anzali Wetland. Comparison of pollution load of nitrate, orthophosphate, total suspended solids and total dissolved solids derived from satellite images during the study period revealed that the Pirbazar and Bahmbar rivers discharged the most loads of pollution to Anzali Wetland respectively.

Key words: Hydrometric station data, Landsat 7 and 8, Nitrate, Total dissolved solids.

INTRODUCTION
In many parts of the world, surface water is the only source of drinking, household and aquaculture consumptions. Nitrate and phosphate compounds are common pollutants in surface water resources, due to release of drainage waters and wastewaters, their concentration in these resources are increasing (Liu *et al.* 2005). According to literature, nitrate concentrations higher than 15 mg L^{-1} are attributed to human-induced contamination (Anku *et al.* 2009). Studies conducted in the last decade indicate that pollution of water resources with nitrate and nitrite is a serious problem in many parts of the world. Studies have exhibited that agricultural lands in England receive nitrate over 125 kg per hectare per year, and 70-80% of nitrate in rivers is related to agricultural land (Neal *et al.* 2006).

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137
Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

Phosphorus is common component of mineral and manure fertilizers because it boosts crop yields. However, plants do not take up large portion of phosphorus applied as fertilizer and either builds up in the soil or washes into rivers, lakes and seas. The results of the new study showed that global human activities emit 1.47 teragrams phosphorus per year into the world major freshwater basins, four times greater than the weight of the Empire State Building. China contributed 30% of the freshwater phosphorus load, followed by India by 8%. The largest contribution to the global phosphorus load came from domestic sewage by 54%, followed by agriculture 38% and industry 8% **(**Mekonnen & Hoekstra 2017 **)**. Estimating water pollution and quality management of water resources is evidently important due to the growing population and the increasing need for desirable water quality. Water quality monitoring and estimation of the pollution load at a large geographical level requires high cost and time consuming. Instead, employing remote sensing techniques is extending to get information without physical contact and based on the reflected energy from objects. By remote sensing technology some of the water quality parameters which affect the optical and/or thermal properties of surface water can be measured with proper accuracy. Moreover, individuals can monitor the trend of water quality parameters, access to contaminated points and, finally determine the source of contamination (Ritchie & Cooper 2001). The literature reviews indicate that among the water quality parameters, the total suspended solids, temperature, total dissolved solids, turbidity, secchi disk depth (physical properties of water), total nitrogen, ammonium, nitrate, total phosphorus, soluble phosphorus, acidity, salinity, chlorine, potassium, sodium, organic soluble matter (chemical properties of water), chlorophyll and dissolved oxygen (biological properties of water) can be determined by remote sensing more accurately (Ritchie *et al.* 2003; Gholizadeh *et al.* 2016). Weiqi *et al.* (2008) studied turbidity, total nitrogen, ammonium, nitrate, total phosphorus and soluble phosphorus using Landsat 5 TM data. They estimated turbidity, nitrate, total nitrogen, soluble phosphorus, ammonium and total phosphorus with 10, 20 and 30% relative error, respectively. Wu *et al*. (2009), suggested an empirical remote sensing model using Landsat 7 TM data to determine total phosphorus. Olet (2010) obtained the total suspended solids in water using Landsat TM data with the determination coefficient and root mean error of 0.5 and 0.41 mg L^{-1} respectively. Toming *et al.* (2016) used remote sensing to evaluate the qualitative parameters of eight small and large lakes in Estonia and stated that remote sensing could estimate chlorophyll a, soluble organic matter and water color with the determination coefficient of 0.83, 0.92 and 0.52 respectively. Combinations of field measurements data, simulation models such as WASP and remote sensing techniques can be used to estimate the pollution load into water resources. In such studied, it was tried to estimate pollution load to a water source (wetland) using a remote sensing. Lai *et al.* (2011), investigated the contamination of non-point sources and their impact on the water quality of the Kauping River in Taiwan, by integrating two models, WASP and IWMM. The non-point contamination entered the river basin was simulated by the IWMM model. Then, results of this model were used as an input data for assessing water quality of river in the WASP model. Land use patterns were also provided by SPOT images and digital evaluation model techniques with the ERDAS IMAGINE process and the Arc-view Geographic Information System. Results showed that the high flow rate (over 200 $m^3 s^{-1}$) during the wet season caused an increase in point pollution load. Besides, the land use patterns including gardens and farms were the main contamination factors, hence should be effectively controlled. Navabian *et al.* (2015) developed a method for simultaneous application of water quality model and satellite imagery to estimate the pollution load caused by the agricultural land use along Pasikhan River. So, the WASP model was used to simulate the spatial and temporal changes of nitrate and phosphate of the river during 2011 and 2012. By determining the cultivation area where influenced on quality of the river using elevation map, the nitrate and phosphate loads were estimated using the calibrated WASP model. Comparing measured (16 and 1.66 kg ha^{-1}) and simulated (14.18 and 1.44 kg ha^{-1}) nitrate and phosphate loads, revealed that the selected procedure exhibits good accuracy to estimate the pollution loads of agriculture pollutant. He *et al.* (2012) evaluated monthly pollution loads based on land cover classification by high resolution Quick Bird remote sensing imagery, demonstrating good agreement between measured and simulated DIN and DTP loads. Other nutrient loads including DON, PON, TP, TOC, DOC and POC displayed lower correlation between measured and simulated corresponding data. Okia & Yasuokab (2008) were made relation between monthly normalized difference vegetation index (NDVI) using NOAA and Advanced Very High Resolution Radiometer (AVHRR) imagery and the annual total nitrogen load discharged from river basins. They found that the impacts of land cover such as plantation and the field weed communities on the total nitrogen load of each river are higher than the impacts of other land cover. Finally, maps of the potential annual total nitrogen load index and the potential annual total nitrogen load for each river basin area index were drawn by considering the relationship between the land

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264 Received: Jan. 08. 2020 Accepted: June 02. 2020
DOI: 10.22124/cjes.2020.4137 Article type: Research

cover types and the annual total nitrogen load discharged from river basins in Japan. Anzali Wetland is one of the 22nd international wetland in Iran, which plays an important role in the region because of its ecological impact on migratory birds in the Southwest Caspian Sea and hydrological values. The rivers leading to the wetland enter large amounts of suspended matter, agricultural (pesticides, fertilizers), industrial (heavy metals including Cd, Pb, Cu, Zn, and Ni) and municipal wastewater (Zare Khosheghbal *et al.* 2013). The controlling and reducing these contaminants need the knowledge of the pollution properties in order to prioritize and apply suitable management systems. Combination of field measurements, simulation models and remote sensing techniques are useful tools and techniques to monitor quality of water body and recognizing the major sources of pollution. So, the present study is suggesting a method to estimate pollution loads from rivers into Anzali Wetland using remote sensing and hydrometric station data. This method is expected to be able to decrease the time and cost of the water resource monitoring.

MATERIALS AND METHODS

Study area

Anzali Wetland, with an area of 180 to 200 km^2 is located at the southwest of the Caspian Sea and is limited to the Sefidrood River Delta from West. Large and small rivers such as Khomamroud, Pirbazar, Pasikhan, Masole, Plangroud, Shijan enter the wetland from South, East and West (JICA 2005). Geographically the wetland is divided into four distinct parts according to differences in the physical properties, chemical composition, morphology and general geography including the eastern, central and western parts as well as Siah Keshim.

The main rivers

The Anzali Wetland watershed with its discharge characteristics covers an area of about 3820 km^2 with 10 major rivers inflowing the wetland. The area of each watershed varies between 100 to 700 km^2. The rivers are considered as permanent and all are originated from the Alborz Mountains, flowing to the north. Khomam River which flows to the west, enters the wetland from the east. Pirbazar and Pasikhan rivers flow toward north, then confluence together before entering the wetlands. Pishroud River (also called Shahkhazar) forming by confluence of Masoule, Khalkaie, Morghak, Bahmbar streams, flows toward the northeast and enter the wetland from west (JICA 2005).

Satellite data

Fig. 2 illustrates the steps for generating the water quality parameters equations in this study. Satellite images acquired by Landsat 7 and 8 were used to determine the water quality parameters (WQPs). The main characteristics of the Landsat satellite images and also implemented spectral bands have been listed in Table 1. Landsat images for the track number (path 166 and row 34) were obtained through internet from Earth explorer gateway. The frame of 166/34 comprises the western parts of Guilan Province, Iran.

Table 1. Main spectral characteristics of the Landsat 8 and 7 images.

Landsat 8	Spatial Resolution m	Spectral Bands	Landsat 7	Spatial Resolution m	Spectral Bands
Band 1 - Coastal aerosol	30	0.43-0.45	-	30	
Band 2 - Blue	30	0.45-0.51	Band 1 - Blue	30	0.45 - 0.51
Band 3 - Green	30	0.53-0.59	Band 2 - Green	30	0.52 - 0.60
Band 4 - Red	30	0.64-0.67	Band 3 - Green	30	0.63 - 0.69
Band 5 - Near Infrared (NIR)	30	0.85-0.88	Band 4 - Red	30	0.75 - 0.90
Band 6 - SWIR 1	30	1.57-1.65	Band 5 - Near Infrared (NIR)	30	1.55 - 1.75
Band 7 - SWIR 2	30	2.11-2.29	Band 7 - SWIR	30	2.08 - 2.35
Band 8 - Panchromatic	15	0.50-0.68	Band 8 - Panchromatic	15	0.52 - 0.90
Band 9 - Cirrus	30	1.38 - 1.36	-	30	-
Band 10 - Thermal Infrared (TIRS) 1	100	10.6-11.19	Band 6 - Thermal Infrared (TIRS)	60	10.4 - 12.5
Band 11 - Thermal Infrared (TIRS) 2	100	11.5-12.51			

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137

Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

Four images from Landsat 8/ OLI and 16 images from Landsat 7/ ETM were implemented in the process for estimating the WQPs. Due to the location of study area in the center of images, SLC-off problem in the Landsat 7 did not influenced derived WQPs. All Landsat images in the period of 2012 to 2013 were checked in terms of cloudiness and we selected the images with minimal cloud cover. Table 2 presents the proportion of the images used in this study. All Landsat 8 and 7 images were geometrically corrected and delivered on level 1 corrected for platform position and radiometric errors. Standard specification of Landsat 8 products is presented in Table 3.

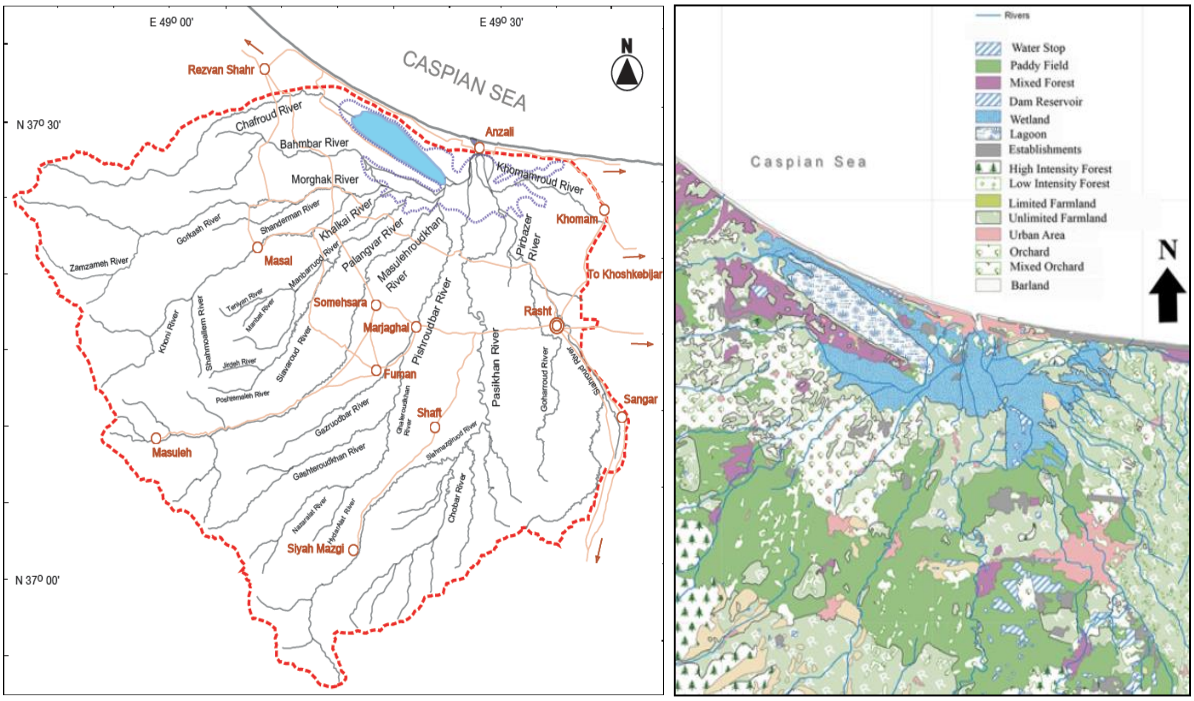

Fig. 1. Main rivers (JICA 2005) and land use (Naseh *et al.* 2012) of the Anzali Wetland watershed.

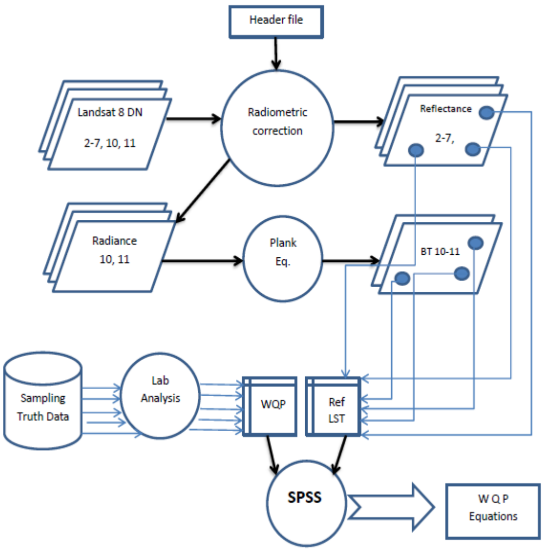

Fig. 2. Flowchart of extraction WQPs equation using remote sensing.

After downloading the Landsat images, selected bands (Table 2) were stacked on each other. The stacked images were subset spatially according to the Area of Interest (AOI). Standard pre-processing practices were performed on images to convert the raw Digital Numbers (DN) to the radiance and reflectance using the scaled and offset coefficients listed in the header files. Land Surface Temperature (LST) was derived from thermal bands using inversion of Planck equation.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264 Received: Jan. 08. 2020 Accepted: June 02. 2020
DOI: 10.22124/cjes.2020.4137 Article type: Research

Table 2. List of available Landsat images and their proportion for the WQPs.

Landsat	Image ID	Date	CC	Product	proportion
8	LC81660342013209LGN00	2013/7/28	5%	OLI_TIRS_L1T	+++
8	LC81660342013161LGN00	2013/6/10	70%	OLI_TIRS_L1T	---
8	LC81660342013145LGN00	2013/5/25	1%	OLI_TIRS_L1T	+++
8	LC81660342013113LGN01	2013/4/23	66%	OLI_TIRS_L1T	---
7	LE71660342013185ASN00	2013/7/4	25%	ETM+ L1T	+++
7	LE71660342013169ASN00	2013/6/18	0%	ETM+ L1T	+++
7	LE71660342013137PFS00	2013/5/17	54%	ETM+ L1T	++
7	LE71660342013121SG100	2013/5/1	8%	ETM+ L1T	+++
7	LE71660342013105SG100	2013/4/15	63%		----
7	LE71660342013073PFS00	2013/3/14	38%		+
7	LE71660342013057PFS00	2013/2/26	80%		----
7	LE71660342013041PFS00	2013/2/10	74%		----
7	LE71660342013025PFS00	2013/1/25	69%		+
7	LE71660342013009PFS00	2013/1/9	47%		--
7	LE71660342013009PFS00	2013/1/9	47%		--
7	LE71660342012327PFS00	2012/11/22	96%	ETM+ L1G	
7	LE71660342012311PFS00	2012/11/6	38%		++
7	LE71660342012295PFS00	2012/10/21	51%	ETM+ L1T	+
7	LE71660342012279PFS00	2012/10/5	36%		---
7	LE71660342012263PFS00	2012/9/19	25%		-

L: Landsat
C/O/T: Instrument; CC=cloud cover, O = OLI, T = TIRS, E: ETM
166: Path (WRS-2), 34: Row (WRS-2), 2013: Year, 076: Julian Day

Table 3. Standard specification of Landsat 7 and 8 products.

Product	Format	Pixel size	Projection	Sensor	Size
Level 1	GeoTIFF 12bit	15 m panchromatic 30 m multispectral 100 m thermal	UTM 39 Datum 84	OLI TIRS	Compacted 1Gb
Level 1	GeoTIFF 8 bit	15 m panchromatic 30 m multispectral 60 m thermal	UTM 39 Datum 84	ETM+	250 Mb

Sampling

To present a method for estimating contamination load of rivers entering Anzali Wetland, water samplings were carried out at the junction of the rivers and the wetland after determining overpass time of Landsat 7 and 8 in the region and weather forecasts 120 h ahead. Fig. 3 illustrates the sampling points. Samplings were carried out four times in the period of 2012-2013 (November 2012, Jan 2013, May 2013, and August 2013). Samples were collected at two different depths (surface and 50 cm from the surface) by suction pond sampler. After sampling, WQPs were measured in the laboratory. Nitrate, total phosphorus and orthophosphate were measured using spectrophotometer (GENWAY model 6705, UK), ammonium by titration, salinity using conductivity meter, acidity by pH meter and total suspended solids using the method of filtering the sample and drying it in the oven (Standard Methods for the Examination of Water and Wastewater 2017).

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264 Received: Jan. 08. 2020 Accepted: June 02. 2020
DOI: 10.22124/cjes.2020.4137 Article type: Research

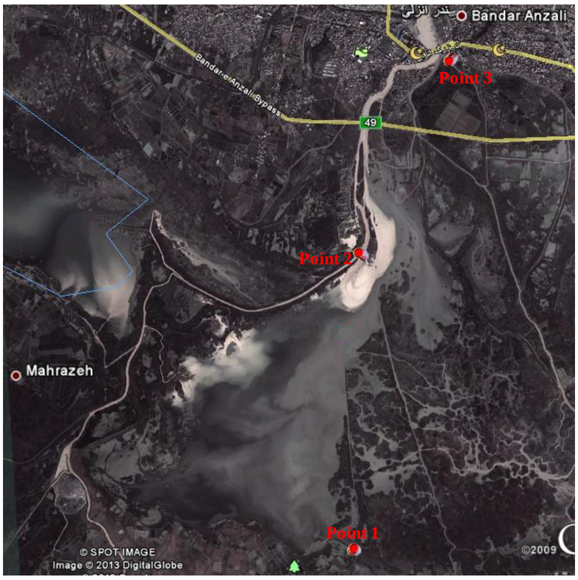

Fig. 3. Sampling points in Anzali Wetland for deriving multi variable equation.

Regression Model

Due to the complexity of the parameters affecting the water quality, nonlinear forms of regression equations in SAS software were employed to extract the regression models. Besides, due to the influences of precipitation and temperature on some water quality parameters such as total dissolved solids, total suspended solids, orthophosphates, ammonium, the precipitation values in three days before sampling and also air temperature in the sampling day were included as extra input parameters in the regression models. The general form of regression models is presented in equations 1 to 3.

$$Y = a \times R_1^b \times R_2^c \times R_3^d \times R_4^e \times R_5^f \times R_7^g \times SST^h \times (rain1 + rain2 + rain3 + T)^i \quad \textbf{(1)}$$

$$TSS = 10^{a \times R_1^b \times R_2^c \times R_3^d \times R_4^e \times R_5^f \times R_7^g \times (0.001SST)^h \times (rain1 + rain2 + rain3 + T)^i} \quad \textbf{(2)}$$

$$TP = 10^{a \times R_1^b \times R_2^c \times R_3^d \times R_4^e \times R_5^f \times R_7^g \times (0.001SST)^h \times (rain1 + rain2 + rain3 + T)^i} \quad \textbf{(3)}$$

where Y, TSS and TP refer to the water quality parameters, total suspended solids and total phosphorus concentration, R_1, R_2, R_3, R_4, R_5 and R_7 refer to the reflectance values in the bands 1 to 5 and 7 for Landsat 7 and the reflectance values in the bands 2 to 7 for Landsat 8, respectively. SST is sea surface temperature derived from thermal bands in both Landsat 7 and 8. Moreover, $rain_1$, $rain_2$ and $rain_3$ refer to the precipitation amount one, two and three days before sampling (mm) and T is air temperature on sampling day (°C). Parameters a, b, c, d, e, f, g, h and i are empirical coefficient that were defined in calibration stage. For more details about equations 1 to 3 (calibration and validation process), refer to Navabian *et al.* (2019).

The regression models were evaluated by statistical parameters such as determination coefficient (R^2), Root Mean Square Error (RMSE) and Normal Root Mean Square Error (nRMSE). The nRMSE values <10%, <10 - 20%<, <20 - 30%<, and 30%> were evaluated as excellent, good, relatively good and weak (Jamieson *et al.* 1991).The statistic parameters were obtained from equations 4 to 6.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \quad \textbf{(4)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}} \quad \textbf{(5)}$$

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137

Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

$$nRMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(O_i - P_i\right)^2}{n}} \times \frac{100}{\bar{O}} \quad \textbf{(6)}$$

where P_i, O_i, n and $\bar{O}$ are predicted values of water quality parameters, observed values of water quality parameters, number of observations and average of observed values.

To estimate the pollution load entering Anzali Wetland with this technique, three important streams confluence the wetland including Pirbazar, Siahdarvishan and Bahmbar rivers were selected. Then, water quality parameters including orthophosphate, nitrate, total dissolved solids and total suspended solids in the cross section of the river entrance to the wetland using calibrated regression models 1 to 3 (Navabian *et al.* 2019) were calculated. These parameters were extracted using Landsat 7 during a period of 2012-2013 (satellite images less than 10% cloudy). The UTM coordinate of the three cross section of the rivers including Pirbazar, Siahdrvishan and Bahmbar was (4147460 m, 364727 m), (4144700 m, 363343m) and (4140951 m, 363185 m) respectively. Due to overpassing time of satellite and cloudy limit in region, we employed satellite images during 28 April, 14 May, 15 June, 2 August and 6 November in 2012 along with those during 25 January, 1 May, 18 June and 4 July in 2013. After deriving the concentration of water quality parameters by remote sensing, the pollution load was calculated by multiplying the daily volume of water entrance to wetland (liters) by concentration of orthophosphate, nitrate, total solids and total suspended solids (mg L^{-1}).

To determine the volume of water entering the wetland, the nearest hydrometric stations of the Pirbazar, Siah drvishan and Bahmbar rivers including the Bridge, Nukhallah and Laksar were selected (Fig. 4). The measured discharge of the streams at the times once satellite images were employed, are presented in Table 4.

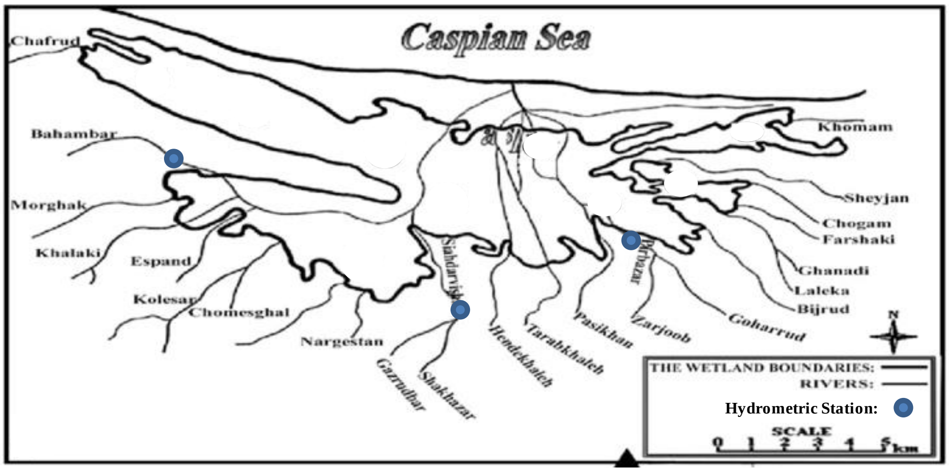

Fig. 4. Anzali Wetland, rivers leading to the wetland and hydrometric stations position.

Table 4. Discharge (m^3 s^{-1}) entering Anzali Wetland from the Siahdarvishan, Pirbazar and Bahmbar rivers.

Date	Bahmbar	Pirbazar	Siahdarvishan
28 April 2012	3.25	6.13	9.37
14 May 2012	0.73	6.56	1.82
15 June 2012	3.81	9.54	12.52
2 August 2012	1.34	4.36	2.37
6 November 2012	1.64	4.79	5.62
25 January 2013	32.29	50.97	100.25
1 May 2013	0.38	3.82	0.923
18 June 2013	0.402	2.13	1.19
4 July 2013	17.1	12.8	23.5
Mean	6.77	11.28	17.5

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137

Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

RESULTS AND DISCUSSION

Tables 5 and 6 indicate the statistical indices of the equations that derived for monitoring the water quality parameters in Anzali Wetland. According to the results, based on Jamieson *et al.* (1991), the accuracy of derived equations for prediction of total suspended solids was in good order, although the accuracy of estimations for the depth of 50 cm was higher than the water surface. The total dissolved solid was also estimated in fairly good accuracy in the both depths (0 and 50 cm). However, the accuracy of the nitrate estimation was not acceptable. The results indicated low accuracy for estimation of total phosphorus (nRMSE > 30%), therefore the derived equation is not recommended for estimating total phosphorus. Comparing the results of this study with other researches showed that the accuracy of derived equations for estimating total suspended solids, nitrate and total phosphorus are very promising (Weiqi *et al.* 2008; Olet 2010).

Table 5. Statistical parameters of the extracted models for water quality parameters of Anzali Wetland Using Remote Sensing in surface water.

Water quality	R^2	nRMSE (%)	RMSE
Total dissolved solid	0.67	18.43	98.71 (mg L^{-1})
Total suspended solid	0.68	9.62	0.21 (Log mg L^{-1})
Total phosphorus	0.25	71.71	1.67 (mg L^{-1})
Nitrate	0.67	28.70	2.12 (mg L^{-1})

Table 6. Statistical parameters of the extracted models for water quality parameters of Anzali wetland Using Remote Sensing in 50 cm depth.

Water quality	R^2	nRMSE (%)	RMSE
Total dissolved solid	0.64	19.91	107.35 (mg L^{-1})
Total suspended solid	0.66	9.88	0.22 (Log mg L^{-1})
Total phosphorus	0.17	76.98	1.74 (mg L^{-1})
Nitrate	0.71	25.16	1.89 (mg L^{-1})

Zoning maps of nitrate, total dissolved solids, total suspended solids and total phosphorus were created using satellite images and calibrated regression models (Eq. 1-3). Figs. 5-8 illustrate the spatial changes of total dissolved solids, total suspended solids, total phosphorus and nitrate in Anzali Wetland on June18, 2013.

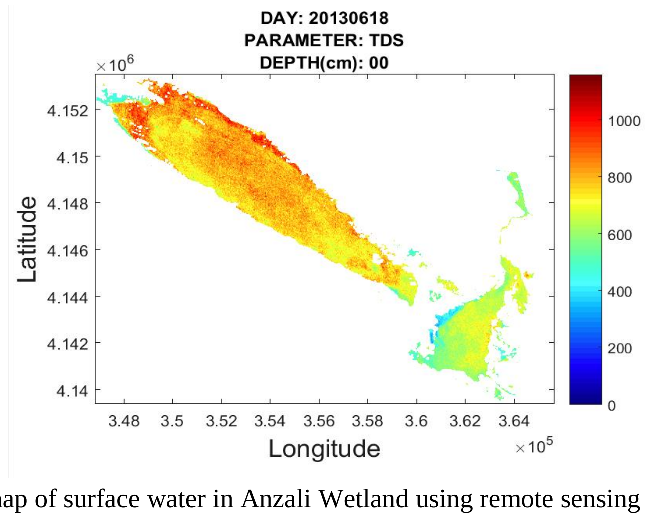

Fig. 5. TDS (mg L^{-1}) map of surface water in Anzali Wetland using remote sensing and calibrated regression model on 18 June, 2013.

Table 7 presents the estimated value of the water quality parameters in the three sampling locations (Siahdarvishan, Pirbazar and Bahmbar rivers) in Anzali Wetland extracted from similar Figs. 4 to 7 on the defined dates. On average, the highest concentrations of total phosphorus, total suspended solids, nitrate and total dissolved solids occurred in the Bahmbar (11.03 mg L^{-1}), Pirbazar (344.28 mg L^{-1}), Pirbazar (17.64 mg L^{-1}) and Bahmbar (1369.03 mg L^{-1}) which are 22, 14, 3 and 3.5 times higher than permissible value of environmental water quality standards (Table 8), respectively. Results indicate that the Pirbazar and Bahmbar rivers by entering high concentration of total phosphorus and eroded particles potentially may lead to increased eutrophication in Anzali Wetland.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137

Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

The highest concentrations of total phosphorus in the Siahdarvishan, Pirbazar and Bahmbar Rivers were 5.482, 4.94 and 11.03 mg L^{-1} in July, November and July, respectively indicating the different behavior of the Pirbazar River watershed compared to those of other two rivers. The Pirbazar River is formed by the confluence of the Zarjoob and Goharrod rivers. Due to discharge of hospital, domestic and agricultural waste to these rivers, there are different sources of phosphorus in Pirbazar than in the other two rivers.

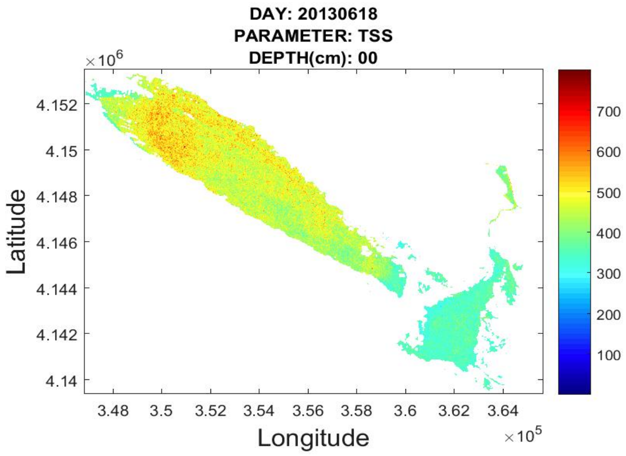

Fig. 6. TSS (mg L^{-1}) map of surface water in Anzali Wetland using remote sensing and calibrated regression model on 18 June, 2013.

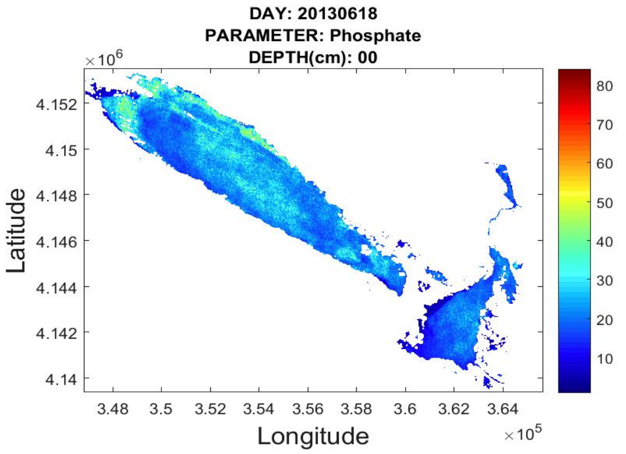

Fig. 7. TP (mg L^{-1}) map of surface water of Anzali Wetland using remote sensing and calibrated regression model on 18 June, 2013.

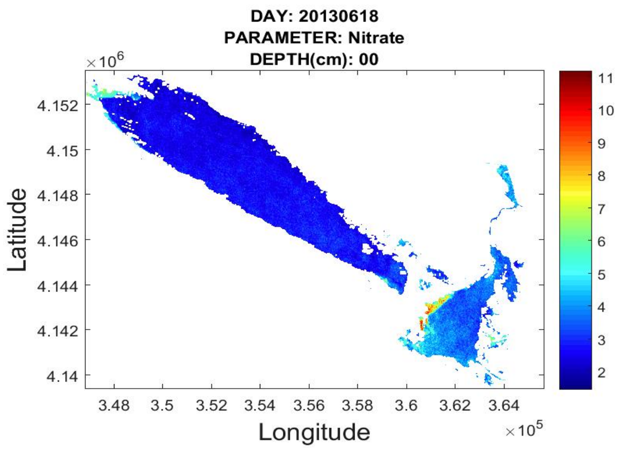

Fig. 8. Nitrate (mg L^{-1}) map of surface water of Anzali Wetland using remote sensing and calibrated regression model on 18 June, 2013.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137

Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

The highest concentration of total suspended solids were recorded during January in all of the three rivers at the same time with heavy rainfall and highest discharge to wetland. The highest total dissolved solids and nitrate concentration were observed in all three rivers in November and January. So, it seems that there may be another source for entrance total dissolved solids except agriculture source. Bahmbar River discharged dissolved solids about 18-23% higher than the other two rivers to the wetland. Table 9 presents the values of pollution load entering to the wetland in the studied period. The results indicated that the pollution load in Siahdarvishan River was higher than in the two other (Pirbazar and Bahmbar) rivers, while the load in Pirbazar was higher than in Bahmbar. However, because of lower river discharge, the concentration of the total phosphorus and total dissolved solids in Bahmbar River were higher than in the Pirbazar and Siahdarvishan rivers.
The highest amounts of pollution loads in terms of total phosphorus, total suspended solids, nitrate and total dissolved solids entering the wetland were recorded for the Siahdarvishan, Siahdarvishan, Siahdarvishan and Pirbazar, respectively.

Table 7. Value of water quality parameters of cross sectional area of Pirbazar, Bahmbar and Siahdarvishan rivers.

River Name	Date	Total Dissolved Solids ($mg L^{-1}$)	Nitrate ($m L^{-1}$)	Total Suspended Solids ($mg L^{-1}$)	Total Phosphorus ($mg L^{-1}$)
Siahdarvishan	28 April 2012	272.425	2.846	8.755	0.577
	14 May 2012	417.078	3.934	32.624	1.017
	15 June 2012	556.954	13.963	46.474	0.969
	2 August 2012	663.170	5.191	34.431	1.859
	6 November 2012	1105.199	0.350	59.088	2.913
	25 January 2013	371.771	16.432	201.290	0.325
	1 May 2013	416.450	5.751	31.429	0.554
	18 June 2013	470.919	11.049	32.505	0.499
	4 July 2013	1212.972	0.550	42.799	5.482
Mean		415.71	6.67	54.37	1.57
Pirbazar	28 April 2012	418.818	7.347	81.840	1.078
	14 May 2012	400.057	6.008	71.775	0.725
	15 June 2012	579.724	11.372	51.514	1.007
	2 August 2012	533.575	8.234	49.228	1.082
	6 November 2012	1156.837	0.919	126.241	4.938
	25 January 2013	513.817	17.648	238.214	1.121
	1 May 2013	492.174	12.758	45.241	0.960
	18 June 2013	409.789	14.550	80.511	0.459
	4 July 2013	850.413	1.402	344.287	3.103
Mean		595.02	8.91	120.98	1.61
Bahmbar	28 April 2012	524.507	11.606	21.315	1.360
	14 May 2012	395.961	5.984	33.852	0.589
	15 June 2012	520.251	10.735	13.774	0.702
	2 August 2012	582.634	3.359	19.779	1.585
	6 November 2012	1369.033	0.392	49.566	7.260
	25 January 2013	465.330	27.741	138.885	0.678
	1 May 2013	1174.729	2.126	5.523	9.996
	18 June 2013	512.490	5.284	41.894	0.791
	4 July 2013	1280.460	0.396	21.617	11.035
Mean		758.37	7.51	38.46	4.88

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137

Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

The highest amounts of contamination discharging the wetland were observed in January 2013 during the study period (May 2012 to July 2013) for all parameters. The results of this study in terms of pollution loads (nitrate, phosphate and total dissolved solids) were in good agreement with the results of Mohammadpour (2012), who reported 16 and 1.66 kg ha^{-1} nitrate and phosphate load in 2011 and with those of Hosseini Zare *et al*. (2016), who reported 37-9079, 0.05-58.8 and 0.003-0.26 ton d^{-1} of total dissolved solid, nitrate and phosphate load respectively discharging from the drainages in different intervals to Karun River, Khuzestan Province, southwest of Iran.

Table 8. Benchmark water quality criteria values.

Criteria	Standard	Obtained from
EC	600 µS cm^{-1}	State of Michigan
Total suspended solid	25 mg L^{-1}	Lioyd (1987)
Total phosphorus	0.5 mg L^{-1}	Wetzel (2001)
Total Nitrogen	5 mg L^{-1}	Wetzel (2001)

Table 9. Predicted values of the pollution load of the Siahdarvishan, Pirbazar and Bahmbar rivers into Anzali Wetland by remote sensing.

River Name	Date	Total Dissolved Solids (Ton)	Nitrate (Ton)	Total Suspended Solids (Ton)	Total Phosphorus (Ton)
Siahdarvishan	28 April 2012	220.54	2.30	0.76	7.08
	14 May 2012	65.58	0.61	0.23	5.13
	15 June 2012	602.47	15.10	1.80	50.27
	2 August 2012	135.79	1.06	0.31	7.05
	6 November 2012	536.64	0.17	0.86	28.69
	25 January 2013	3220.13	142.32	19.95	1734.49
	1 May 2013	33.21	0.45	0.12	2.51
	18 June 2013	48.41	1.13	0.15	3.34
	4 July 2013	2462.81	1.11	3.31	86.89
Mean		813.95	18.25	3.05	214.94
Pirbazar	28 April 2012	221.81	3.89	1.01	43.34
	14 May 2012	226.74	3.40	1.05	40.68
	15 June 2012	497.87	9.76	1.47	44.24
	2 August 2012	200.99	3.10	0.63	18.54
	6 November 2012	478.76	0.38	0.86	52.24
	25 January 2013	2262.75	77.71	10.46	1049.05
	1 May 2013	162.44	4.21	0.54	14.93
	18 June 2013	75.41	2.67	0.35	14.81
	4 July 2013	940.48	1.55	2.80	380.75
Mean		563.03	11.85	2.13	184.29
Bahmbar	28 April 2012	147.28	3.25	0.37	5.98
	14 May 2012	25.14	0.38	0.09	2.14
	15 June 2012	171.25	3.53	0.37	4.53
	2 August 2012	67.45	0.38	0.15	2.28
	6 November 2012	193.98	0.05	0.24	7.02
	25 January 2013	1298.20	77.39	5.97	387.46
	1 May 2013	38.56	0.06	0.02	0.18
	18 June 2013	17.80	0.18	0.05	1.45
	4 July 2013	1891.80	0.58	1.97	31.93
Mean		427.94	9.53	1.03	49.22

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137

Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

CONCLUSION

This study exhibited that remote sensing can be employed to estimate the pollution load of water resources including rivers and wetlands. Increasing accuracy in regression equations and estimating the quality parameters of water resources lead to an improvement in the estimation of pollution load. Estimating the pollution load of the Siahrodvishan, Bahmbar and Pirbazar rivers to Anzali Wetland displayed that the hydrological behavior of pollutants and the contamination rate both contribute to the amount of pollution load. Recognizing these characteristics can be a better step in controlling the pollutant discharges to Anzali Wetland. In addition, the type of farming and fertilization, applying pesticide and herbicides, agronomic operations and soil characteristics affect the amount of salts from the fields and consequently their entry into water resources.

ACKNOWLEDGMENTS

This article was supported by Iran Nation Science Foundation with 89002948 code and the authors are grateful for the support provided by the fund. It is hoped that the findings of this study will be used by water authorities.

REFERENCES

American Public Works Association 2017, Standard methods for the examination of water and wastewater. Water Environment Federation, 23rd Edition, 1546 p.

Anku, YS, Banoeng, BY, Asiedu, DK, & Asiedu, SM 2009, Water quality analysis of groundwater in crystalline basement rocks, northern Ghana. *Environmental Geology*, 58: 989-997.

Gholizadeh, MH, Melesse, AM, & Reddi, L 2016, A comprehensive review on water quality parameters estimation using remote sensing techniques, *Sensors (Basel)*, 16: 1-43.

He, B, Oki, K, Wang, Y, & Kawasaki N 2012, Analysis of stream water quality and estimation of nutrient load with the aid of Quick Bird remote sensing imagery, *Hydrological Sciences Journal*, 57: 1-11.

Hosseini zare, N, Gholami, A, Panahpour, E, & Jafarnezady, AR 2016, Identifying and determining pollution load of agricultural pollutants in the catchment basin of Karun and Dez rivers, *Plant Protection*, 39: 121-134 (In Persian).

Jamieson, PD, Porter, JR, & Wilson DR 1991, A test of the computer simulation model ARCWHEAT1 on wheat crops grown in New Zealand, *Field Crops Research*, 27: 337-350.

JICA 2005, The study on integrated management for ecosystem conservation of Anzali Wetland. Nippon Koei Co. Ltd., 182 p.

Lai, YC, Yang, CP & Hsieh, CY 2011, Evaluation of non-point source pollution and river water quality using a multimedia two-model system. *Journal of Hydrology*, 409: 583-595.

Liu, WH, Zhao, JZ, Ouyang, ZY, Söderlund, L & Liu, GH 2005, Impacts of sewage irrigation on heavy metal distributi on 541and contamination in Beijing, China. *Environment International*, 31: 805-812.

Mekonnen, MM & Hoekstra, AY 2017, Global anthropogenic phosphorus loads to freshwater and associated grey water footprints and water pollution levels: A high-resolution global study. *Water Resources Research*, 54: 345-358.

Mohamadpour, Z 2012, Transfer modeling of nitrate and phosphorus produced by agricultural wastewater in Pasikhan River. M. Sc. Dissertation in Irrigation and Drainage Field. University of Guilan, Rasht, Iran, 88 p.

Navabian, M, Mohamadpor, Z, Vazifeh Doost, M, Esmaeili Varaki, M & Shaykhi Garakoee, K 2015, Predicting nitrate and phosphate load from paddy field using WASP model and remote sensing (Case study: Pasikhan River). *Iranian Journal of Irrigation and Drainage*, 9: 624-635 (In Persian).

Navabian, M, Esmaeili Varaki, M & Vazifeh Doost, M 2019, Feasibility study of Anzali Wetland quality monitoring using remote sensing. *Iranian Journal of Soil and Water Research*, 50: 1813-1824 (In Persian).

Neal, C, House, WA, Jarvie, HP, Neal, M & Hill Wickham, LH 2006, The water quality of the River Dun and the Kennet and Avon Canal. *Journal of Hydrology*, 330: 155-170.

Oki, K & Yasuoka, Y 2008, Mapping the potential annual total nitrogen load in the river basins of Japan with remotely sensed imagery, *Remote Sensing of Environment*, 112: 3091-3098.

Olet, E 2010, Water quality monitoring of roxo reservoir using landsat image and in-situ measurement, M. Sc. in Geo-information Science and Earth Observation, Specialisation:Environmental Hydrology, International Institute for Geo-Information Science and Earth Observation (ITC), Netherlands, pp. 1-69.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264 Received: Jan. 08. 2020 Accepted: June 02. 2020
DOI: 10.22124/cjes.2020.4137 Article type: Research

Ritchie, J, & Cooper, Ch 2001, Remote sensing thechniques for determining water quality, USDA Agriculture Research Service Hydrology and Remote Sensing Laboratory and National Sedimentation Laboratory Beltsville, MD 20705 and Oxford, MS 38655. 8 p.

Ritchie, J, Zimba, P, & James, H 2003, Remote sensing techniques to assess water quality Everitt, *Photogrammetric Engineering & Remote Sensing*, 69: 695-704.

Toming, K, Kutser, T, Laas, A, Sepp, M, Paavel, B, & Nõges, T 2016, First experiences in mapping lake water quality parameters with Sentinel-2 MSI imagery, *Remote Sensing*, 8: 640.

Vesali Naseh, MR, Karbassi, A, Ghazaban, F, Baghvand, A, & Mohammadizadeh MJ 2012, Magntic susceptibility as a proxy to heavy metal content in the sediments of Anzali wetland, Iran. *Iranian Journal of Environmental Health Sciences & Engineering*, 9: 34.

Weiqi, H, Shan, C, Xuehua, L & Jining, C 2008, Water quality monitoring in slightly-polluted inland water body through remote sensing, A case study in Guanting Reservoir, Beijing, pp. 1-11.

Wu, M, Zhang, W, Wang, X & Luo, D 2009, Application of MODIS satellite data in monitoring water quality parameters of Chaohu Lake in China, *Environmental Monitoring and Assessment*, 148: 255-264.

Zare Khosheghbal, M, Charkhabi, AH, Sharifi, F & Ghazban, F 2013, An Investigation of Sediment Pollution in Anzali Wetland, *Polish Journal of Environmental Studies*,22: 283-288.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 251~264
DOI: 10.22124/cjes.2020.4137

Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research

برآورد بار آلودگی ورودی به تالاب انزلی با استفاده از فناوری سنجش از دور

مریم نوابیان[۱و۲]*، مجید وظیفه‌دوست[۱]، مهدی اسمعیلی ورکی[۱و۲]

۱- گروه مهندسی آب، دانشکده علوم کشاورزی، دانشگاه گیلان، رشت، ایران

۲- گروه مهندسی آب و محیط زیست، پژوهشکده حوضه آبی دریای خزر، دانشگاه گیلان، رشت، ایران

(تاریخ دریافت: ۹۸/۱۰/۱۸ تاریخ پذیرش: ۹۹/۰۳/۱۳)

چکیده

برآورد بار آلودگی ورودی به منابع آب می‌تواند در تعیین سهم آلایندگی بخش‌های مختلف و در نتیجه اولویت‌بندی راهکارهای کنترل و کاهش آلودگی مؤثر باشد. برآورد بار آلودگی نیازمند داشتن اطلاعات کمی و کیفی از میزان آلودگی است. بنابراین، باید هزینه و زمان قابل توجهی برای اندازه‌گیری آن صرف شود. فن سنجش از دور با استفاده از تصاویر ماهواره‌های تخصصی و به‌روز با دقت مناسبی توان بالقوه تعیین غلظت برخی از فراسنجه‌های کیفی آب را دارد. هدف از این پژوهش، استفاده از فناوری سنجش از دور و داده‌های ایستگاه هیدرومتری در برآورد بار آلودگی ورودی به تالاب انزلی است. بدین منظور پس از واسنجی تصاویر ماهواره‌های لندست ۷ و ۸ با معادلات رگرسیونی حاصل از نمونه‌برداری میدانی از وضعیت کیفی تالاب انزلی درماه‌های آبان ۹۱، بهمن ۹۱، اردیبهشت ۹۲ و مرداد ۹۲)، مقادیر فراسنجه‌های کیفی سه رودخانه مهم منتهی به تالاب انزلی (بهمبر، سیاه‌درویشان و پیربازار) شامل مقادیر نیترات، کل جامدات محلول، جامدات معلق و ارتوفسفات برآورد شد. سپس بار آلودگی از ضرب دبی در مقادیر برآوردی غلظت فراسنجه‌های کیفی محاسبه شد. نتایج نشان داد دقت سنجش از دور برای برآورد فراسنجه‌های کیفی نسبتاً مناسب است و بیشترین بار آلودگی ورودی به تالاب انزلی در دوره مورد بررسی (اردیبهشت ۹۱ تا تیر ماه ۹۲) در دی ماه در رودخانه سیاه‌درویشان روی داد. مقایسه متوسط غلظت برآورد شده توسط تصاویر ماهواره‌ای نیترات، ارتوفسفات، کل جامدات معلق و کل جامدات محلول در سه رودخانه در طول دوره مورد بررسی نشان داد که به ترتیب رودخانه‌های پیربازار و بهمبر در ورود این آلاینده‌ها سهم بیشتری داشتند.

*مؤلف مسئول

Bibliographic information of this paper for citing:

Navabian, M, Vazifehdost, M, Esmaeili Varaki, M 2020, Estimation of pollution load to the Anzali Wetland using remote sensing technique. Caspian Journal of Environmental Sciences, 18: 251-264

DOI: 10.22124/cjes.2020.4137
Received: Jan. 08. 2020 Accepted: June 02. 2020
Article type: Research