Estimation of Sediment, Organic Carbon, and Phosphorous Loads from Pasikhan River into Anzali Wetland, Iran

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***Abstract*-The Anzali Wetland, located on the southern coast of the Caspian Sea in northern Iran, is internationally known as a habitat of migratory birds. This is an important area as a spawning and nursery ground for fish, and as a breeding and wintering area for a wide variety of waterfowl. Environmental conditions in the Anzali Wetland have been degraded due to the increased inflow of sewerage, wastewater, and solid waste from industry, agriculture and urban areas. There is also an inflow of sediment from the upper stream mountainous area. This study aims to measure and estimate the total annual OC and phosphorous delivered from Pasikhan River into the Wetland. The estimation of sediment delivery to the Anzali Wetland was updated based on the suspended load measurements in sedimentological stations for nine major entering rivers. Total sediment load was estimated at 683.5 × 10^3 ton y^{-1}; this shows a significant increase from previous estimations. This indicates that soil erosion is an important problem in the Anzali watershed. Water sampling was performed at Pasikhan River's Nokhaleh Hydrometric Station, since Pasikhan is considered the most important river entering the Anzali Wetland during one year. The samples were analyzed for phosphorous fractions and organic carbon content of suspended sediment. P concentration and OC showed monthly changes. Both were high in wet months (September to March) and lower in dry months. This pattern also emphasizes the importance of soil erosion on the conditions of the Anzali Wetland. Total OC and P load from Pasikhan River into the Wetland were estimated to be 2710 ton y^{-1} and 245 ton y^{-1}, respectively.**

Keywords- Eutrophication; Particulate Phosphorous; Soil Erosion; Suspended Sediment

I. INTRODUCTION

The Anzali Wetland (also known Anzali Lagoon, Anzali Mordab, or Anzali Bay), located on the southern coast of the Caspian Sea in northern Iran, is a large complex of freshwater lagoons with extensive reed-beds, shallow impoundments and seasonal flooded meadows. It covers an area of about 200 square kilometers. The Anzali Wetland is internationally known as a habitat of migratory birds and is considered an important spawning and nursery ground for fish, as well as a breeding and wintering area for a wide variety of waterfowl. It was registered under the Ramsar Convention in June 1975 [1], making it one of the oldest Ramsar sites in Iran.

Environmental conditions in the Anzali Wetland have been degraded due to the increased inflow of sewerage, wastewater and, solid waste from industry, agriculture, and urban areas, and sediment from the upper stream mountainous area. The lagoon has decreased since the 1930s to less than a quarter of its former size, and its depth has decreased from 11 meters to less than 2.5 meters. Accordingly, it was listed in the Montreux Record in 1993 as a site in need of priority conservation efforts due to recent water quality deterioration caused by urbanization, agricultural drainage, and sediment flux, among other issues.

Holčík and Oláh [2] estimated the total annual load of nutrients for the 11 streams entering the Lagoon to be 4898 t of nitrogen and 378 t of phosphorus. Much of this is transported directly to the sea through the Lagoon's outlets, while about 38% remains in the Lagoon. Many researchers [3-6] have reported on the Anzali Wetland's heavy metal pollutions.

Phosphorus (P) is regarded as a key factor responsible for the eutrophication of freshwater and estuarine systems [7, 8]. Not all the forms of phosphorus are bioavailable and, therefore, they are likely to increase eutrophication [9]. Phosphorus in aquatic systems is generally partitioned into particulate (organic and sediment-bound) and dissolved fractions. Dissolved phosphorus (measured as FRP) is found in the form of phosphate ions (H_2PO^-, HPO^{2-}), and it may be readily taken up by aquatic plants and micro-organisms. Particulate phosphorus enters stream channels primarily through riparian litter fall, soil erosion, and sediment transport. The concentration and load of particulate and dissolved forms of phosphorus in waterways reflect the stresses imposed by land uses and land practices in the catchment. There is no information regarding the particulate and dissolved fractions of phosphorus delivered to the Anzali Wetland thorough the entering rivers. Moreover, there is little data on the organic carbon concentration of the sediment transported by the rivers. The present study's objectives were to (i) update the estimation of sediment load of the entering rivers to the Anzali Wetland, (ii) select one of the most important rivers and measure organic matter and phosphorous concentrations of the water during the year, and (iii) make an estimation of total annual OC and phosphorous delivered from the selected river into the Wetland.

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II. MATERIAL AND METHODS

A. Study Area

The Anzali wetland is located in the northern part of Iran, along the coast of the Caspian Sea in the province of Guilan (Fig 1). The wetland is approximately located at north latitude between 37° 25′ and 37° 32′, and east longitude between 49° 15′ and 49° 36′. The total watershed area including the wetland is 3740 km^2. Forests cover approximately 43% of the catchment area. The rice fields and rangelands occupy 24.7 and 9.7 % of the watershed area, respectively (Table 1). The mean annual precipitation is 1279 mm. The annual mean discharge into the wetland is estimated at 76.14 m^3 s^{-1}. There are nine major rivers entering the wetland (Table 2). Considering the stations as watershed outlets, the total area of these 9 river watersheds is 3123 km^2. The sum of mean annual discharge for the 9 rivers is 65 m^3 s^{-1}.

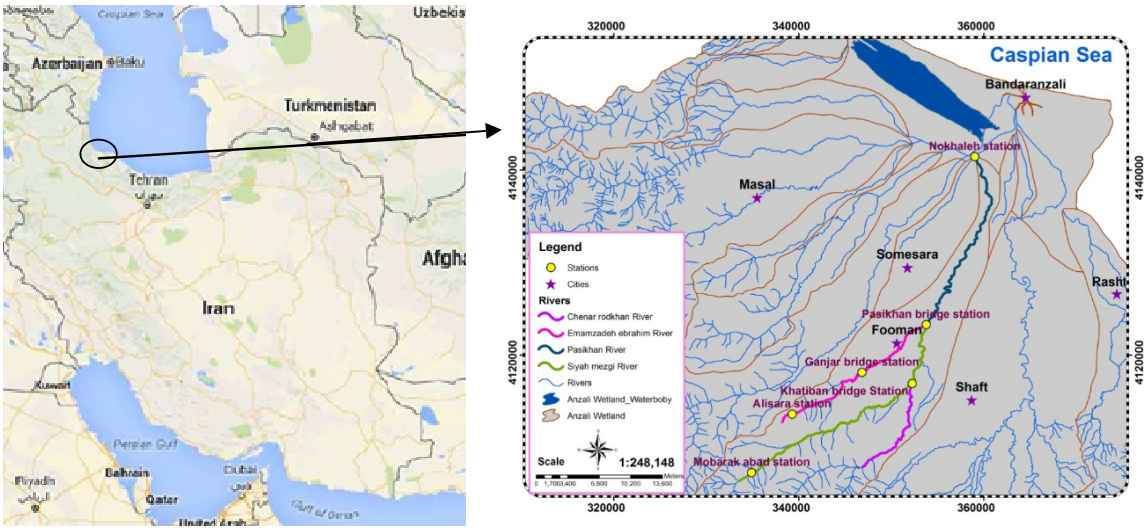

Fig. 1 The location of the Anzali Wetland (left) and the river network (right, adapted from [14])

TABLE 1 LAND USE IN THE ANZALI LAGOON WATERSHED

Land use	Area, ha	Percentage
Barren land	4 000	1.0
Rangeland	36 300	9.7
Forests	161 920	43.2
Rice fields	92 550	24.7
Other agriculture	31 900	8.5
Settlements	2 600	0.6
Anzali Lagoon	21 800	5.8
Reservoirs	10 000	2.6
Fishponds	1 100	0.2
Other land use	11 830	3.1
Total watershed	374 000	100.0

TABLE 2 RIVERS, HYDROLOGICAL STATIONS, FLOW DISCHARGE AND SEDIMENT YIELDS

No	River	Station	Watershed area (km^2)	Mean annual discharge (m^3 s^{-1})	Mean annual SSY[a] (×10^3 ton y^{-1})	Mean annual TSY[b] (×10^3 ton y^{-1})
1	Pirbazar	Pirbazar	368.7	9.10	66.6	76.6
2	Pasikhan	Nokhaleh	795.1	20.70	163.7	188.3
3	Shakhraz	Laksar	441.8	10.70	68.4	78.6
4	Massuleh	Chomesghal	355.0	5.40	76.0	87.4
5	Golsar	Golsar	257.5	6.90	35.0	40.2
6	Khalkai	Kotamjan	342.9	4.47	67.7	77.9
7	Morghak	Kotamjan	308.8	3.53	64.3	73.9
8	Bahambar	Aghamahale	116.8	1.89	12.7	14.6
9	Chafrood	Roudbarsara	136.4	2.11	39.8	45.8
Sum			3123	64.8	594.2	683.3

[a] SSY, Suspended sediment yield
[b] TSY, Total sediment yield

B. Measurements and Calculations

Though there were a few existing reports on the discharge and sediment deposited in the Anzali Wetland, these estimations

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were updated by obtaining new data from hydrological stations for the 9 major rivers. Suspended-sediment yield was estimated by the flow-duration, rating-curve (FDRC) method, which is based on an empirical relation between suspended-sediment load (SSL) and discharge (Q). This relation is usually defined as a power function, SSL = aQ^b, and is referred to as a suspended-sediment rating curve [10]. Rating-curve parameter (*a* and *b*) estimates for transformed-linear models were obtained by the method of least squares. The bedload sediment was estimated to be about 15% for the rivers, based on the watershed and river characteristics and USBR suggestions. The bedload was added to SSY to obtain total sediment yield.

Based on the watershed information, flow discharge, and sediment load, Pasikhan River was selected for sampling and measuring. Sampling was performed monthly in normal conditions and also during the five floods from September 2013 to September 2014. Suspended-sediment samples were collected using a 2 L bottle via depth-integrating technique following procedures by Edwards and Glysson [11]. Nokhaleh was the sampling station (41° 20′ 10″ E; 36° 27′ 21″ N). The water samples were analyzed for pH, EC, TDS, organic carbon, nitrogen concentration, and total dissolved and particulate phosphorous. The organic matter was determined by burning; determination of phosphorus was done by digestion with ascorbic acid; and nitrogen was determined by Kjeldahl [12, 13]. The sum of total dissolved P (TDP) and particulate P (PP) concentrations gives a quantitative analysis of total P (TP) in river water.

III. RESULTS AND DISCUSSION

A. Sediment Yield

Total sediment delivery to the Anzali Wetland is estimated to be 683543 tons/year through the 9 rivers studied, which suspended sediment accounts for 87 percent (Table 2). Specific sediment ranged from 125.2 to 335.9 ton km^{-2} y^{-1} for Bahambar and Chafrood watersheds, respectively. With the assumption of a sediment delivery ratio equal to 0.3, soil erosion can be estimated to be 4.17 to 11.2 ton ha^{-1} y^{-1}. Holčik and Oláh [2] estimated the annual sediment to be 386602 t for 11 streams entering the Wetland. It is not clear whether they accounted for bedload. Several studies [15] show that land degradation and soil erosion has increased rapidly during the last decades in Iran. The high sediment delivery rate to the Anzali Wetland resulted in a depth decrease from 11 meters to less than 2.5 meters.

B. Organic Carbon and Phosphorous Delivery

Table 3 presents general water characteristics, including pH, electrical conductivity (EC), total solids, and total dissolved solids. The river's water pH ranged from 7.07 to 7.70 during the year. The river's electrical conductivity was at a minimum in September and October (high rainfall) and consequently the flow discharge was at its peak. On the other hand, EC rose up to maximum levels from May to July when the flow discharge was at its lowest.

TABLE 3 ELECTRICAL CONDUCTIVITY, PH, TOTAL SOLIDS, AND TOTAL DISSOLVED SOLIDS FOR PASIKHAN RIVER

Months	pH	EC ($\mu S\ cm^{-1}$)	Total solids (mg lit^{-1})	Total dissolved solids (mg lit^{-1})
September	7.32	399	740	190
October	7.50	409	588	100
November	7.48	433	545	110
December	7.09	541	613	171
January	7.18	550	669	190
February	7.23	588	684	194
March	7.52	529	617	168
April	7.70	531	664	268
May	7.43	667	840	350
June	7.31	910	997	496
July	7.36	731	879	441
August	7.07	680	776	241

Fig. 2 presents the monthly changes in the organic carbon concentration in Pasikhan River's suspended sediment. The high content of OC in the suspended sediment during the wet season (September to February) indicates that surface soil erosion of the upstream (forest and range lands) plays an important role in this context.

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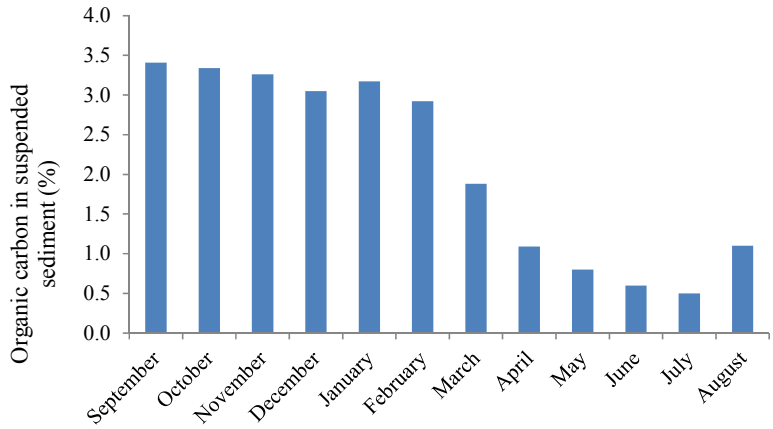

Fig. 2 Changes with time in organic carbon concentration of suspended sediment in Pasikhan River

Fig. 3 presents monthly changes in phosphorous fractions in Pasikhan River. Total phosphorous ranged from 0.065 mg L^{-1} in July to 0.553 mg L^{-1} in September. While the dissolved P did not show high variation during the year, monthly changes in particulate P followed the same trend as TP: it was low in dry months and high in wet months. Dissolved P comprised less than of 20% of TP during the wet season and about 50% during the dry season. Dissolved P comprised 32% of TP, on average, which is in consistent with Buhvestova et al. [16]. The pattern of monthly variation of phosphorous fractions is also similar to OC variation (Fig. 2) and it emphasizes the role of soil erosion.

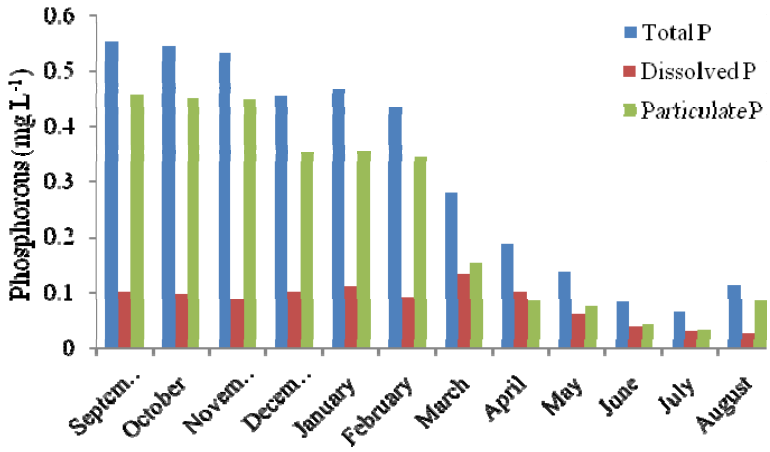

Fig. 3 Monthly changes in phosphorous fractions in Pasikhan River

Table 4 offers the estimated results of total phosphorous and organic carbon load from Pasikhan River into the Anzali Wetland. These estimations were based on the long-term averages of flow discharge and suspended sediment load. Total P load is 245 ton y^{-1}; 85% of this is related to the wet season. Total OC load was estimated to be 2710 ton y^{-1}, and 62% of this is related to the wet season. Based on the data, the P and OC losses from the watershed area are 0.31 and 3.41 kg ha^{-1} y^{-1}, respectively. Buhvestova et al. [16] estimated the range of phosphorus losses from 0.12 to 0.21 kg ha^{-1} y^{-1} for the Peipsi lake watershed.

TABLE 4 TOTAL PHOSPHOROUS AND ORGANIC CARBON DELIVERED TO THE ANZALI WETLAND BY PASIKHAN RIVER

Months	Mean discharge (m^3 s^{-1})	Total P (ton)	Suspended sediment load ($\times 10^3$ ton)	Total OC (ton)
September	30.36	43.5	20.7	705.4
October	30.61	43.2	2.1	71.6
November	27.74	38.3	7.9	256.2
December	22.16	26.0	3.5	107.6
January	23.7	28.6	7.1	226.6
February	25.06	28.2	11.1	322.8
March	22.13	16.1	9.9	186.5
April	17.91	8.6	7.5	81.8
May	9.05	3.2	10.6	85.1
June	11.37	2.5	19.0	107.9
July	7.86	1.3	26.6	132.9

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August	20.44	5.9	38.7	425.9
Annual	20.70	245.3	163.7	2710

IV. CONCLUSIONS

The estimation of sediment delivery to the Anzali Wetland was updated based on the suspended load measurements in sedimentological stations for 9 major entering rivers. Total sediment load was estimated to be 683×10^3 ton y^{-1}, a significant increase from previous estimations. This shows that soil erosion is an important problem in the Anzali Watershed. Water sampling was performed in Pasikhan River, considering it the most important river entering the Anzali Wetland for one year. The samples were analyzed for phosphorous fractions and organic carbon content of suspended sediment. P concentration and OC showed monthly changes. Both were high in wet months (September to March) and lower in dry months. This pattern also emphasizes the importance of soil erosion on the conditions of the Anzali Wetland. The very high loads of P and OC have resulted in eutrophication of the Wetland, a fact that has been shown by several researchers [17-19].

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