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Water quality evaluation of Karkheh River by considering irrigation and drinking consumption

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Abstract

Karkheh River is the third largest river of Iran and has strategic importance for its geographic zone and also has the great impact on the environmental phenomenon. Large part of the river flows in Khouzestan Province and is the main water supply for farming and irrigation of agricultural lands. Therefore, plan and performance of huge agricultural projects of the region is highly depends on the river's behavior. For this reason water quality for drinking and agriculture consumptions in downstream of the reservoir dam was studied. Duration of statistical evaluation was considered between 2002 to 2011, and qualitative information of Karkheh River was obtained from 11 hydrometric stations that were being in this river's segment. Annual average values such as *EC*, *SAR*, *TDS*, *Chlorine*, *Sodium* and *Calcium* which are the main quantities of water quality issues related to drinking and agriculture-irrigation water have studied during 10 years period of study. Moreover, international standards such as *Schoeller*, *Wilcox* and *FAO* were considered for the evaluation. The results indicate that in primary segment of the river after the dam, water quality is more suitable for drinking and agricultural consumptions than in middle part and downstream of river especially near to Hour-Al-Azim Pond ;for example, *Wilcox* Diagram shows that the water quality of the river for irrigation near the stations of Paye-Pol, Abdolkhan and Hamidiyeh are in class *C3S1* or acceptable, while downstream stations such as Yazde-No, Pole-Bostan and Pole-Sabeleh and Hoveyzeh are in class *C4S2* or inappropriate.

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Introduction

Nowadays, evaluation of the water quality of rivers in basins is the most important issue of surface waters. To obtain a clear identification of water suitability for various expenditures and evaluating management strategies for a watershed, it is necessary to assess the water quality parameters (Devi and Goswani, 2015). Natural and anthropogenic interventions can alter the water quality. The qualitative parameters of river's water are directly dependent on parameters such as geological formations of the basin, climate, ion exchange between surface water and groundwater, river discharge regime and etc (Rahmani *et al.,* 2008). In Thus, the water quality of river should be continuously analyzed for both irrigation and agricultural applications (Behan Sad, 2010).

The population of 5 million, possessing the big rivers of Karun, Karkheh and Dez and exploitation of most large projects such as water dams, river training, agriculture and irrigation and drainage systems made Khouzestan Province the most important and strategic province of Iran. Regarding the mega project of "340 thousand hectares" (part of project of "550 thousand hectare" for reclamation of west and southwest lands of Iran) which covers the plains and lands of Andimeshk, Shoush, Hamidiyeh, Sousangerd, Bostan, Hoveyzeh and etc (Fig. 1), the comprehensive and accurate recognition about the water quality of Karkheh as the most important water supplier of mentioned projects is vitally important (Azarang, 2015).

Evaluation of water quality parameters has been performed on various rivers of the world and Iran. Dasilva and Maria (2001) have used the physicochemical parameters to evaluate the quality of Pardo River in Brazil. They have used the data of 8 hydrometric stations and concluded that the water quality parameters have the lowest levels in dry and arid seasons. Also, Boyacioglu *et al.,* (2008) have considered the variations of qualitative parameters of Tahtali Basin at Turkey and studied the changes of *Chlorine*, *nitrate*, *sulfate*, and *total dissolved solids (TDS)* in 7 hydrometric stations. Rahman *et al.,* (2014) have evaluated the water quality of Mayor River in Bangladesh used for irrigation via the Wilcox Diagram and concluded that the water is not appropriate for irrigation because of high salinity.

Khoramabadi *et al.,* (2014) have studied the qualitative parameters of the Khoramrood River and Farid Gigloo *et al.,* (2013) have investigated the quality of Zaringol River in Iran Also, Zare Garizi *et al.,* (2012) have evaluated the long-term changes of water quality of Chehel-Chai River. Salari *et al.,* (2012) have studied the water of Karun River Ahwaz and reported the inappropriate quality of water of this region. In this regard, Madadinia *et al.,* (2014) have studied the Karun River using the qualitative indices of water at the city region and reported that the quality is inappropriate regarding the conventional standards for miscellaneous uses. Hoseinzadeh *et al.,* (2012) have considered the water quality of Saroogh River of Takab based on the Wilcox Index. Ashayeri *et al.,* (2014) have investigated the water quality for agricultural purpose of Darehrood River.

Present work for the first time studies the water quality of Karkheh River from both agricultural and drinking aspects using international standard indicators in Khouzestan Province; the evaluated parameters of study have great importance for drinking and irrigation purposes. During the time period of this work, Karkheh river has be undergone the noticeable changes regarding the dramatic decrease in rains and hydrologic drought. Moreover, entering of wastewaters and various pollutants has declined the river's water quality. Therefore, the scientific investigation of its water quality would be valuable for all water dependent works.

Materials and methods

This work covers the downstream parts of Karkheh basin which itself is a part of huge basin of Persian Gulf and Oman Sea. The area of Karkheh Basin is about 50,000 km^2 located at the west and western south of Iran (Fig. 2).

Fig. 1. Agricultural lands Operation in Khouzestan province.

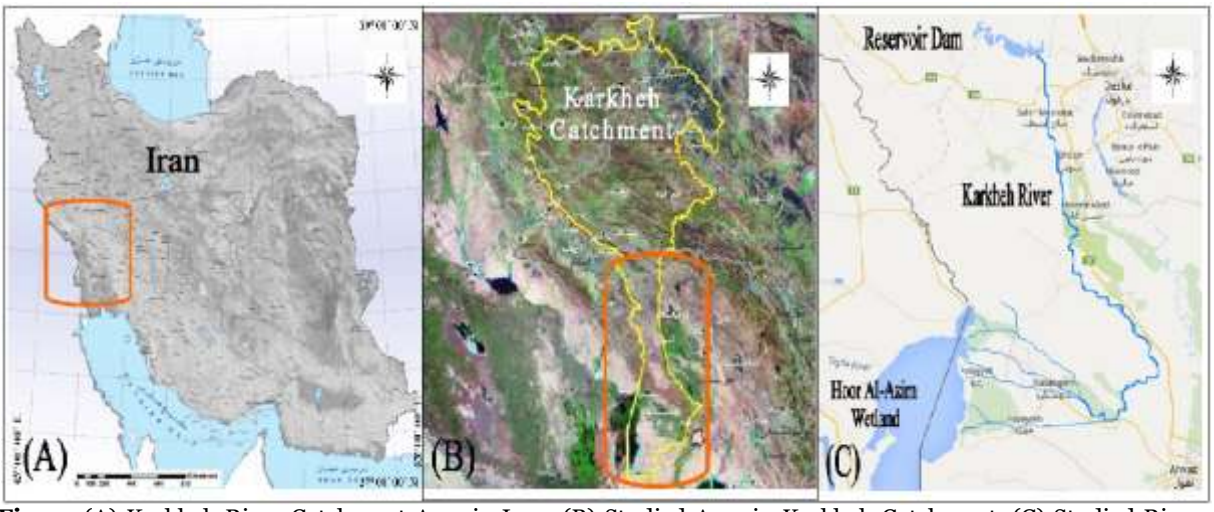

Fig. 2. (A) Karkheh River Catchment Area in Iran, (B) Studied Area in Karkheh Catchment, (C) Studied River Reach.

Karkheh is the third high discharge river in Iran and its length, from source to its end in Hour-Al-Azim Pond ,exceeds about 1100 kilometers .The main branches of the river are Gamasiyab, Gharasoo, and Kashkan. The Karkheh River is not directly discharged into the Persian Gulf; it multiply branches before entering Hour-Al-Azim Pond and finally discharged into the Persian Gulf through the Arvand River at the Iran-Iraq boundary. Water quality of Karkheh River has been studied by gathering data from11 hydrometric stations in which are located at downstream of Karkheh Reservoir Dam to Hour-Al-Azim Pond (Table 1) during 10 years of 2002-2011 and for each parameter we considered the average of 10 years in each station.

Studied parameters were included *Acidity (pH)*, *Electrical Conductivity (EC)*, *Total Dissolved Solids (TDS)*, *Sodium Adsorption Ratio (SAR)*, some *anions* like *Bicarbonates (HCO3)*, *Chlorine* (Cl^-), *Sulphates (SO4)*, and also *cations* like *Potassium* (K^+), *Magnesium* (Mg^{++}), *Calcium* (Ca^{++}), and (Na^+)

which are valuable parameters in water quality controls.

Global criteria and standards of *Schoeller*, *Wilcox*, and *FAO* have been used to evaluate the qualitative condition of Karkheh River at the stations which are defined as below:

Schoeller diagram

Qualitative evaluation of surface waters for drinking consumptions can be performed using this diagram. Table 2 indicates the *Schoeller* classification that is extracted from the diagram.

Wilcox diagram

Various methods can evaluate water quality for agricultural consumptions which mostly are prepared based on *total dissolved solids* (*TDS*) and ionic compounds as well as *Wilcox* Diagram in which by combinations of salinity parameter (*EC*) and alkalinity parameter (*SAR*) would determine the quality of water sources for agricultural uses. Regarding two mentioned parameters, the agricultural waters are classified into 4 categories. Tables 3 and 4 show the water quality based on Wilcox Diagram.

FAO Standard

This standard is based on the irrigation protocol presented by the Food and Agriculture Organization, FAO. Table 5 shows the qualitative classification of waters for agricultural use based on the FAO standards.

Results and discussion

According to the obtained data from hydrometric stations of the studied region of Karkheh River, the average quantities were summarized in table 6.

Also, table 7 shows the average of *Electrical Conductivity*, *SAR* and the average annual *pH* in each hydrometric station.

The results of *Schoeller*, *Wilcox*, and *FAO* standards were used to evaluate the qualitative condition of water at hydrometric stations of the Karkheh River.

Previously, Choramin *et al.,* (2015) have assessed the water quality of Bahmanshir River in Khouzestan province using *Schoeller* and *Wilcox* Diagram. Also, SolaimaniSardo *et al.,* (2013) have investigated the status of water quality of ChamAnjir River in Khorramabad City using these standards.

Table 1. Information of Hydrometric Stations Used in Research.

Station Code	Station Name	River Name	Longitude	Latitude	Studied Period (year)	Operation Year
21-191	Paye-Pol	Karkheh	33° 12’	48° 25’	10	1954
21-193	Abdolkhan	Karkheh	31° 38’	48° 38’	10	1965
21-199	Hamidiyeh	Karkheh	31° 50’	48° 43’	10	1950
21-488	Yazde-No	Karkheh-Nour	31° 52’	48° 39’	7	2005
21-489	Neysan	Neysan	31° 55’	48° 18’	10	1986
21-491	Houfel	Houfel	31° 58’	48° 18’	10	1986
21-525	Vosayleh	Karkheh-Nour	31° 50’	48° 45’	10	1979
21-711	Pole-Bostan	Houfel	31° 51’	48° 00’	9	2002
21-717	Pole-Rofayea	Neysan	31° 56’	47° 09’	10	1997
21-826	Pole-Sabeleh	Sabeleh	31° 59’	48° 02’	10	1997
21-940	Hoveyzeh	Karkheh-Nour	31° 47’	48° 07’	10	1987

Schoeller criterion consideration

To assess the water quality of Karkheh River for drinking consumptions the *Schoeller* criterion were used. Table 8 shows the outcomes of *Schoeller* criterion considering data of Table 2.

The results shows that the water quality of most of stations except Paye-Pol, Abdolkhan and Vosayleh is acceptable for drinking consumption based on *TDS* amounts. However, the *SO4* amount is still inappropriate for drinking at Vosayleh station. None

of the studding parameter is not in proper amount in all of stations. The amount of the ion of *Cl* is only acceptable in 6 stations which has the most acceptable rank among other parameters. In general, by applying *Schoeller* standard it would be concluded that the parameters of water quality are appropriate for drinking consumption only at Paye-Pol and Abdolkhan stations and other regions of the Karkheh River have not drinkable water. The stations of Paye-Pol and Abdolkhan are the first stations after the Reservoir Dam and benefit from clear water of the dam, while the stations of Pole-Bostan, Pole-Rofayea, Pole-Sabeleh, and Hoveyzeh that are at the end part of the Karkheh River, have inappropriate condition for all parameters of drinkable water quality that can be resulted of entering sewage and various contaminants in Karkheh River.

Table 2. Classification of water quality for drinking according to Schoeller Diagram.

TDS (mg/L)	SO_4 (mg/L)	CL (mg/L)	Na (mg/L)	TH (mg/L)	Quality
<500	<145	<175	<115	<250	Good
500-1000	145-280	175-350	115-230	250-500	Acceptable
1000-2000	280-580	350-700	230-460	500-1000	Inappropriate
2000-4000	580-1150	700-1400	460-920	1000-2000	Bad
4000-8000	1150-2240	1400-2800	920-1840	2000-4000	Drinkable in Emergency
>8000	>2240	>2800	>1840	>4000	Non-Drinkable

Wilcox Diagram evaluation results

Table 9 and figure 3 show the results of evaluating the water quality based on the *Wilcox* Diagram.

Fitting the *EC* and *SAR* amounts with the *Wilcox* Diagram, the water quality of Karkheh River can be evaluated for irrigation uses. From the agricultural perspective, increasing of *sodium* amounts in soil and elevating of *sodium-calcium* and *sodium-magnesium* ratios causes dispersion of soil particles, reducing permeability and drainage capability of it and also cause of burns on plants leaves.

Table 3. Classification of water quality according to SAR and Its application for irrigation.

Type of water	SAR value	Suitability for Irrigation
Low sodium water (S1)	0-10	Suitable foe all soils and all crops expect those which are highly sensitive to sodium
Medium sodium water (S2)	10-18	May be used on coarse textured or organic permeable soils. Addition of gypsum either to the water or soil is required for use on fine textured soils, otherwise it is harmful as it renders the soil less permeable, plastic and sticky when wet and tendency to crusting on drying. The soils tend towards alkaline because of increase in pH value.
High sodium water (S3)	18-26	May be used provided gypsum is added, and good drainage and high leaching is provided.
Very high sodium water (S4)	Above 26	Generally not suitable.

The water quality class based on *Wilcox* Diagram at the Paye-Pol, Abdolkhan, hamidiyeh, Neysan, Houfel, Vosayleh Channel and Pole-Rofayea stations is *C3S1* or acceptable level while in Yazde-No, Pole-Bostan, Pole-Sabeleh and Hoveyzeh Stations the water quality class is *C4S2* or inappropriate. By *Wilcox* evaluation, *C1S1* class has the best quality and can be used for irrigation of all types of plants and in all kinds of soils.

In this class, the *EC* always is lesser than 250 *micromhos/cm* and the *sodium* amount is minimal. Sundaray and Nayak (2009) using *Wilcox* diagram have assessed the water quality of Mahandy River in India and showed that water has low salinity and is in class *C1S1* and *C2S1*. None of the stations of our work has the water quality of this class. Classes *C3S1*, *C3S2*, *C3S3*, *C2S3* and *C1S3* or appropriate class, can only be used for the lands with good texture and good permeability and drainage satisfactorily has done on them.

Table 4. Classification of water quality according to EC and Its application for irrigation.

Type of water	Classification	Electrical conductance (micromhos / cm)	Suitability for irrigation
Fresh water		0-100	Excellent to good
Low Saline (C1)	Excellent	101-250	Suitable for almost all crops and all soils except extremely low permeable soils
Medium saline (C2)	Good	251-750	Normal salt tolerant plants can grow. Moderate leaching is required
Saline (C3)	Permissible	751-2000	Suitable drainage is required. Only high-salt tolerant plants can grow
Highly Saline (C4)	Doubtful	2001-3000	Bad water for irrigation
Very highly saline (C5)	Unsuitable	Over 3000	Unsuitable for irrigation

Table 5. Classification of water quality in agriculture consumption (FAO Method).

Potential Irrigation Problem		Units	Degree of Restriction on Use		
			None	Slight to Moderate	Sever
Salinity (affects crop water availability)		µmhos/cm	<700	700-3000	>3000
EC_w		mg/l	<450	450-2000	>2000
TDS					
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC and SAR together)			>700	700-200	<200
SAR = 0-3 and	EC_w =		>1200	1200-300	<300
SAR = 3-6	=		>1900	1900-500	<500
SAR = 6-12	=		>2900	2900-1300	<1300
SAR = 12-20	=		>5000	5000-2900	<2900
SAR = 20-40	=				
Special Ion Toxicity (affect sensitive Crops)					
Sodium (Na)					
Surface irrigation	SAR	<3	3-9	>9	
Sprinkler irrigation	meq/L	<3	>3		
Chlorine (Cl)					
Surface irrigation	meq/L	<4	4-10	>10	
Sprinkler irrigation	meq/L	<3	>3		
Trace Elements					
Miscellaneous Effects (affects susceptible crops)					
Bicarbonate (HCO_3)		<1.5	1.5-8.5		
(overlead sprinkling only)	meq/L		>8.5		
pH		-	Normal Range 6.5-8.4		

The *sodium* amount is partly high in these classes of waters and *EC* reaches up to 2000 *micromhos/cm*. As mentioned above the water quality of stations of Paye-Pol, Abdolkhan, Hamidiyeh and some others (fig. 3) are in this level (*C3S1*). Also, Faghihi *et al.,* (2009) have assessed the water quality in Paye-Pol and Hamidiyeh stations for cultivation purposes during the years 2002 to 2008 and found that

according to the *Wilcox* diagram, the Paye-Pol station status has been *C3S1* and Hamidiyeh status has been *C3S2* which confirms our results for these stations. The last class is *C4* or *S4* in *Wilcox* Diagram that has the bad quality water and cannot be used for most kinds of plants except those one that can tolerate high *sodium* concentrations. The *EC* amount is higher than 2000 *micromhos/cm* and sodium amount is more than 26 *mg/L*. The water quality of downstream stations (as mentioned above, fig. 3) are in this level.

Table 6. Average values of quantitative and qualitative parameters of Karkheh River hydrometric stations.

Station Name	Na	HCO_3	CL	SO_4	Ca	Mg	TH	K
				(mg / L)				
Paye-Pol	93	170	146	212	102	28	370	3
Abdolkhan	99	171	152	219	100	31	375	3
Hamidiyeh	181	157	261	324	110	42	446	4
Yazde-No	349	172	547	514	147	78	685	5
Neysan	224	156	326	376	119	49	495	4
Houfel	239	159	348	388	124	50	513	4
Vosayleh	162	168	231	308	113	39	439	4
Pole-Bostan	302	160	461	438	133	62	586	4
Pole-Rofayea	265	165	397	420	127	60	563	4
Pole-Sabeleh	284	157	430	423	133	58	569	4
Hoveyzeh	334	166	500	545	151	77	691	5

Table 7. Average values of EC, SAR and pH in different hydrometric stations.

Station Name	pH	EC (µmhos/cm)	SAR
Paye-Pol	7.82	1082	2.07
Abdolkhan	7.78	1121	2.20
Hamidiyeh	7.98	1607	3.66
Yazde-No	8.02	2939	5.86
Neysan	8.01	1859	4.23
Houfel	8.01	1956	4.42
Vosayleh	8	1485	3.25
Pole-Bostan	8.03	2408	5.17
Pole-Rofaea	8.01	2179	4.55
Pole-Sabeleh	8.04	2257	4.92
Hoveyzeh	8.03	2732	5.38

FAO Standard results

FAO is also used to evaluate the water quality for agricultural consumptions. Based on *FAO* Standard the water quality is classified into 3 ranks including limitless, low to moderate or severe limit for each station. Evaluation of water quality for all stations by this standard dose not fit in the context of this article. Therefore, three selected hydrometric stations of Paye-Pol, Yazde-No, and Hoveyzeh were evaluated through the *FAO* standard.

Paye-Pol Station

The *EC* and *TDS* of this station were ranked at the low to moderate limit for irrigation uses. Considering the *EC* and *SAR* parameters simultaneously, water quality of this station ranks at the limitless level.

While, respect to amount of sodium ion, it is limitless for surface irrigation and has low to moderate limit for drip irrigation. Also, considering the Chlorine and bicarbonate amounts Paye-Pol water quality is in low to moderate limit for both surface and drip irrigation. Finally, its *pH* is at the appropriate level.

Table 8. Results of water quality survey of Karkheh River hydrometric stations by using Schoeller index.

Station Name	TDS (mg/L)	SO_4 (mg/L)	CL (mg/L)	Na (mg/L)	TH (mg/L)
Paye-Pol	Acceptable	Acceptable	Good	Good	Acceptable
Abdolkhan	Acceptable	Acceptable	Good	Good	Acceptable
Hamidiyeh	Inappropriate	Inappropriate	Acceptable	Acceptable	Acceptable
Yazde-No	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate
Neysan	Inappropriate	Inappropriate	Acceptable	Acceptable	Acceptable
Houfel	Inappropriate	Inappropriate	Acceptable	Inappropriate	Inappropriate
Vosayleh	Acceptable	Inappropriate	Acceptable	Acceptable	Acceptable
Pole-Bostan	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate
Pole-Rofayea	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate
Pole-Sabeleh	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate
Hoveyzeh	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate

Table 9. Guide of Karkheh River hydrometric stations in Wilcox diagram.

Paye-Pol	Abdolkhan	Hamidiyeh	Yazde-No	Neysan	Houfel	Vosayleh	Pole-Bostan	Pole-Rofayea	Pole-Sabeleh	Hoveyzeh

Yazde-No Station

The *EC* and *TDS* were in low to moderate limit level while it ranks at the limitless level considering both *EC* and *SAR*, simultaneously. The *sodium* and *Chlorine* of the water are in severe limit for surface irrigation while the condition is low to moderate for drip irrigation. The bicarbonate is in low to moderate level of limit for agricultural use and its *pH* is normal.

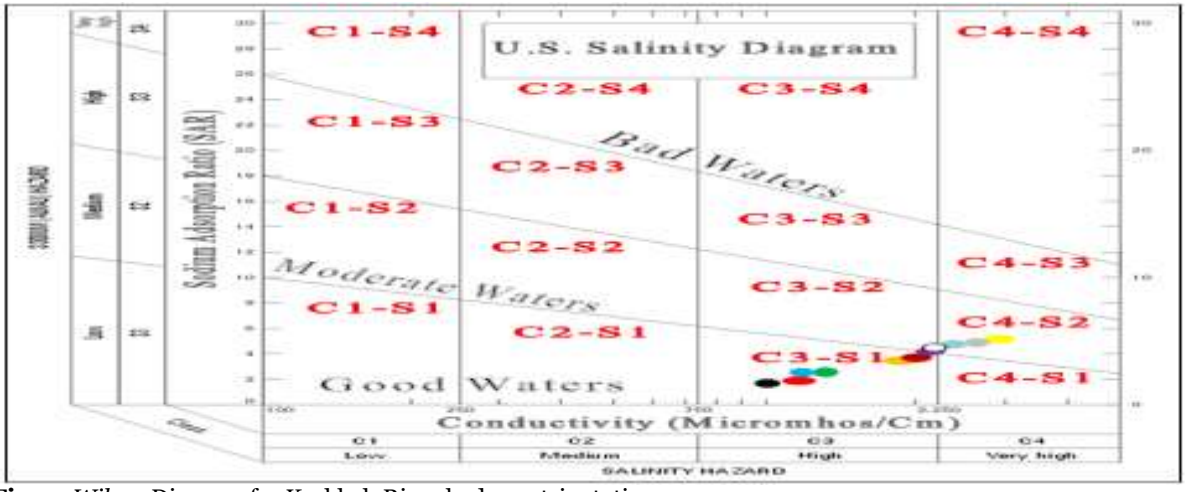

Fig. 3. *Wilcox* Diagram for Karkheh River hydrometric stations.

Hoveyzeh Station

The *EC* and *TDS* are in low to moderate level of limit in this station. water quality of Hoveyzeh Station ranks in limitless level when *EC* and *SAR* are considered simultaneously. The *sodium* and *Chlorine* ions are in severe limitation level for surface irrigation while they are in low to moderate level for drip irrigation. The *bicarbonate* is in low to moderate level. Finally, the *pH* of the water is in appropriate condition.

Salajegheh *et al.,* (2011) have investigated the *EC*, *TDS* and *SAR* parameters in Karkheh River in the time period of 1988 to 2002 and reported the severe decrease of water quality of the river due to unfavorable changes of land uses.

Fig. 4. Enter various sewer to downstream of Karkheh River in Bostan City.

According to the Samani *et al.,* (2009) the water quality of Karkheh River at the stations near the dam is appropriate for both drinking and agricultural uses. Also, Moazed *et al.,* (2010) have studied the water quality of Hamidiyeh Station in a 10 years period of 2000-2009 which their obtained data are in agreement with the present work. Based on our outcomes of *Schoeller*, *Wilcox* and *FAO* standards it can be concluded that the water quality of downstream of Karkheh River is not good and qualified for drinking and agricultural uses especially in median and end parts which may be due to entering of wastewater and drainage waters from the agricultural applications into the Karkheh River and its branches at downstream. Figure 4 shows a view of condition of downstream branches of Karkheh near the Bostan Town.

Conclusion

In this work, the water quality of Karkheh River as the main source of water supply for both drinking and agricultural consumptions in Khouzestan Province was investigated. The *Schoeller* Diagram was used to evaluate the water quality for drinking and *Wilcox* Diagram and *FAO* standard were utilized to assess the water quality for agricultural purposes. The results indicated that generally the water of upstream stations near the Karkheh dam such as Paye-Pol and Abdolkhan have a higher quality for both drinking and irrigation and the water quality is decreased in stations at the downstream such as Yazde-No, Pole-Bostan, Pole-Sabeleh and Hoveyzeh which ranks in inapropriate and is not suitable for irrigation. Based the low water quality of downstream stations may be attributed to discharge of industrial sewage and agricultural drainage water into the river. It suggested doing similar studies in other important rivers of Iran and Kouzestan Province as well as further studies on Karkheh River using other standards and methods in different time periods.

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