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Integrated river quality management by CCME WQI as an effective tool to characterize surface water source pollution (Case study: Karun River, Iran)

Ranjbar Jafarabadi, A.[1*], Masoodi, M.[2], Sharifiniya, M.[3], Riyahi Bakhtiyari, A.[1]

1. Department of Environmental Sciences, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor, Mazandaran, Iran
2. Department of Environment Science, *Gorgan University of Agricultural and Natural Resource, Iran*
3. Department *of Fishery* Science, *Gilan University, Iran*

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ABSTRACT: Evaluation of surface water quality is a complex process undertaking multiple parameters. Converting great amount of parameters into a simpler expression and enabling easy interpretation of data are the main purposes of water quality indices. The main aim of this study is to plan effective water resources management system for Karun River by combination of CCMEWQI and Geographic Information System (GIS). The investigation was carried out to set a management plan through exploratory and spatial analysis of physicochemical water parameters of collected samples from 10 stations over one year period. Since all indices were obtained from index, river zoning was conducted by GIS. Moreover, trace metals concentrations (As, Cr, Cd, Fe, Zn, Mn, and Al) ranged in safer limit. The highest values of F_1 belonged to aquatic life and the lowest ones belonged to irrigation. Aquatic life and drinking uses received the maximum values of F_2. The lowest values were devoted to livestock and then recreation uses. It was inferred from index that the quality of the Karun River is principally impacted by high turbidity, TDS, NO_3, SO_4, and PO_4 due to high suspended sediment loads. The main cause is incremental agricultural, industrial, and residential effluents. Amongst stations, station one only received the priority for drinking water supply and recreation.

Keywords: CCME water quality index, GIS, Karun River, river water quality, water management plan, water quality index.

INTRODUCTION

Rivers are imperative carriers of water and nutrients to areas all around the earth and provide important sources of water for drinking and industrial, aquaculture, and recreational usages. Because surface waters (streams and rivers) are among the most sensitive, susceptible, and endangered ecosystems worldwide (World Resources Institute, 2001), there are urgent demands for comprehensive methodological approaches to assess the actual state of these ecosystems and to monitor their rate of changes (Rosenberg and Resh, 1993). Physical, chemical, and bacteriological measurements commonly form the basis of monitoring because they provide throughout spectrum of information for

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[*] Corresponding Author Email: ali_rjcomeon@yahoo.com

suitable and accurate water management (Metcalfe, 1989).Nevertheless, in running waters, where changes in hydrology are swift and hard to assess, they cannot reflect the integration of numerous environment factors and long-term sustainability of river ecosystems for their instantaneous nature. Integrated river management planning is an enduring process that supports sustainable water use while protecting the water environment. It is even more essential in semi-arid regions such as Iran that experience water shortage problems. According to the indicators of United Nations (UN) and the International Water Management Institute (IWMI), Iran is in a severe water crisis situation (Ehsani, 2005). Thus, applying an integrated river quality plan for saving surface waters and using them as fresh water resources is very vital for the country.

Water quality indices (WQI) techniques

Water quality assuagement and monitoring of rivers have been globally used all over the world to determine the sources of pollutants (man-made or natural) and their effects (temporally and spatially). Evaluation of surface water quality may be a complicated process due to undertaking multiple parameters which impact the overall water quality. To analyze water quality, different approaches like statistical analyses of individual parameters and multi-stressors water quality indices (WQI) have been considered (Venkatesharaju *et al.*, 2010). Water Quality Indices (WQIs) are efficiently used and they serve as a tool to communicate and translate data on water quality (Poonam *et al.*, 2013). The communication of water quality data is especially challenging when the intended audience for the water quality data is general public who is not directly interested in water quality data. Data are not usually available in simply understandable form. Their complex nature makes it difficult to be reviewed by untrained people. To fill this gap of communication, various water quality indices have been developed which reduce the large water quality data into easily interpretable values.

There were a number of institutions that had applied some form of an index on water quality data prior to the development of the CCME WQI. The usefulness of indices as an evaluation tool and their ability to communicate complex information in simple manner made them widely accepted for water quality management. Many researchers (e.g. Smith, 1990; Swamee and Tayagi, 2000; Said *et al.*, 2004; Lumb *et al.*, 2006; Davis, 2006; Kaurish and Younos, 2007; Al-Janabi *et al.*, 2015; Edwin and Murtala, 2013; Damo *et al.*, 2013; Mahesh Kumar *et al.*, 2014; Ajayan and Ajit Kumar, 2016) have developed their own rating schemes during the last four decades. Some of the water quality indices that have been frequently employed in public domain for this purpose are the National Sanitation Foundations' WQI, British Columbia Water Quality Index (BCWQI), Canadian Water Quality Index (CWQI), Oregon WQI, and the Florida Stream WQI (Said *et al.*, 2004).

Presently, many research projects and studies are being conducted by methods to create water quality indices. For example, US National Sanitation Foundation Water Quality Index (NSFWQI) (Sharifi, 1990), Canadian Council of Ministers of the Quality Index (BCWQI), and Oregon Water Quality Index (OWQI) (Abbasi, 2002; Debels *et al.*, 2005; Kannel *et al.*, 2007). These indices are based on the comparison of the water quality parameters to regulatory standards and give a single value to the water quality of a source (Abbasi, 2002; Khan *et al.*, 2007). Table 1 provides a summary of WQI application in different river basins.

Table 1. A summary of WQI application

River and location	Number of station	Basis of study	Main pollutant	refrence
Han River and its tributaries in Seoul, Korea	26	spatial and temporal	temperature, pH, DO, BOD,COD, suspended solid, total nitrogen and total phosphor	Heejun, 2005
San Antonio River in USA		spatial and temporal	pH, DO, temp, TDS, total nitrate–nitrogen, total orthophosphate, turb, alk, TH	Anderson et al., 2007
Tigris River in Baghdad city	3	monitoring program	pH, TDS, Calcium, Total Alkalinity, Ammonia, Nitrate, Nitrite, Turbidity, Lead Chromium, Iron	Al-Janabi et al., 2015
Kelani River Basin, Sri Lanka	27	spatial and temporal	pH, TDS, DO, Total phosphate, Nitrate, Nitrite, Hardness, Conductivity, BOD COD, Total coliform and Feacal coliform bacterial counts, Cd, Pb, Al, Zn, Cu and Cr	Mahagamage and Pathmalal, 2015
Al-Hill River in Al-Hilla city-Iraq	3	spatial and temporal	Turb, Alk, Cl, pH, Mg, Ec, Ca, TH	Mokif, 2015

In this work, CCME Water Quality Index and GIS techniques have been used to investigate Karun River water quality and determine effects of anthropogenic and natural pollutants on the river water quality. Also, the priority of usage in each zone form upstream to downstream was determined.

MATERIALS AND METHODS

Study area

Karun River is the only navigable river in Iran. It receives many tributaries such as Dez and Kuhrang before passing through Ahvaz as the center of province. The largest river in Iran covers 65,230 square kilometers (25,190 sq mi) in parts of two provinces. Sixty-four percent of the volume flows in Khuzestan province. The River is almost 950 kilometers (590 mi) long. The largest city on the river is Ahvaz, with over 1.3 million inhabitants. Since the British first discovered oil at Masjed-Soleyman, Karun has been an important route for the transport of oil to the Persian Gulf and remains a strategic commercial waterway. Water from Karun provides water irrigation to over 280,000 hectares (690,000 acres) of the surrounding plain. The average, maximum, and minimum annual flow rate is 21694, 38323, and 12242 million cubic meter per year, respectively. Geographical position of study area can be seen in Figure 1.

Sampling stations and methods

Grab samples of water were collected at 10 sampling stations. Both in-situ and laboratory analysis of the collected samples were performed using analytical methods and guidelines published by United Nation Environment Program (UNEP) and Global Environment Monitoring System/ Water Program (2004). Over one year period, twelve samples from each station and totally 120 samples during four seasons were collected. Critical parameters chosen to evaluate the WQI were Turbidity, TDS, SO_4, Chloride, As, Cr, Cd, Fe, Zn, Mn, Al, Dissolved Oxygen, BOD_5, pH, phosphates, nitrate, Ca, and Mg. Location of Sampling stations and geographical positions can be seen in Table 2.

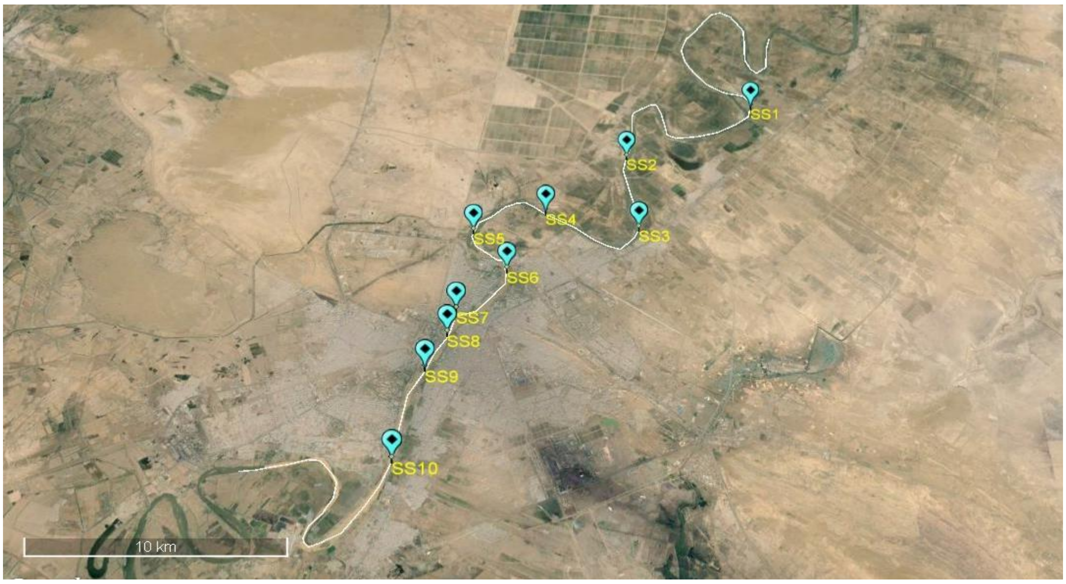

Fig. 1. Study area and water quality monitoring stations along side of the River

Table 2. Geographical positions of selected water quality monitoring stations and distance between each other.

Station [a]		SS_1	SS_2	SS_3	SS_4	SS_5	SS_6	SS_7	SS_8	SS_9	SS_{10}
Coordinates(UTM)[b]	Y	3480740	3477593	3473405	3474413	3473378	3471165	3469032	3467831	3466112	3461814
	X	292371	286507	287063	282960	279789	281361	279289	279011	278183	277180
Distance (km) Between stations		0	8.5	5.5	5.5	4.7	4.2	4.3	2.5	3.5	5.5

a= Sampling Stations b=Universal Transverse Mercator

Conceptual framework of CCME water quality index

In 1997, the CCME Water Quality Index technical subcommittee was formed to assess the various approaches already being used and subsequently formulate a CCME WQI. The CCME WQI has been applied successfully on several ambient water quality data sets from across Canada and is being used to communicate ambient water quality data in several provinces (CCME, 2001). WQI is not a substitute for detailed analysis of water quality data and should not be used as a sole tool for management of water bodies. CCMEWQI compares observations to a benchmark instead of normalizing observed values to subjective rating curves, where the benchmark may be a water quality standard or site Specific background concentration (CCME, 2001; Khan *et al.*, 2003). So, it can be applied by the water agencies in different countries with little modification.

To categorize water quality under this, four categories have been suggested i.e. Excellent, Good, Fair, and Poor (Khan *et al.*, 2004). The CCME WQI model is consisted of three measures of variance from selected water quality objectives (Scope; Frequency; Amplitude). These three measures of variance combine to produce a value between 0 and 100 that represents the overall water quality. The CCME WQI values are then converted into rankings by using an index categorization schema. Figure 2 shows the conceptual model for the index. The values of three measures of variance from selected objectives are combined to create a vector in an imaginary ‘objective exceedance’ space. It is consisted of three measures.

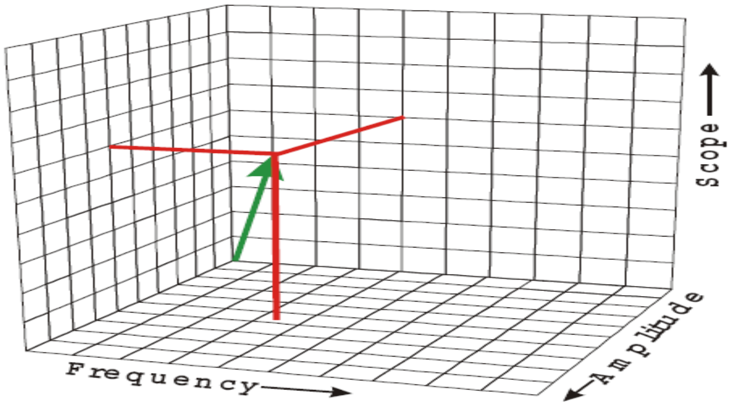

Fig. 2. Conceptual model for CWQI

F_1 represents the extent of water quality guideline noncompliance over the time period of interest. The measure for frequency is F_2. This represents the percentage of individual tests that do not meet objectives ("failed tests"). F_3 is for amplitude representing the amount by which failed tests do not meet their objectives. The first step (F_1) is Calculation of Excursion. Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective when the test value must not exceed the objective. The next (F_2) is the calculation of normalized sum of excursions. Nose is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). The last step (F_3) is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives to yield a range from 0 to 100. CCME WQI original factor formulas are presented in Table 3. The WQI is then calculated as Eq. (1)

$$CCME\ WQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right] \tag{1}$$

The WQI values are then converted into rankings using the categorization schema as shown in Table 4.

Table 3. CCME WQI factor formulas

Factor	CCME WQI formula	
F_1	$F_1 = \left(\frac{Number\ of\ Variables}{Total\ Number\ of\ Variables} \right) \times 100$	(2)
F_2	$F_2 = \left(\frac{Number\ of\ failed\ Samples}{Total\ Number\ of\ Samples} \right) \times 100$	(3)
F_3	$Excursion_i = \left(\frac{failed\ test\ value_i}{Objectives_j} \right) - 1$	(4)
	$Excursion_j = \left(\frac{Objectives_j}{failed\ test\ value_i} \right) - 1$	(5)
	$nse = \frac{\sum_{i=1}^{n} excursion_i}{Total\ Number\ of\ Samples}$	(6)
	$F_3 = \frac{nse}{0.01 nse + 0.01}$	(7)

Table 4. CCME WQI Categorization Schema

Rank	WQI Value	Description
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all of the time.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

PRINCIPAL COMPONENT ANALYSIS

In this study, WQIs were calculated at ten stations (SS) and forty locations (L) along the river for its five intended uses: drinking, irrigation, aquatic life, recreation, and livestock. The set of data used in the CWQI 1.0 model for the calculation of WQIs was adopted from the results of monitoring program conducted. In this monitoring program, surface water quality was monitored using grab sampling with short holding time (<1 day) on a monthly basis.

To adopt best suited water quality guidelines (objectives) for WQI, calculation in context of indigenous water quality conditions was a significant important consideration. Numerous sets of standards, or guidelines for water quality, have been issued from time to time by various agencies and authorities (e.g. United States Environmental Protection Agency (EPA), World Health Organization (WHO), European Union (EU), and individual countries), intending to define the maximum acceptable limit of water pollution by various pollutants. Standards for ambient water quality are commonly designated according to the intended use of the water resource.

RESULTS

Temporal and spatial variations of physical and chemical parameters

As a result, an increasing trend in the main irrigation parameters (pH and TDS) is observed as the river flows downstream. The temporal and spatial trend variation of mineral surface water quality parameters in Karun River are shown in Table 5.

The application of irrigation water containing high concentrations of EC, TDS, pH, and Na may cause salinity and sodic problems in the receiving soils that may result in decreased crop yields. Moreover, trace metals concentrations (As, Cr, Cd, Fe, Zn, Mn, and Al) are ranged in safer limit. The presence of Cr, Cd, and As in Karun River indicates the significant effect of drains. This effect is not neutralized to some extent as the river flows upstream towards downstream. BOD and DO are the most important parameters in water quality assessment. Adequate dissolved oxygen concentrations are essential to the overall health of the aquatic community. Warmer water temperatures during the summer months generally increase biological activity and overall productivity. Warmer temperatures also enhance bacteria activity and consumption of oxygen. Solubility of oxygen also decreases with warmer temperatures. Thus, oxygen concentrations in river may also drop below water quality requirements in summer. The temporal and spatial variation of BOD and DO in Karun River are shown in Table 6.

Table 5. Temporal and spatial variation of mineral surface water quality parameters in Karun River

Parameter	Season	Range	Unit	Observed maximum spatial variations (Number of stations)
pH	Winter	9.5-8.8	-	4 to 5
	Spring	8.4-9.8		3 to 4-6 to 7
	Summer	8.9-9.6		6 to 7
	Autumn	9.1-9.5		1 to 2-8 to 9
TDS	Winter	2000-2816	mg/L	8 to 9
	Spring	920-2638		1 to 2-4 to 5
	Summer	960-2765		1 to 6
	Autumn	1660-2680		1 to 2-8 to 9
PO_4^{-3}	Winter	4.8-2.8,2.8-1.1,1.8-3.2	mg/L	5 to 6-7 to 8-9 to 10
	Spring	1.1-3.7		1 to 2-4 to 5
	Summer	1.3-3.3		4 to 5
	Autumn	1.2-3.3		1 to 2-8 to 9
NO_3^-	Winter	2.8-3.8,3.8-2.1,2.8-4.4	mg/L	1 to 2,7 to 8, 9 to 10
	Spring	2.1-4.4		1 to 2-4 to 5
	Summer	2.24-4.4		4 to 5
	Autumn	2.3-4.3		1 to 2-8 to 9
$SO4^{-2}$	Winter	5-2.5,1.8-3.2	mg/L	7to 8-9 to 10
	Spring	2.4-5.2		7 to 8
	Summer	1.3-5.7		4 to 5
	Autumn			1 to 2-8 to 9

Table 6. Temporal and spatial variation of BOD and DO in Karun River

Parameter	Season	Range	Unit	Observed spatial incline of parameters (Number of stations)
BOD_5	Winter	2.3-3.4	mg/L	7 to 8
	Spring	1.6- 3.7		2 to 3-4 to 5
	Summer	2.1-3.4		1 to 10
	Autumn	2.2-4.11		1 to 8
DO	Winter	4.7-6.1	mg/L	6 to 7-8 to 9
	Spring	5.1- 6.8		4 to 5-6 to 7
	Summer	4.7-7.1		6 to 7
	Autumn	4.7- 6.5		6 to 7

In contrast to downstream, low concentrations of BOD were detected in upstream. Discharge variations in the Karun River mainly depend on the flow of the channels. Channels and natural streams are mainly located along side of river and especially in downstream. The main contribution of municipal and industrial effluents and surface drains are observed around SS_8 and SS_9.

Variation rates of turbidity seasons were considerable in four sampling. The temporal and spatial variation of turbidity in the Karun River can be seen in Table 7.

The temporal and spatial variation of chlorine in Karun River can be seen in Table 8.

Temporal and spatial variations of heavy metals

Variations rate of heavy metals was insignificant and most of them were under value of standards. Fig. 4 indicates the changes of measured parameters in sampling stations in four seasons.

Index score computation and exploration of factor weights

A summary of three computed measures of variance for selected water uses including F_1 (scope), F_2 (frequency), and F_3 (amplitude) can be seen in Table 9. Among all the water uses, F_1 has higher values than F_2 and lower values than F_3 in all the selected river stations. It indicates that there is a higher percentage of failed variables than the percentage of individual failed tests. Moreover, F_1 values rise from SS1 to SS4 for drinking water supply. They also increase from SS_1 to SS_4 for other purposes. However, a noticeable decrease from SS_4 to SS_5 for drinking and aquatic life can be seen. This trend infers that major water quality variables failed (do not meet their objectives) in the downstream polluted by the surface drains. The highest values of F_1 belonged to aquatic life and the lowest ones belonged to irrigation.

Table 7. Temporal and spatial variation of turbidity in Karun River

Parameter	Season	Range	Unit	Observed spatial maximum incline of Turbidity	Observed spatial maximum decline of Turbidity
Turbidity	Winter	180-380,450-650,640-60	NTU	2 to 3-4 to 5	5 to 6
	Spring	16.6-573		2 to 3-4 to 5	5 to 6
	Summer	24-578		4 to 5	5 to 6
	Autumn	210-420,420-620-620-50		3 to 4- 4 to 5	5 to 6

Table 8. Temporal and spatial variation of chlorine in Karun River

Parameter	Season	Range	Unit	Observed spatial maximum incline of Chlorine	Observed spatial maximum decline of Chlorine
Chlorine	Winter	70-14	mg/L	-	2 to 3
	Spring	9.3-93.3		2 to 3-7 to 8	3 to 4
	Summer	13.6-93.7		2 to 3-7 to 8	3 to 4
	Autumn	68-12		-	2 to 3

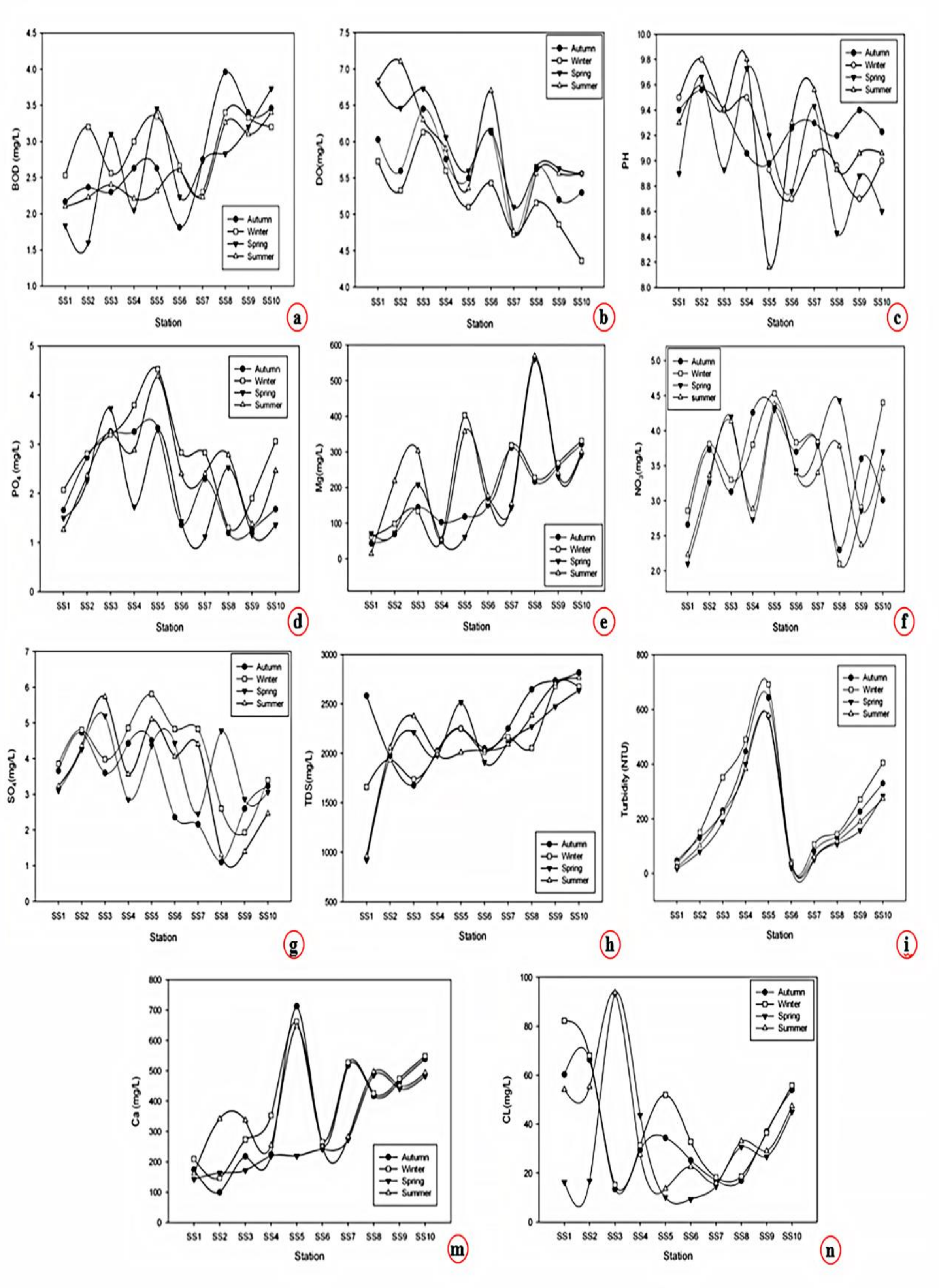

Fig. 3. The variations of measured parameters in ten stations in four seasons

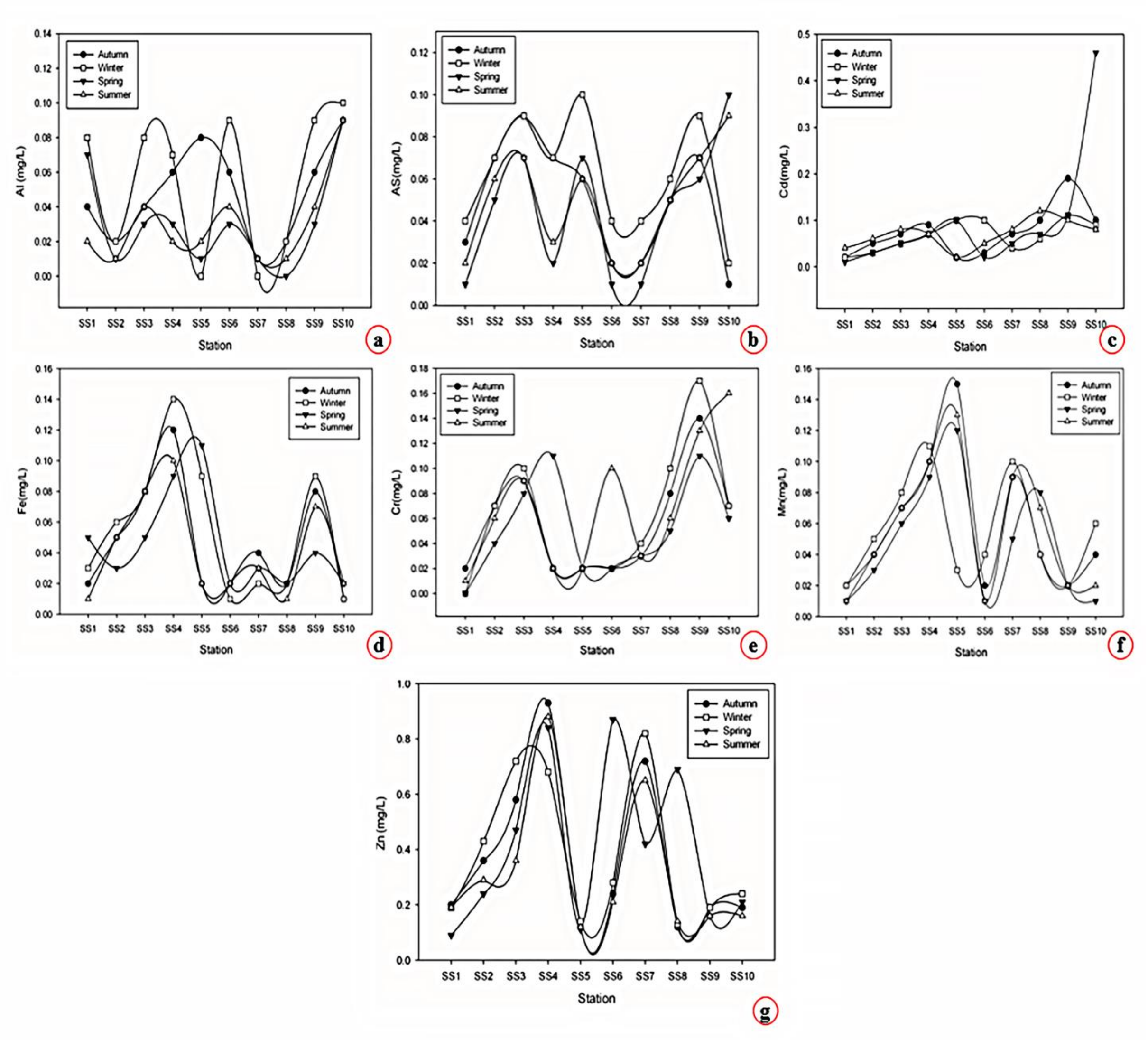

Fig. 4. Seasonal variations of measured heavy metal parameters in sampling stations

Table 9. F_1 (Scope), F_2 (Frequency), and F_3 (Amplitude) for different water uses of the Karun River in four seasons

Station	Data summary	Drinking	Aquatic	Recreation	Irrigation	Livestock
SS_1	CWQI	69	31	65	81	81
	Categorization	Fair	poor	Fair	Good	Good
	F_1	27	73	25	12	14
	F_2	21	64	25	10	12
	F_3	41	71	50	29	26
SS_2	CWQI	49	23	60	62	63
	Categorization	Marginal	poor	Marginal	Marginal	Marginal
	F_1	36	73	25	12	14
	F_2	35	69	25	12	14
	F_3	72	88	60	63	61
SS_3	CWQI	40	21	59	54	58
	Categorization	poor	poor	Marginal	Marginal	Marginal
	F_1	45	73	25	25	14
	F_2	40	71	25	23	14
	F_3	85	92	61	72	71

Table 9. F_1 (Scope), F_2 (Frequency), and F_3 (Amplitude) for different water uses of the Karun River in four seasons

Station	Data summary	Drinking	Aquatic	Recreation	Irrigation	Livestock
SS_4	CWQI	38	21	60	53	54
	Categorization	poor	poor	Marginal	Marginal	Marginal
	F1	45	73	25	25	29
	F2	34	71	25	25	21
	F3	90	93	59	74	72
SS_5	CWQI	40	24	54	36	34
	Categorization	poor	poor	Marginal	poor	poor
	F_1	18	64	25	38	43
	F_2	18	57	25	33	33
	F_3	100	100	71	100	100
SS_6	CWQI	66	30	59	84	84
	Categorization	Fair	poor	Marginal	Good	Good
	F_1	27	73	25	12	14
	F_2	27	67	25	11	13
	F_3	45	71	61	23	20
SS_7	CWQI	49	24	47	67	71
	Categorization	Marginal	poor	Marginal	Fair	Fair
	F_1	45	73	50	25	14
	F_2	35	67	46	19	14
	F_3	68	86	62	48	46
SS_8	CWQI	43	24	61	56	57
	Categorization	poor	poor	Marginal	Marginal	Marginal
	F_1	45	73	25	25	29
	F_2	39	64	25	25	19
	F_3	78	90	57	68	66
SS_9	CWQI	43	21	53	46	49
	Categorization	poor	poor	Marginal	Marginal	Marginal
	F_1	36	73	50	38	29
	F_2	34	67	31	30	29
	F_3	86	94	55	81	79
SS_{10}	CWQI	42	21	51	48	51
	Categorization	poor	poor	Marginal	Marginal	Marginal
	F_1	36	73	50	38	29
	F_2	30	67	31	26	25
	F_3	88	93	61	78	76

Aquatic life and drinking uses received the maximum values of F_2. The lowest values were devoted to livestock and then recreation uses; therefore, the percentage of individual failed tests received the minimum for livestock and reached the peak for aquatic life and drinking water supply, respectively. Similarly, F_3 values are also higher for aquatic life as compared to the irrigation, recreation, livestock, and drinking uses.

Generally, the water quality was assessed on the basis of three measures: i) the number of variables (water quality constituents) which exceeded the safe limits, ii) the number of individual measurements that did not meet the safe limits during the study period, and iii) the difference amount of failed measurements from their own safe limits for a particular use. The spatial degradation of river water quality was more prominent in case of aquatic life rather than the irrigation, recreation, livestock, and drinking uses on overall basis. Fig. 5 presents the water quality level of Karun River in terms of WQI and ranking based on it. Spatial variation of calculated WQIs for different water uses are shown in the mentioned figure during four seasons while discussion follows:

a) Drinking water: Drinking water quality initially remained marginal at SS_2 and SS_7. River may be less affected by anthropogenic activities near SS_3. After SS_3, quality deteriorated and ranked poor for all the remaining sampling sites except SS6 and SS7. The worst water quality conditions were at SS_4 and SS_{10} where WQI scores were 38 (the lowest) and 42, respectively. It indicates high level of contamination. The best condition was observed in SS_1.

b) Aquatic: Water quality was poor for aquatic life from SS1 to SS10. The worst status was observed in SS10 with WQI score of 21. Apparently, the WQI score decreases from upstream to downstream.

c) Irrigation: At the majority of sampling stations, quality ranged in marginal, fair, and good categories. The only station with poor water quality was SS_5 (WQI = 36) where the river was intensely polluted by the drains. It is important to note that the water quality of the river was ranked poor for its all uses, i.e. drinking, aquatic life, irrigation, and livestock except recreation at mentioned sampling site.

d) Recreation: All sampling stations have appropriate level for this purpose. The water quality ranged in marginal categories and the only sampling station with fair condition was SS_1 (WQI = 65). The highest scores of marginal condition are related to SS_2 and SS_4 with WQI score of 60 and the lowest score belonged to station SS_{10} (WQI =51). It indicates that downstream of the river (SS_{10}) has received a huge amount of pollutant loads.

e) Livestock: Water quality for livestock in most of the sampling stations ranged in marginal, fair, and good categories similar to recreation use. The highest WQI score was achieved in SS_4 and SS_1 by WQI score of 84 and 81(good), respectively. SS_7 is the only sampling site with ranking of fair (WQI = 71).

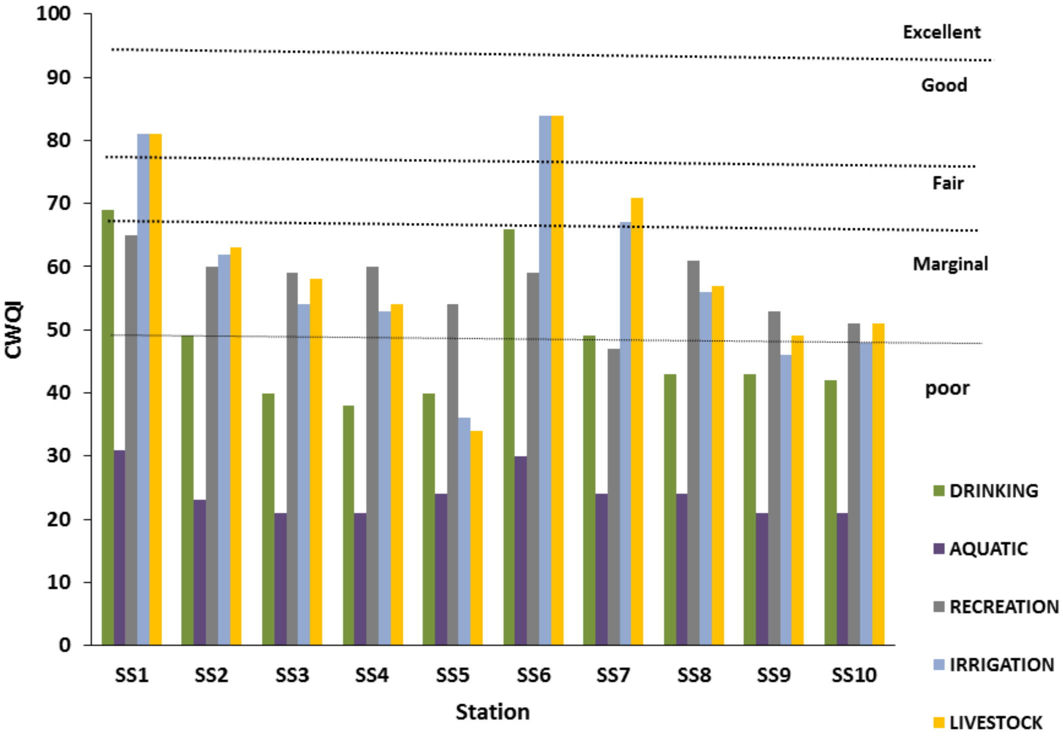

Fig. 5. Comparative diagram of Water Quality Indices according to different water uses at selected stations in four seasons

Inferences of zone characterization

To determine the changes in water quality index along river, interpolation was used. Before zoning, semi-variance was calculated by formula 8. Then, the semi-variorum graphs of these variables were obtained. After determining the sample size by the method of Kriging interpolation (Meer, 1993), it was concluded that method was not suitable for this study.

$$\gamma(h) = \frac{\left[z(x) - z(x+h)\right]^2}{2n} \tag{8}$$

So, Inverse Distance weight (IDW) method was applied for interpolation. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. Measured values which are the closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locally dependent variable. The IDW is a mapping technique which is an exact, convex interpolation method that fits only the continuous model of spatial variation (Adebayo Olubukolaoke *et al.*, 2013**)**. The IDW derives the value of a variable at some new locations using values obtained from known locations (ESRI, 2004). This is expressed mathematically in Eqs. (9) and (10) (Tomislav, 2009).

$$\hat{z}(S_0) = \sum_{i=1}^{n} \lambda_i (S_0) z(S_i) \tag{9}$$

$$\hat{z}(S_0) = \lambda_0^T Z \tag{10}$$

The simplest approach for determining the weights is to use the inverse distance from all points to the new points (Eq. 11).

$$\lambda_i(S_0) = \frac{\dfrac{1}{d^{\beta}(S_0 S_i)}}{\sum_{i=0}^{n} \dfrac{1}{d^{\beta}(S_0 S_i)}}; \beta > 1 \tag{11}$$

where λ_i is the weight for neighbor i (the sum of weights must be unity to ensure an unbiased interpolator), d (S_o, S_i) is the distance from the new point to a known sampled point, β is a coefficient that is used to adjust the weights, and n is the total no of points in the neighborhood analysis.

The IDW method of the spatial analyst extension in Arc GIS 9.3 was used for mapping of the variables. All the measured points (water quality data) were used in the calculation of each interpolated cell (water quality grid). A feature dataset (river network) was obtained for the mask. Only the cells located within the specified shape of the feature data (river network) received the values of the first input raster (water quality grid) on the output raster (water quality result). The output raster is the cells extraction of the water quality grid (input raster) that corresponds to the routes defined by final classifications presented in Table 4 (Fig. 6).

DISCUSSION AND CONCLUSION

In order to achieve an integrated water quality management plan in Karun River, CCME WQIs model and GIS were applied to derive the information from complex set of parameters from 10 stations. The raw water quality in the basin was categorized as fair and marginal to poor along river for irrigation, recreation, and livestock and also as marginal to poor for drinking. The water quality for recreation uses and its WQI scores were computed using Florida and Thailand guidelines, but WQI scores for protection of aquatic life, irrigation, and livestock uses were computed using Canadian water quality guidelines.

Similarly, there are numerous investigations which have used CCME

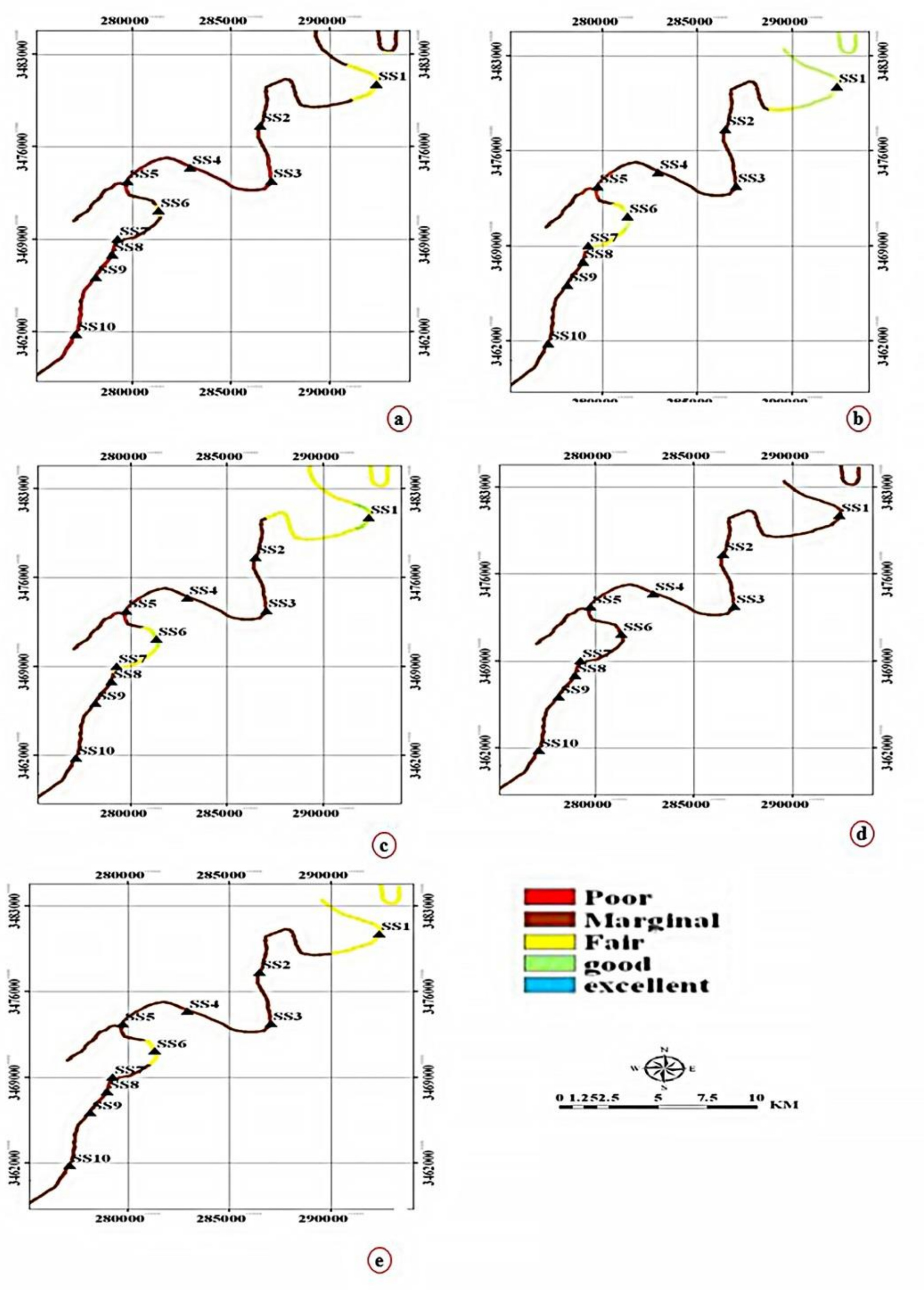

Fig. 6. Zoning of Karun River

WQI to evaluate the surface source water quality all around the world, including Boyacioglu (2010) who applied CCMEWQI to obtain a tool in classification of surface waters according to quality defined by the European Legislation- 75/440/EEC in the Kucuk Menderes Basin, Turkey. Results revealed that the overall surface water mainly fell within the A2 water class (normal physical treatment, chemical treatment, and disinfection, e.g., prechlorination, coagulation, flocculation, decantation, filtration, disinfection (final chlorination)).

Hurley *et al*. (2012) used CCME WQI to characterize drinking source water quality. Their results demonstrated that CCME WQI provides a valuable means of monitoring, communicating, and understanding surface source water quality.

Al-Janbi *et al*. (2015) used CCME WQI for the 3 stations located along the Tigris River in Baghdad city, Iraq (the field work was conducted during the period from February to December 2010). Based on the results obtained from the index, the water quality of Tigris River ranged from 37 to 42, which indicates that the river has the worst quality due to the effects of various urban pollutant sources.

Munaa *et al*. (2013), in their research to determine water quality of Surma River, used CCME WQI. Surma River was found to be 15.78 according to CCME-WQIs model, which indicated that water quality of this river near Sylhet city is poor and frequently impaired. Selvam *et al*. (2013) used GIS and CCME to determine Water quality of groundwater resources around Tuticorin coastal city, South India. In the study area, water sample values of CCME WQI map show five classes of water quality in the study area viz. excellent, good, fair, marginal, and poor. The overall view of the CCME WQI of the study zone shows that a higher CCME WQI value occurs in SW portion during PRM period and SE and SW portion during POM period, indicating the deteriorated water quality. The study concludes that the groundwater quality is impaired by man-made activities, and proper management plan is necessary to protect valuable groundwater resources in Tuticorin city.

Mahesh Kumar *et al*. (2014) applied CCME WQI on Chikkakere, a lake in Periyapatna, Mysore district, Karnataka state, India, to study its impact on the protection of aquatic life. From the results of CCME water quality, it is clear that the water quality is poor for overall purpose, drinking, aquatic, recreation, irrigation, and livestock. The index value range from minimum 6 to 32, 6 for both recreation and irrigation, 12 for aquatic, 15 for drinking, 21 for overall, and 32 for livestock.

Recently, Mokif (2015) used CCME WQI for evaluation of treated water at three adjacent water treatment stations in Al-Hilla city, Iraq. The calculated results for water quality reveal that all selected water treatment stations are good (80-94) according to classification of CCME WQI.

In comparison with our study in Iran, recently, Abtahi *et al.* (2015) reconsidered the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) to achieve an efficient drinking water quality index (DWQI) for assessment of drinking source water quality in rural communities of Khuzestan Province, Iran, in 2009-2013. Based on this index, proportions of the drinking water sources with the excellent, good, fair, marginal, and poor qualities were determined to be 6.7, 59.1, 26.2, 7.8, and 0.1%, respectively.

Vadiati *et al*. (2013) also used Fuzzy model to evaluate water quality of Karun River. They applied multiple parameters in this research, including DO, BOD_5, chloride, nitrate, and EC from 17 stations over one-year period (2010-2009). The results revealed that water quality was classified in three classes of good, bad, and moderate. Hosseini *et al*. (2013), using NSFWQI, evaluated water quality of Karun River during five years (2007-2011). The results demonstrated that water quality of Karun River during the recent five years had reduced from good and moderate range in 2007 to bad in 2011, and the river had fallen in class 3 of annual water quality classification system and self-purification power of river was low during these years.

In this study, the CCME WQIs analysis demonstrated that the water quality of river basin has been deteriorated due to incremental discharges into the river from industrial, agricultural, and municipal sources. The excessive presence of turbidity and TDS can be attributed to natural and anthropogenic sources (mostly). There are several factories around the river which discharge uncontrolled effluents from those point-source areas into the river. The quality of surface water in the upstream in Karun River is still relatively good, except for some locally polluted areas. However, in the downstream, especially parts surrounded by industrial zones and large urban areas (Ahvaz), the water quality gradually deteriorates. Due to wastes from living, husbandry, and production activities, there is an increasingly alarming contamination of water as a result of overuse of pesticides and chemical fertilizers in rural area.

In this research, the results of analysis reflected that the index decreased from SS_1 to SS_{10} for most uses. For drinking, SS_1 has the best status and showed relatively fair condition. All stations containing poor and unsuitable condition show that the indices are inappropriate for aquaculture. In the majority of the stations, the water quality for recreation ranged in marginal categories and the only station with fair condition was SS_1. The highest score of marginal condition was related to SS_2 and SS_4 and the lowest score of marginal condition was allocated to SS_{10}. Water quality for irrigation ranged marginal, fair, and good categories in most of the stations. The only station with poor water quality was SS_5, where the river was intensely polluted by drains. Similar to recreation usage, the water quality for livestock mainly ranged from marginal to good categories. So, indices for livestock and irrigation uses showed that they received more priority compared to other applications and quality parameters for the mentioned uses which were closer to the standards. Also, it was inferred from index that the quality of Karun River is principally impacted by high turbidity, TDS, NO_3, SO_4 and, PO_4 due to high suspended sediment loads. It may be correlated to natural and anthropogenic sources in downstream or likely local activities.

Generally, the study investigated how index methods are effective in deriving the information from complex water quality data sets. In this scope, CCMEWQI was used to interpret data sets. The samples analyzed for Turbidity, total dissolved solids (TDS), SO4, Chloride (Cl), As, Cr, Cd, Fe, Zn, Mn, Al, Dissolved Oxygen (DO), biochemical oxygen demand BOD_5, pH, phosphates, nitrate, Ca, and Mg parameters taken monthly over 1 year from the ten monitoring sites were processed. Results revealed that the water uses and overall surface water quality mainly have been changed from upstream to downstream because of discharging agricultural and residential effluents. This study also indicated that the CCMEWQI may assist water managers to integrate and interpret the picture of overall water quality based on water quality monitoring data and also providing management solutions to reduce effluents and agricultural drainage to the river is strongly proposed. Eventually, waste minimization and end of pipe approaches in factories are effective on the reduction of pollution levels.

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