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Effects of seasonal climate change on Chemical Oxygen Demand (COD) concentration in the Anzali Wetland (Iran)

A. Tahershamsi [1], A. Bakhtiary [2] and A. Mousavi [3]

[1] Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran
[1] Department of Civil Engineering, Khaje Nasir Toosi University of Technology, Tehran, Iran
[1] Department of Agriculture, University of Gilan, Rasht, Iran
Email: Abakhtiary@kntu.ac.ir

Abstract: The Anzali Wetland is a distinguished coastal wetland in the southern coast of the Caspian Sea in north of Iran. This wetland is connected to the Caspian Sea through a channel and is supported with freshwater by 10 major rivers. The Anzali Wetland plays a key role as a habitat for many indigenous plants and animal species. It is believed that the ecosystem of the wetland is threatened by inflow of excessive amounts of COD (Chemical Oxygen Demand), T-N (Total Nitrogen) and T-P (Total Phosphorus). In this paper, a two-dimensional depth-averaged model for hydrodynamic and advection-dispersion is used to determine COD distribution in a large area of Anzali Wetland. Forcing actions of rivers input and wind is taken into account. According to available field data, the model is executed for three periods which are dry (23rd August-1st September), early rainy (13th October-25th October) and mid-rainy (2nd December-14th December) seasons. The simulated values are compared with observed ones at four stations. The results indicate that COD concentrations at all four stations were high denoting noticeable organic pollution in the wetland especially in the dry season.

Keywords: *Numerical model; Anzali Wetland; Hydrodynamic; Advection-dispersion; Water quality; COD (Chemical Oxygen Demand)*

1. INTRODUCTION

Wetlands are increasingly forming an important link in the treatment train that used in urban catchments to improve storm water quality, retard flows, and provide amenity. Due to their position between continent and sea, they constitute weak systems in terms of hydrodynamics, sediment behavior and hydrobiology. The Anzali Wetland is no exception as environmental troubles have emerged during last decades. Several relevant research projects have been performed on the Anzali Wetland [Ayati, 2003, Nippon Koie, 2005, Taher-shamsi, 2004, Taher-shamsi&Bakhtiary 2008]. This research has show that the water environment in the wetland has been deteriorating by continuous wastewater inflow from human activities such as domestic, industrial, and agricultural activities. It is generally believed that pollution loads impact upon the ecosystem of Anzali Wetland. Certain phenomena are reported such as excessive growth of Azolla, Phragmites and anaerobic conditions in the bed of the wetland. These phenomena may be related to the inflow of excessive amounts of COD (Chemical Oxygen Demand), T-N (Total Nitrogen) and T-P (Total Phosphorus) [Nippon Koie, 2005].

COD is an indicator of organic pollution, which is caused by the inflow of domestic, livestock and industrial waste that contains elevated levels of organic pollutants [Ayati, 2003]. The organic pollution load from the Anzali watershed to Anzali wetland has been estimated by equation shown below [Nippon Koie, 2005].

Pollution load (ton/day) = $\sum$ Organic pollution in each river (ton-COD/day) * each river flow (ton/day)

This paper investigates the use of a numerical model to simulate the hydrodynamic behavior and determine COD parameter distribution within the Anzali Wetland in north of Iran. The effects of rivers discharge and wind are considered in this model and tidal effects of the Caspian Sea are believed to be negligible. In this paper seasonal variation of the Anzali Wetland as a short term global change have been discussed. Therefore, the effects of rainfall change on river input have been investigated.

The investigation also involves calibration of MIKE21 two-dimensional hydrodynamic and advection-dispersion model according to the field data collected through recent researches carried out in the wetland. Similar worldwide researches have been performed using two-dimensional depth-integrated models [Bernon, I, 2004, Ferrarin, C, 2005 and Somes, N, 1999].

2. STUDY AREA

The Anzali Wetland covers an area of 193 km2 in Guilan Province of Iran on the southern coast of Caspian Sea (Fig. 1). It is internationally known for migratory birds and was registered as a Ramsar site in June 1975 in according with Convention on Wetlands of international Importance, especially as Waterfowl Habitat [Tahers-hamsi&Bakhtiary 2008].

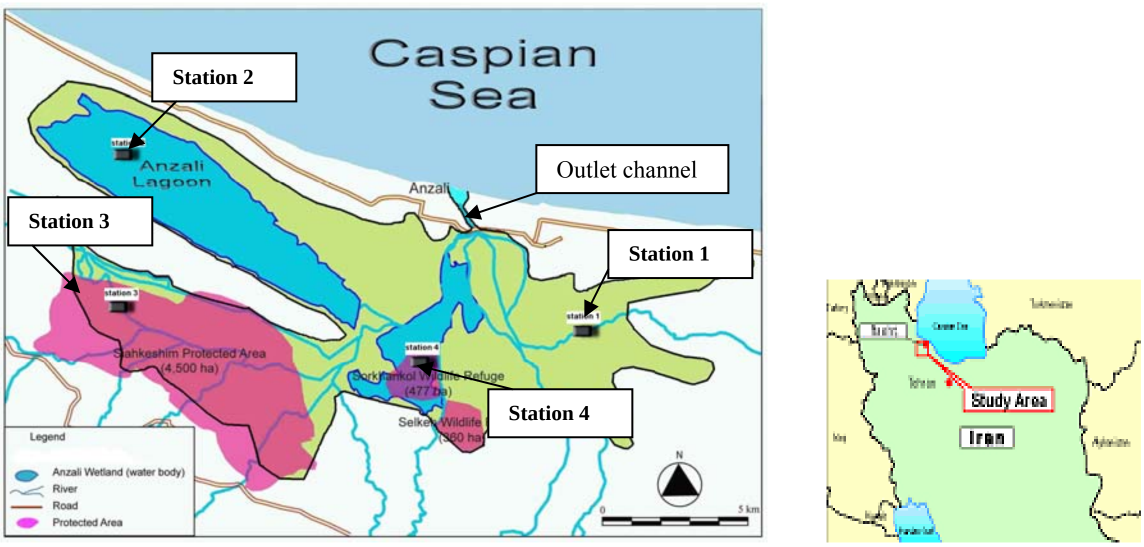


Fig. 1. Anzali Wetland and its location in Iran.

The wetland is located at the north of its watershed having a northing from N 37º-23' to 37º-33' and easting of E 49º-15' to 49º-38'. The Anzali Wetland watershed has a catchment area of 3610km^2. There are 10 major rivers entering the wetland. The rivers have perennial flow and eventually drain into the Caspian Sea via Anzali Wetland [Taher-Shamsi, 2004].

3. METHODS AND MATERIALS

3.1. Model description

The mathematical modeling of physical processes in shallow waters has undergone a large development during the last decades. Due to complexity of processes involved, this development will continue for a long time. However, it can be considered that some models are already in a mature stage, as it is the case of two-dimensional vertically integrated models.

A numerical model used in the analysis of the Anzali Wetland hydrodynamics and water quality is the Danish Hydraulic Institute's (DHI) depth-averaged, two-dimensional modeling system known as MIKE21 [DHI, 2005]. MIKE21 simulates the variation of water levels and flows (depth and flux) and compounds concentrations in response to variety of forcing functions. The water levels and flows are resolved on a square or rectangular grid covering the area of interest. The main inputs to the model are topography of the area (bathymetry), bed resistance coefficients, eddy viscosity coefficients, wind fields, and water level and/or discharge boundary conditions. This model also allows flooding and drying over the computational grid during the model simulation.

The MIKE21 software solves vertically integrated equations of continuity and momentum in two horizontal dimensions. The equations are solved by implicit finite difference techniques with the variables defined on a space staggered grid. These equations are shown below:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t} \quad (1)$$

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}(\frac{p^2}{h})+\frac{\partial}{\partial y}(\frac{pq}{h})+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2h^2}-\frac{I}{\rho_w}[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial y}(h\tau_{xy})-\Omega q-fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}(p_a)=0 \quad (2)$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}(\frac{q^2}{h})+\frac{\partial}{\partial x}(\frac{pq}{h})+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2h^2}-\frac{I}{\rho_w}[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})+\Omega p-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}(p_a)=0 \quad (3)$$

where $h(x,y,t)$ is water depth, $d(x,y,t)$ is time varying water depth, $\zeta(x,y,t)$ is surface elevation, $p,q(x,y,t)$ are flux densities in x and y directions, respectively. (u,v) are depth averaged velocities in x and y directions, respectively. $C(x,y)$ is Chezy resistance, g is acceleration due to gravity, $f(V)$ is wind friction factor, $V,V_x,V_y(x,y,t)$ wind speed and components in x and y directions respectively, $\Omega(x,y)$ is Coriolis parameter, $P_a(x,y,t)$ is atmospheric pressure, ρ_w is density of water, x,y are space coordinates, t is time and $\tau_{xx},\tau_{xy},\tau_{yy}$ are components of effective shear stress respectively. Using AD module along with hydrodynamic module, advection-dispersion equation can be solved together with above equations. Advection-dispersion equation is as follows:

$$\frac{\partial}{\partial t}(hc)+\frac{\partial}{\partial x}(uhc)+\frac{\partial}{\partial x}(vhc)=\frac{\partial}{\partial x}(h.D_x.\frac{\partial c}{\partial x})+\frac{\partial}{\partial y}(h.D_y.\frac{\partial c}{\partial y})-F.h.c+S \quad (4)$$

where c is compound concentration, D_x, D_y are dispersion coefficients in x,y directions, respectively, $S=Q_s(c_s-c)$, Q_s is source/sink discharge and c_s is concentration of compound in the source/sink discharge [DHI, 2005]

3.2. Input data

The proposed model covers a large portion of the Wetland, from river inlets to the beginning of outlet channel (Fig. 1), which conveys specific difficulties due to its large size. To reduce CPU time while keeping a good resolution, a grid with cell size of 100m*150m is used.

According to the Wetland sampling field survey data available for three periods of time in 2003, the model was run for the corresponding periods; These periods are dry (23rd August-1st September), early rainy (13th October-25th October) and mid-rainy (2nd December-14th December) seasons. Therefore the modeling period was chosen to be 31 days with time step of 40 seconds resulting in a maximum Courant number of 4.97. The starting times for each of the models were August 1st, October 1st and November 16th respectively.

Bathymetry is probably the most important among many factors that affect the flow properties in shallow systems like the Anzali Wetland. Modeling experiences indicate that bathymetry controls the spatial variability of current magnitude and direction, constituting a factor that assures the reliability of the numerical model. Thus, an accurate bathymetric representation is one of the most important and fundamental requirements in successful modeling [Dias, J, 2006]. Therefore bathymetric data was provided by using Iran NCC[1] maps and JICA report of bathymetric survey of the wetland.

3.3. Boundary conditions

The main hydrodynamic forcing actions for a coastal wetland have been classified as tidal forcing, rivers input and wind. Due to negligible tides of the Caspian Sea, tidal forcing is not considered as an important item influencing Anzali Wetland hydrodynamics. However, the effects of rivers input, wind and also evaporation and rainfall are taken into consideration.

In a typical two-dimensional free-surface model, open boundary conditions and wind field data are required to compute flow through the model domain. To simulate wetland outlet channels to the sea, four open boundaries were defined. Main rivers were introduced to the model using 10 isolated sources. The time series of rivers boundary conditions contain outlet direction, daily river and COD discharges, and velocity. Wind velocity was considered constant in the whole wetland and its time series data contain velocity and direction of the wind for every 3 hours.

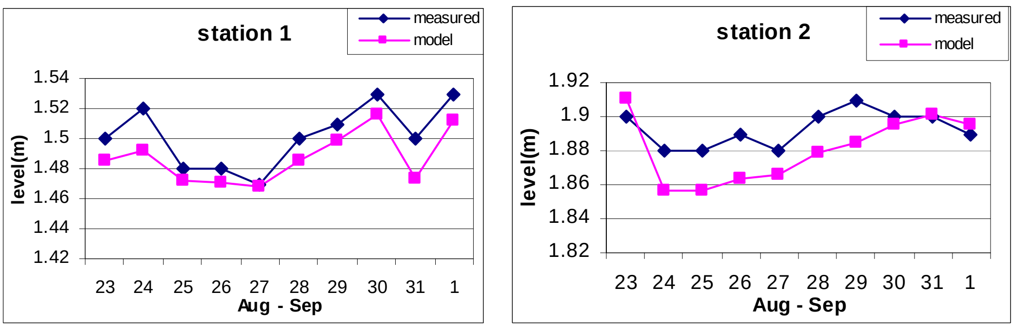
3.4. Sensitivity analysis and calibration

A large number of sensitivity tests were initially carried out to analyze the hydrodynamic and advection-dispersion models sensitivity to the variations in different parameters (initial surface elevation, eddy viscosity, resistance, and COD dispersion coefficients). Chosen hydrodynamic and advection-dispersion parameters are listed in Table 1. As shown below, Manning number has different values in different parts of the wetland due to vegetation characteristics. Sensitivity analysis showed that the model was insensitive to eddy viscosity and the calibration parameter for hydrodynamic module was Bed roughness. For advection-dispersion model the calibration parameters were dispersion coefficients in x and y directions. According to the considerable bio-degradable COD values of the wetland, decay coefficients time series was considered for the COD concentration. For polluted water and wastewater, a typical value of decay factor (base 10 at 20^{o}c) is 0.1 d^{-1} [Metcalf & Eddy, 2003]. As decay factor depends on temperature, a time series of decay factor was introduced to the model. By insight and according to air pollution condition of the area, COD concentration of precipitation and evaporation was set to zero.

Table 1: Hydrodynamic and advection-dispersion parameters of the model

Parameter	Unit	Range	Selected Value
Eddy viscosity	m^2/s	0.01-50	10
Bed roughness	$m^{(1/3)}/s$	20-50	25
The COD decay factor	s^{-1}	-	$F_T = F_{20}\theta^{T-20}$
Dispersion in x direction	m^2/s	5-40	20
Dispersion in y direction	m^2/s	5-40	10

Calibration of the hydrodynamic model was performed using available field survey data for 4 stations during a 10-days period, August 23^{rd} to September 1^{st}, which was carried out by JICA. The stations were located in different parts of the wetland (Fig. 1). Fig. 2 and Fig. 3 compare the field data and calibrated results of hydrodynamic and advection-dispersion models. The calibrated model was also run for early and mid-rainy seasons which led to reasonable results. The COD concentrations in all four stations were high denoting noticeable organic pollution in the Wetland especially in the dry season.



[1] National Cartographic Center of Iran

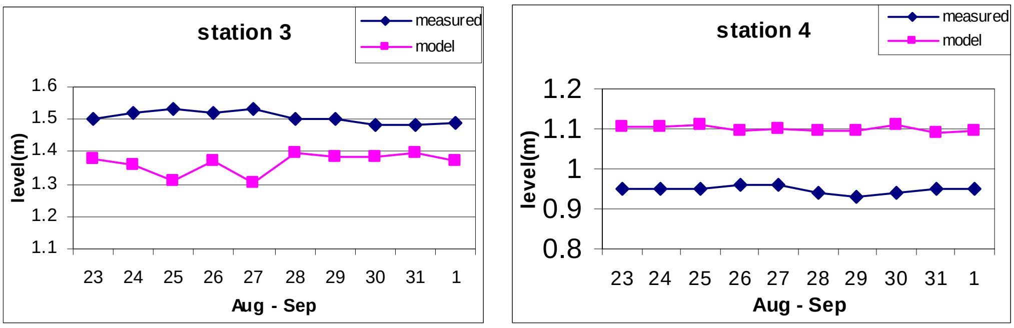


Fig. 2. Results of hydrodynamic model calibration for eastern (station 1), western (station 2 at Anzali lagoon and station 3), and central (station 4) parts of the wetland.

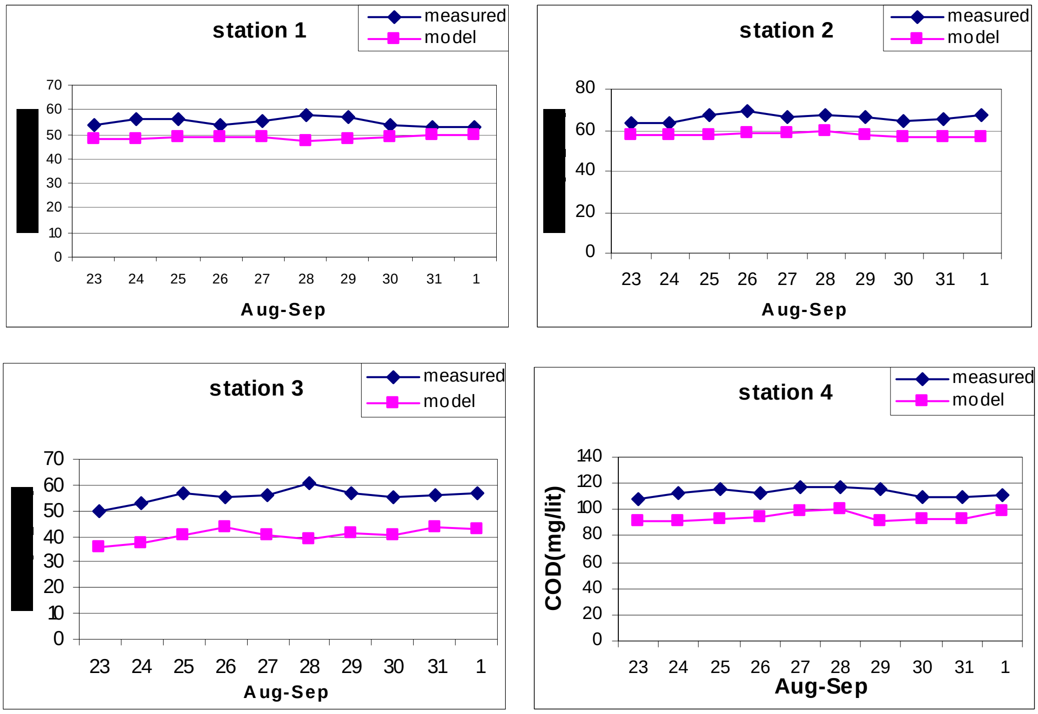
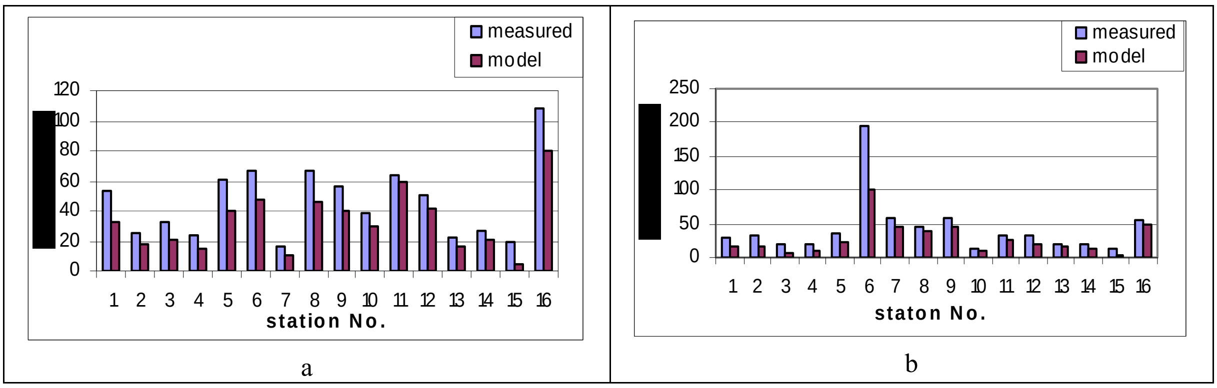


Fig. 3. Results of COD advection-dispersion model calibration for eastern (station 1), western (station 2 at Anzali lagoon and station 3), and central (station 4) parts of the wetland.



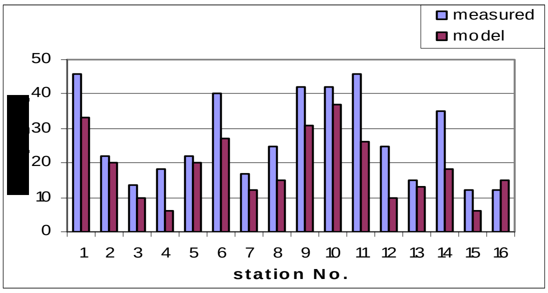


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Fig. 4: The COD concentration in 16 stations and different seasons, (a) August 23rd, (b) October 13th, (c) December 2nd

4. CONCLUSION

Rivers and wind forcing actions for depth-averaged hydrodynamic and advection-dispersion models for investigation of the COD concentration in the Anzali Wetland were considered. For AD and HD models, calibration parameters were bed resistance and dispersion coefficients in x and y directions, respectively. Using the calibrated model, the COD concentrations were determined for dry, early-rainy and mid-rainy seasons. Approximately 50% of the total organic pollution load flowed into the Wetland from the Pirbazar River.

It means that the Wetland water quality is strongly affected by domestic wastewater discharges from Rasht city. The average COD concentration in the domestic wastewater of Rasht was 156 mg.l-1. As results shown, the COD concentrations in all stations, especially in eastern and estuary stations, were high denoting noticeable organic pollution in the Wetland. The concentrations were higher in the dry season. Summarized model results are shown in Table 2. The models applied to the Anzali Wetland make use of a roughly adequate bathymetry. However, the existed differences might be result of several factors, including: inaccurate definition of the bathymetry in some regions of the model, and uncertainties in the field data.

Table 2: Results of COD in wetland water

Area		Eastern part	Central part	Estuary of the wetland	Siahkeshim (South-West)	Lagoon	Average
Aug.	Average	35	39	43	27	44	39
	Range	22-54	12-107	17-195	15-50	13-67	12-195
Oct.	Average	35	39	43	27	44	39
	Range	22-54	12-107	17-195	15-50	13-67	12-195
Dec.	Average	35	39	43	27	44	39
	Range	22-54	12-107	17-195	15-50	13-67	12-195
Criteria (US EPA)		High: COD >30 mg.l-1, Moderate: COD 20-30 mg.l-1, Slight: COD 10-20 mg.l-1, Minimal: COD 20-30 mg.l-1					

Application of this model will serve as a basis for implementing an eutrophication model to the Anzali Wetland which is the eutrophic wetland .Various water quality parameters of importance like salinity and Total Phosphorus (T-P) is ongoing.

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