DEVELOPING A WATER QUALITY MANAGEMENT MODEL FOR KARUN AND DEZ RIVERS

[*1]**M. Afkhami**, [2]**M. Shariat**, [3]**N. Jaafarzadeh**, [4]**H. Ghadiri**, [5]**R. Nabizadeh**

[1]Islamic Azad University, Sciences and Research Branch, Ahvaz, Iran

[2]Science and Research Campus, Islamic Azad University, Tehran, Iran

[3]Ahvaz Jondishapoor Medical Sciences University, Ahvaz, Iran

[4]Nathan Campus, Griffith University, Queensland, Australia

[5]Department of Environmental Health Engineering, School of Public Health,
Medical Sciences/University of Tehran, Tehran, Iran

ABSTRACT

The Karun and Dez rivers basin are the largest rivers basin in Iran which are situated in the south west of the country. Karun River originates from Zagros mountain ranges and passing through Khuzestan plain, reaches the Persian Gulf. Several cities lie along its path of them the most important is Ahvaz, the center of Khuzestan province. To achieve water quality goals in Karun and Dez rivers, a water quality management model has been developed through the GIS approach and a mathematical water quality model. In Karun and Dez rivers, water quality has decreased due to heavy pollution loads from Khuzestan province cities and surrounding areas. In this survey, pollution sources, land use, geographic features and measured water quality data of the river basin were incorporated into the Arc-view geographic information system database. With the database, the model calculated management type and cost for each management project in the river basin. Until now, river management policy for polluted rivers in Iran has been first of all to get penalties from pollution sources and secondarily, to construct treatment plants for the pollution sources whose wastewater is released untreated and for which the wastewater quality goal of the Iranian Department of the Environment is not met. Different management projects with a time program were proposed and they were compared with the results of the river quality without any management approach. It became clear that the results based on the management approach were much better than those for the unmanaged condition from the viewpoint of the achievement of water quality goals and cost optimization.

Key Words: Dez, Karun, management model, quality, river, water

INTRODUCTION

More than one third of Iran's total surface water of 94 billion m³ is flowing into the Khuzestan province but ironically most of its inhabitants are suffering from poor quality drinking water, especially during the summer months. More than 70% of the four million population of the khuzestan province, which includes the inhabitants of the provincial capital city of Ahvaz and the two major port cities of Abadan and Khoramshahr, are dependent on Karun river and its subsidiaries (KWPA, 2000 and 2001). According to the World Commission on Dam's report (WCD, 2000), Iran with 7.2 million hectares of land under irrigation agriculture is the largest in the Middle East, followed by Turkey (42 million ha) and Iraq (3.5 million ha). A large proportion of Iran's irrigated lands are in the Khuzestan province. Country wide 90% of Iran's freshwater needs are from groundwater sources and only 10% from rivers. In Khuzestan province however the opposite is true as 85% of its freshwater need is provided by rivers and only 15% taken from groundwater. Five

*Corresponding author-Email: *info@mehranafkhami.com*
Tel: +98 611 3365219, Fax: +98 611 3388474

rivers with the total annual capacity of 31 billion m^3/annum flow into the Khuzestan plain, among them, Karun, with 22 billion m^3/annum being by far the largest and also the longest river (860 km) in the province and in the country as a whole. The overall size of the Karun's catchments is 65,230 km^2. Karun originates from the Zagros mountain range on the western borders of Iran and 460 km of its 860 km journey to the Persian Gulf is in Khuzestan's alluvial plain where irrigated agriculture has at least a 3000 years history. As shown in Fig. 1, for the last 60km of its journey, Karun joins Tigris and Euphrates which flow in from the Iraqi side of the border, to form a large shipping waterway called Arvand River (Shiva, 2002). In this study, a GIS based management model was introduced to take into account the characteristics of the water quality management projects and the cost function. To date, conventional mathematical programming such as linear programming, non-linear programming, dynamic program-ming and integer programming have been used to solve the problems for regional water quality management. Revelle *et a1*., (1968) developed a river Water Quality Management Model (WQMM) using linear programming. The principal constraints prevented violation of the dissolved oxygen standards and the results of the model were compared with those based on dynamic programming. While Liebman and Lynn (1966) and Klemetson and Grenny (1985) utilized dynamic programming, McNamara (1976) and Fujiwara (1990) developed a deterministic WQMM by non-linear programming. A WQMM was also developed with integer programming (Bishop and Grenny, 1976; Burn, 1989) using transfer coefficients to constitute constraint equations. Lohani and Thanh (1979) considered river flow as a random variable and a probabilistic WQMM was constructed using the DO-sag equation. Fujiwara et al. (1987) constructed an optimisation problem of linear programming using the Streeter-Phelps equation, Lee and Lin (2000), their recursive equation and a cumulative probability density function of river flow. Genetic Algorithms (Goldberg, 1989) imitate the genetic evolution process of creatures in nature in order to determine the global optimum in mathematical programming. Genetic algorithms (GA) have some practical advantages. First, the concept is very simple and easy to understand and it can be applied to many problems for which traditional mathematical programming techniques are intractable. Second, its searching strategy is very efficient and, according to the theory, it will finally find the global optimum solution. Chen and Chang (1998) did introduce a GA to solve a non-linear fuzzy multi-objective programming model, but they only considered Biologycal Oxygen Demand (BOD) and Dissolved Oxygen (DO) as water quality parameters and the water quality calculation was based on the Streeter-Phelps equation. The first objective of this research was to develop a WQMM to achieve specific water quality goals (Krenkel and Novotny, 1980) and the optimization of management projects costs. Most WQMMs can calculate BOD and DO as a standard. For the purpose of this study, nitrogen and phosphorus were included in the management model of this study as well as BOD and DO. With a management approach exact output from the mathematical water quality model can be used in this management model. The second objective was to apply this management model to the Karun and Dez river, which is heavily polluted, and identify whether the management approach out-performs other approaches. From the application result, a regional water quality management plan would be designed to improve the river water quality. Among various sources of pollutants, the focus was placed on the pollutants from domestic, agricultural and industrial wastes, which are the most important factors in the river basin.

MATERIALS AND METHODS

This study has been done in Khuzestan province, south west of Iran (Fig. 1). A literature review was made through searching in books, journals and different papers. 20 stations were selected at Karun and Dez rivers; then twelve samples were collected monthly from each station. The samples were transferred to the laboratory and were prepared for analysis. The main reference for experimental issues was standard methods for the examination of water and wastewater. SPSS and Minitab software were used to perform a

statistical analysis of the results. A WQMM, in which water quality calculation results from the Qual2e model (Brown and Barnwell, 1987) were accurately reflected in the optimization problem whilst considering various water quality parameters such as BOD, DO, total nitrogen (TN) and total phosphorus (TP). The management model was applied to the Karun and Dez rivers where water quality is so poor that a comprehensive countermeasure for water quality restoration is necessary. The Arc-view geographic information system (GIS) was used to estimate pollution loads for the river basin.

At the end after developing a WQMM to achieve specific water quality goals (Krenkel and Novotny, 1980), introduction of management projects and their cost optimization have been done.

RESULTS

Salt in the soil profile and groundwater

Alluvial deposits in Karun and Dez river system, and three other smaller rivers, have resulted in the formation of Khuzestan plain. The plain is very flat and the rivers are prone to regular flooding despite the fact that both Karun and Dez are regulated by a number of large hydro-electric dams. The soil profile is very rich in salt deposits and groundwater is both shallow and highly saline (Ghadiri, 1985; Ghassemi *et al.*, 1995). From about 40km north of Ahvaz where the watertable is less than 1.5m deep, salt accumulation on the soil surface is clearly visible on the surface. As the groundwater table becomes even shallower further south, soil salinity is further widespread. (Afkhami, 2003). The 120 km distance between Ahvaz and Khoramshahr consists almost entirely of highly saline soils with heavy texture and high groundwater table of 0.60-1m. five new large sugar cane projects with the total area of 70000 hectares, have been planned for this region (Fig. 1). Groundwater hydrology of the Khuzestan plain also appears to have played a major part in land degradation during the great Persian Empire of 2 to 3 thousand years ago. Remnants of irrigation canals from that era can still be seen in regions around Ahvaz, an indication that the land was being used for agriculture but rising ground water and the salinization forced farmers to abandon the lands

and move further north or towards Mesopotamia. Now after more than 2000 years, the government of Iran is trying to leach the salt out of the soil profile and resurrect agricultural activities to these salt affected lower regions of the Khuzestan plain, a very costly exercise with a very doubtful outcome.
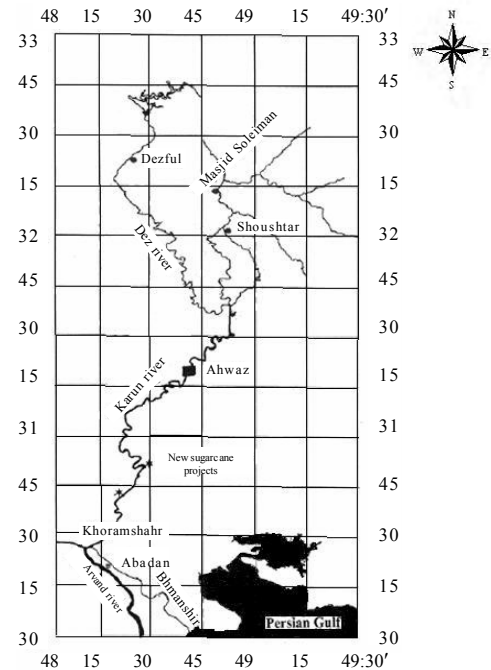

Fig. 1: The Karun river system in the Khuzestan province

Agriculture

Agriculture is by far the biggest consumer and polluter of the Karun river. Table 1 shows the current and predicted water consumption by the three main users of the Karun river. The total water consumption of agriculture and fish farming activities is currently around 10 billion m³/annum with plans to expand this amount by approximately 80% over the next 10 years. In the Agricultural sector, the main contributors to the deterioration in water quality are large agro-business units in Dezful region, large scale government owned sugar cane plantations with their modern irrigation and drainage systems and private farms and fish farms established along the Karun and Dez river system itself. By far the biggest single problem that the Karun river is facing is its rising level of salinity which is already above the drinking water limit (WHO, 2004) for several months of the year

for the two downstream cities of Abadan and Khoramshahr. Prior to growing sugar cane in these five new multi-million dollar projects, an elaborate and expensive drainage system has to be put in place and salt has to be washed down the soil profile and into the drainage system through the ponding technique.

Industrial effluents

Khuzestan is the most industrialized province of Iran and more than 25% of Iran's heavy industries are located there. Most water polluting industries of Iran such as the petroleum industry, gas and sugar refineries, petrochemical factories, paper mills, gas and petroleum based power plants, steel plants and other heavy industries are built in and around the provincial capital city of Ahvaz on the banks of the Karun river. As well as using Karun water for their needs, these industries release their sewage effluent directly into this river mostly without any treatment. Further downstream of the river and near the twin port cities of Abadan and Khoramshahr, where the Karun joins the Euphrates and the Tigris rivers, large petrochemical plants, petroleum refinery, soap factory and many others further contribute to the degradation of water quality in the Karun. In total, more than 315 million cubic meters of industrial sewage effluent directly enters into Karun river annually.

Table 1: Current and predicted future annual consumption of Karun's water

Type of consumption	Current consumption (billion m^3)	Predicted future consumption (billion m^3)
Agriculture	10	18
Drinking and industry	0.6	1
Fishery	0.6	2.1
Total	11.2	21.1

Municipal effluent

The majority of Khuzestan's population of 4 million is directly dependent upon Karun for their drinking and sanitary water consumption. Municipal sewage from several large and small cities such as Ahvaz, Abadan, Khoramshahr, Dezful, Shoushtar, Mahshahr, and Masjed-Soleiman enters the river. Table 2 shows the volume, flow rate and the salinity (Electric Conductivity, EC) of some of the sewage discharge entering Karun river in an untreated form from these municipalities.

Table 2: Municipal sewage effluent entering Karun from the major cities along the River

City	Flow rate(m^3/s)	Volume (million^3/year)	EC(mmho/cm)
Ahvaz	4.5	140	4
Abadan	0.7	19	3.6
Khoramshahr	0.5	14	5.4
Dezful	0.6	19	2.1
Shoushtar	0.3	8	2.1
Other towns	0.5	10	
Total	7	210	

Seawater intrusion

The border river of Arvand Rood, which is formed when the Karun and the two Iraqi rivers of Tigris and Euphrates join together, as well as being a major shipping waterway for both countries, irrigates the largest date palm plantation in the world. In recent years both Iran and Iraq have significantly increased water uptake from their respective rivers resulting in a decrease in the flow rate in Arvand Rood. This has lead to an increase in the distance upstream that sea water is now capable of reaching during the high tides. During the drought years of 1998-2001 sea water backed up to the main pumping stations of the city of Abadan severely contaminating its drinking water supply. The date palm plantation industry has already been damaged by the steady rise in river salinity. Seawater intrusion, if it continues, will ultimately destroy both countries' multi-million dollar date export industry given time.

Water quality model and pollution load

QUAL2E was chosen as the water quality model for this study because it is a one dimensional steady state model and it is easily applicable to this type of management. Modeling was performed from the Shahid Abasspoor and Dez Dams, which are located in the upper parts of the rivers, to the estuary bank as shown in Fig. 1. The main river channel was divided into 5 reaches. Hydraulic calculations in the QUAL2E model were performed with the depth-flow and velocity-flow equation (Brown and Barnwell, 1987). Initially, the model was calibrated using the data set observed at the Karun river in 1999 from Karun river waterway project. Immediately after joining the effluent flow of the Karun Dez river. However the calculated BOD and DO were lower than those observed in 1999. Likewise, the water quality

data for stations observed on different sampling dates were also compared with the calculated values. Data sets of the model for verification including point source pollutant loads and stream flow were prepared based on conditions in October 2002 till September 2003. Unfortunately, as a large volume of water is needed for agricultural use in some special months, thus, the fluctuation of the river water quality is very high, and it was difficult to use the observed data for that particular date for verification. For BOD and DO, the calculated results show quite a good correspondence with the standards. To obtain pollution load data from point sources and incremental inflows in the model, the basin was divided into 5 sub-basins using Arc-view spatial analyst pollution loads from each sub-basin were estimated using a 180m*180m grid based database compiled from the pollution sources data. Based on the unit load approach, pollution loads from point sources and non-point sources were estimated using the Arc-view GIS. The pollutant removal rate of management projectswere taken into account when estimating the pollution loads from the WQMM with pollution
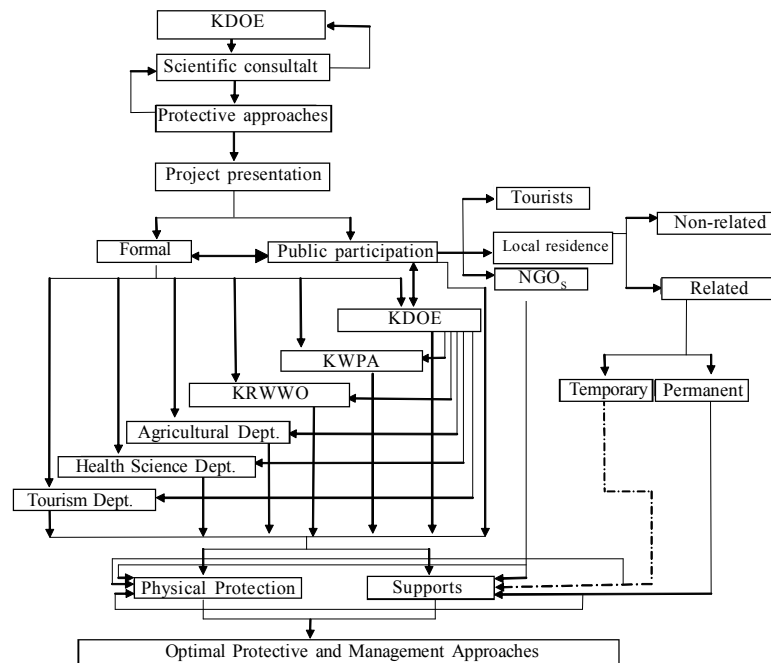

Fig. 2: The pattern of protective and management approaches

WQMM, water quality manage-ment model; BOD, biochemical oxygen demand; DO, dissolved oxygen; TN, total nitrogen; TP, total phosphorus; GIS, geographic information system; WWTP, wastewater treatment plant; GAs, genetic algorithms; KDOE, Khuzestan department of environment; KWPA, Khuzestan water and power Authority; KRWWO, Khuzestan rural water and wastewater organization.

loads of each reach calculated from delivery ratios (the ratio of the mass of pollutants delivered to a stream divided by the mass of pollutants generated at the source (Novotny and Olem, 1994)).

Proposed management options
In this section, the proposed management options for water pollution control of the Karun-Dez basin are presented. These options have been identified and proposed through the cooperation of experts and the stakeholder organizations and agencies in the study area (Fig. 2). The proposed options, which should be implemented during a 10 years timeframe, have been categorized into three groups, namely direct, indirect, and supporting projects. The general characteristics of these projects are presented below:
Direct projects
Direct projects are those which can directly improve the river water quality. The direct projects are classified into industrial, domestic,

and agricultural sectors as follows:

- Industrial Sector: The proposed direct projects for the industrial sector have been presented considering the following main categories:
  - point source reduction
  - improved solid waste disposal
  - reduction of water withdrawal from Karun river and
  - control of miscellaneous polluter

As most of the industrial point loads are violating the wastewater discharge standards of Iranian Department of the Environment, point source reduction will have significant effect on the Karun river water quality.

- Domestic sector: The proposed direct projects for the domestic sector have been prepared considering source reduction as the main objective. The most important proposed projects that can improve the river water quality for the domestic sector are:
- implementation or completion of wastewater collection and treatment systems for cities in the study area and
- separation of biomedical wastewater of hospitals located in the study area and surface runoff management in urban areas.
- Agricultural and Agro industrial sector: The direct water pollution reduction projects for agricultural and agro industrial sector have been prepared considering source reduction as the main objective. These projects are categorized into two sections, namely pesticide and fertilizers pollution reduction, and deployment of modern irrigation projects of agricultural return flows. The most important proposed projects for agricultural and agro-industrial sector are:
- improvement and optimization of the crop pattern and irrigation systems,
- using the resistant and plentiful seeds,
- reducing the application of pesticides and chemical fertilizers in agricultural lands,
- use of suitable pesticide and fertilizers in agricultural networks,
- transferring agricultural return flows,
- recycling and reuse of agricultural wastewater,

- watershed management
- reduction of the pollution loads of the hatchery projects.

Indirect projects

Indirect projects are those which can indirectly reduce the river water pollution. These projects can also provide a long term stability in water supply and demand and restore the ecological condition of the system. The most important indirect projects are proposed are:

- review of inter basin water transfer projects to create balance between water supply and use,
- development of the infrastructure needed in the domestic sector such as improvement of the domestic water supply system,
- improving the domestic water use pattern,
- separation of drinking and non-drinking water
- reducing water losses.

Supporting projects

The supporting projects are aimed at providing the basic information and research background needed for the implementation, monitoring, and evaluation of the master plan of water pollution reduction of Karun river. The supporting projects have been proposed considering the following objectives:

- development of a water quality monitoring network
- man power capacity expansion and behavioral improvement of existing institutional framework
- Policies and rules scientific and research based approaches.

Successful implementation of the agricultural water pollution reduction projects will reduce the concentration of pesticides and total dissolved solids in agricultural return flows as well as improving the irrigation efficiency by up to 20 percent. The pollution load reduction for each sector has been estimated using the hierarchical structure and the relative weights of water quality variables. Based on the results of this study, which are presented in Table 3, the water pollution in agricultural, industrial, domestic, and miscellaneous sectors can be reduced 45, 88, 30, and 65 percent respectively. Table 3 presents the share of each sector in annual water use, pollution load, and the

percentage of pollution reduction due to implementation of the proposed water pollution control projects. However, as evidenced in table 3, the pollution load is not completely related to water use. For example, the domestic sector that uses only 4 percent of the total water use discharges 26 percent of the total pollution load of the system. Table 3 also shows the range of variation of the estimated share of each sector in pollution load due to uncertainty in estimation of water use, and quantitative and qualitative characteristics of discharged wastewater. The estimated share for agricultural and miscellaneous sectors is less certain because of either insufficient or imprecise data related to the assessment of pollution loads of return flows, urban surface runoff, leakage from land fills, underground storage tanks, and pipes which are used for storage or transfer of oil and related products. (Afkhami, 2005).

Table 3: Percent of pollution reduction in different sectors considering proposed pollution reduction projects

Sector	Percent of pollutant reduction in eachSector	Share of each sector from total pollution reduction	Percent of total pollution reduction
Domestic	30	48	14.5
Industry	88	26	23
Agriculture and Agro-industry	45	23	10.5
Miscellaneous	65	3	2
Sum	-	100	50

DISCUSSION

One of the most important phases of this study has been the need to determine an accurate timetable and budget for implementation of the projects. The projects with a higher effectiveness have been prioritized and budgetary spending has been provided. These priority projects will be executed during the first few years of the water pollution reduction strategy. The share of this allocation from the total budget is very high because of the high cost of collection system. The allocated budgets to other sectors in this table also show the amount needed for a one percent reduction of water pollution in each sector. As demonstrated below, the unit reductions in urban and industrial projects are more than agricultural and miscellaneous sectors. In a suggested framework for approving, monitoring, and evaluation of Karun pollution reduction projects,

the Commission on Karun Environmental Protection will be the major overseer for these activities. The representative of Khuzestan Environmental Protection Office will be the executive secretary of the commission. The commission will select the members of urban, agricultural and agro-industrial and industrial committees. The main task of these committees will be to review and tentatively approve the suggested water pollution reduction projects and their associated budget requirements considering the overall framework for the master plan of Karun pollution reduction. These recommendations will then be passed to the Commission for final approval. The committees should request details of design, required budget, and the implementation timetable for different projects from all of the involved organizations. Each committee should approve the above details based on the compatibility of each project with the master plan for Karun pollution reduction, available amount of budget and time needed for implementation. Where budget restrictions affect the commencement and delivery of a project, then the affected projects should be prioritized keeping in mind the overall framework and other "cause and effect" issues related to the overall implementation of the master plan. For this purpose, the projects are prioritized in this study based on their effectiveness in Karun river pollution reduction within the assessment limited time framework. As an example, in the agriculture and agro-industrial section that consumes 88.5% of the total water and produce 48% of the contamination, development of modern methods of irrigation and increasing efficiency like treatment and reuse of drainages that needs five years time and 100,000 million Rials, totally can reduce contamination by 10.5% with spending 447000 million Rials. The WQMM using pollution mitigation projects developed in this study was applied to the Karun and Dez rivers because of their very poor water quality. Pollution loads used in the model were calculated using Arc-view. The project type and cost of the projects in the river basin to simultaneously achieve the water quality goals and pollution reduction cost optimization were calculated from the model. Nowdays, water quality management policy in Iran has focused mainly on wastewater treatment capacity expansion through the construction of new

WWTPs. However, from an economic viewpoint this is extremely ineffective and therefore it is necessary to establish a systematic water quality management plan that directly considers the cost of pollution mitigation projects. In the WQMM the results calculated using the QUAL2E model is directly used to check the water quality goal. Accordingly, the WQMM has several advantages in that it can reflect the non-linearity of the mathematical water quality model, consider several water quality parameters and find the exact optimal solution to the cost optimization problem. According to the above mentioned results, some self-governing communities in the river basin would need to invest heavily in river quality management whilst other communities would contribute little and it is appreciated that mediating the profits and losses of the self-governing communities in the river basin is very difficult. Nonetheless, it is expected that the results of this study could be beneficial for the water quality management plan for comprehensive and cost-effective management of the Karun and Dez rivers in both the short and long term.

ACKNOWLEDGEMENTS

REFERENCES

Afkhami, M., (2003). Environmental Effects of Salinity in the Karun Dez basin, Iran. Int. J. Arab. Water. World. Beirut. Lebanon.

Afkhami, M., Shariat, M., Jafarzadeh, N., Ghadiri, H. and Nabizadeh, R., (2005) Quality and Operation management plan of Karun and Dez Rivers at basic reaches. Research Program of TSRC. IAU. Tehran. Iran.

Bishop, A. B., Grenny, W. J., (1976). Coupled optimization-simulation water quality model. J. Environ. Eng. Division., ASCE., **92** (5): 1071-1086.

Brown, L. e., Barnwell, J. R., (1987). The Enhanced Stream Water Quality Models Qual2e and Qual2e-Uncas: Documentation and User Manual. EPN 600/3-87/007. US Environmental Protection Agency, Athens. 15-16.

Burn, D. H., (1989). Water-quality management through combined simu-lation-optimization approach. J. Environ. Eng., ASCE **115** (5): 1011-1024.

Chen, H. W., Chang, N. B., (1998). Water pollution control in the liver basin by fuzzy genetic algorithm-based multi objective programming model-ing. Water. Sci. Technol., **37** (3): 55-63.

Cho, J. H., (2001). Development and Application of a River Water Quality Management Model to Optimize the Waste Load Abatement Cost by Genetic Algorithm, Second Interim Report of the Interdisciplinary Research Program of the KOSEF. Republic of Korea 2001 p. 56.

Fujiwara, O., (1990). Preliminary optimal design model for wastewater treatment plant. Journal of Environmental Engineering. ASCE., **116** (I): 206-210.

Fujiwara, O., Gnanendram, S. K., Ohgaki, S., (1987). Chance constrained model for river water quality management. J. Environ. Eng. ASCE., **113** (5): 1018-1031.

Ghadiri, H., (1985). Reclamation of Salt Affected Soils of Khuzestan and the Deterioration of Water quality of Karun River. Shahid Chamran University. Ahvaz, Iran.

Ghassemi, F., Jakeman, A. J. and Nix. H. A., (1995). Salinization of Land and Water Resources: Causes, Extent, Management, and Case Studies. NSW University Press. Sydney, Australia.

Goldberg, D. E., (1989). Genetic Algorithms in Search, Optimization and Machine Learning. Addison-Wesley. Massachusetts, USA.

Guidelines for drinking-water quality. (2004). Vol1, 3rd Ed. WHO. Geneva. Switzerland.

Klemetson, S. L., Grenny, W. J. (1985). Dynamic optimization of regional wastewater treatment systems. J. Water. Pollut. Shar. Control. Federation., **57** (2): 128-134.

Krenkel, P. A., Novotny, V., (1980). Water Quality Management. Academic Press, Y. N. USA., 10003.

KWPA., (2000)., An Assessment of Pollutants in Karun River. A report prepared by the Water Quality Assessment section, Khuzestan Water and Power Authority. Ministry of Power. Ahvaz, Iran.

KWPA., (2001). Salinization of Abadan Water. A report prepared by the Division of Water utilization, Khuzestan Water and Power Authority. Ministry of Energy. Ahvaz, Iran.

Lee, C. C., Lin, S. D., (2000). Handbook of Environmental Engineering Calculations, Mc Graw Hill, N. Y. USA., 189-190.

Liebman, J. C., Lynn, W. R., (1966). Optimal allocation of stream dissolved oxygen, Water. Resources. Res., **2** (3): 581-591.

Lohani, B. N., Thanh, N. C., (1979). Probabilistic water quality control policies. J. Environ. Eng. Division., ASCE, **104** (4): 713-725.

McNamara, J. R., (1976). Optimization model for regional water quality management. Water. Resources. Res., **12** (2): 125-134.

Novotny, V., Olem, H., (1994). Water Quality Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold. N. Y. USA.,603.

Revelle, C. S., Loucks, D. P., Lynn, W. R., (1968). Linear programming applied to water quality management. Water. Resources. Res., **4** (I): 1-9.

Shiva, V., (2002). Water wars: Privatization, Pollution and Profit. South End Press.

WCD., (2000). Dams and Development: A Framework for Decision Making. A report of the World Commission on Dams, Earth Scan Publication, London.