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DEVELOPING A QUANTITATIVE MODEL FOR ENVIRONMENTAL RESOURCE MANAGEMENT IN THE FUNCTIONAL SCOPE OF LARGE DAMS. A CASE STUDY OF KARKHEH DAM

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Abstract

This study was performed to quantify the effects of land use changes resulting from the construction of Karkheh Dam, in southwest of Iran, on the water quality of Karkheh River. For this purpose, the periodical Landsat TM and ETM+ images were used to assess the changing trends of the land use types before and after the dam construction. The water quality data were collected from the hydrometric stations and the possible correlation between the changes in the land use types and water quality parameters was detected through regression models. The obtained results showed a significant correlation between the changes in the different land use types and the variations of the water quality parameters in the lower basin of Karkheh Dam at the confidence intervals of 95% and 99% (p-values=0.05 and 0.01). The results indicated that the development of the irrigated lands and water supply for the farmlands would be the main factor for the declined water quality of the river at the downstream areas. The land use map showed that the current area of the irrigated lands is approximately 76% of the entire basin area, while the regression models revealed that the maximum permissible area of this land use type should be 46% of the total area of the basin. This indicates that the development of agricultural fields would be the main cause for the decline in the water quality of the river at downstream areas.

Keywords: land allocation, land use, Landsat images, large dam, water quality

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1. Introduction

The construction of storage dams has long been the focus of attention in order to regulate the flow of rivers and supply water for power generation and other types of water use, especially irrigation, drinking water, and domestic and industrial purposes (Raso et al., 2019). "Providing water for the necessary uses", "reducing floods", "expanding irrigated agricultural lands at the downstream of dams" and "generating electricity" have always been the obvious benefits of dam construction (especially the construction of large dams). Constructing large dams despite the social and economic benefits, causes irreparable environmental damage (Choi et al., 2005; Cooper et al., 2017; Wildi, 2010). Large dams have a significant role in land use changes in the downstream areas of dams (Azarang et al., 2017; Wijesundara and Dayawansa, 2011; Xisto da Silva et al., 2020).

Nowadays, management of water resources, in addition to the engineering considerations, focuses on the cultural, socioeconomic, and environmental issues (Gu et al., 2020; Sait Tahmicioglu et al., 2007) If environmental challenges are ignored and necessary actions are not taken to prevent or mitigate the adverse and damaging environmental impacts of dams during the pre-construction, post-construction, and operational phases, the ecological equilibrium of the

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regions will be disrupted and irreversible effects will impose on the upstream and downstream catchments of the dams. This will lead to the degradation of the fauna and flora and a serious damage to the diversity (Graco-Roza et al., 2021; Pirestani and Shafeghati, 2009). Therefore, environmentalists emphasize the need to review and complete studies on the negative environmental impacts and consequences of the construction of large dams on rivers and provide practical management, civil, and engineering solutions (Awang et al., 2015; De Baum, 2016; Poff and Schmidt, 2016; Scudder, 2012). Raso et al. (2019) examinied the economic dimension of the construction of dams and showed that although dams affect the hydraulic regime of the river, they generate economic benefits. The results of domestic and international studies show that the damage caused by construction of large dams on the receiving environment during the construction and operation phases, is so extensive that it is difficult to restore the affected lands and habitats (Akindele and Indabawa, 2015; Bahroun and Chaib, 2017). “Sediment accumulation due to soil erosion in the upstream catchment of dams”, “interrupted balanced ecological link between the upstream and downstream areas of dams, such as disrupting the migration routes of aquatics from downstream to upstream areas, which causes serious damage to the regeneration process and even their extinction”, “nitrification in the reservoir of dams”, “tangible changes in river ecosystems”, “water quality changes due to land use change in the downstream catchments of dams” are among the problems that challenge the positive consequences of the construction of large dams and should be mitigated (Chessman and Townsend, 2010; Graco-Roza et al., 2021; Salman, 2017; Taleb et al., 2004). The impact of land use changes on river water chemistry is a topic that has recently come to the attention of researchers around the world. Ahearn et al. (2005) in a study on the impacts of land use and land cover influence on the water quality parameters of the streams in Cosumnes Watershed (in the USA) found that TSS loading was significantly higher in farmlands and densely populated areas. Chessman and Townsend (2010) investigated the impacts of land use types on the water chemistry of the rivers in a tropical region of northern Australia and reported a high pH, salinity, and nutrients in the rivers induced by agricultural and urban land uses. Luo et al. (2020) investigated the association between land use changes on the water quality parameters of the streams in Shaying River Basin in China and reported a significant seasonality relationship between the expansion of built-up areas and the water quality. Namugize et al. (2018) conducted a similar research for the uMngeni River Catchment in South Africa. They found a significant relationship between land use patterns and water quality variables and concluded that the changes are site-specific and varies from one sub-basin to another. The review of relevant literature show that the study on the relationship between land use changes and water quality parameters in river basins is complex and in its early stages. As emphasized by Namugize et al. (2018), studies of this type are complex in nature and vary from place to place. Gu et al. (2020) assessed the social and environmental effects of large dams based on phase-based logic and reported that dam construction can leave many impacts on the surrounding environment. These impacts can have various aspects and it is necessary to evaluate them comprehensively.

Therefore, considering that these studies are still in the initial stage and a lot of research is needed to determine the role of land use changes among many parameters affecting water quality in a river basin, as well as the site-specific nature of these studies, any research in this field can be helpful and somehow creative.

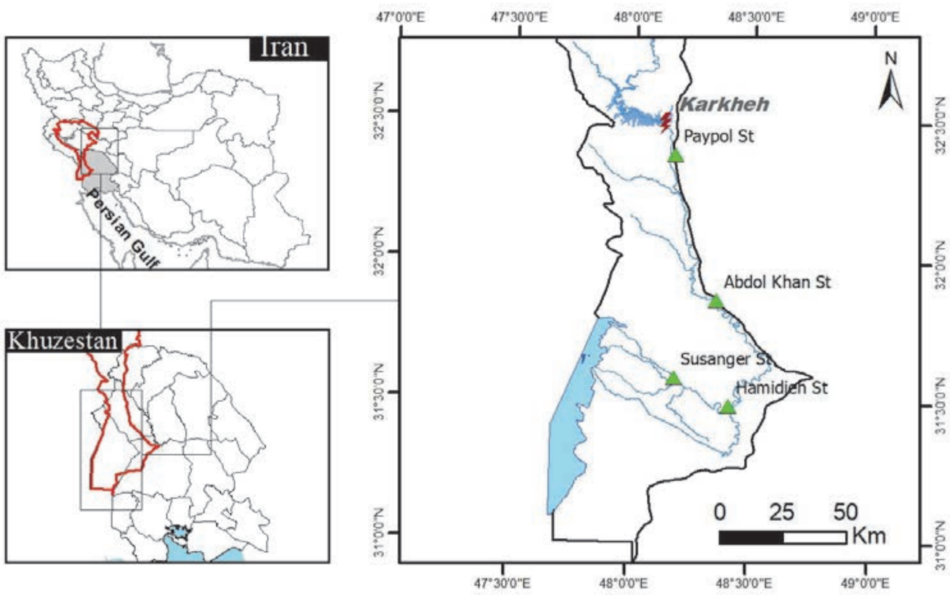

Fig. 1. Geographical location of the study area

Table 1. Specification of the satellite images of the Lower Karkheh River Basin over a period of 1993 to 2013

Satellite	*Sensor*	*Year of capture*	*WRS² Pass/Row*	*Spatial resolution*	*Number of bands*
Landsat 5	TM	1993	163/38	30	7
Landsat 7	ETM+	2003	163/38	30, 15⁺	8
Landsat 8	OLI	2013	163/38	30	9

Furthermore, lack of comprehensive approaches and applicable tools (such as, management models) for the assessment of environmental challenges and the mitigation of adverse environmental effects of construction of large dams at downstream basins is among the most important shortcomings of water supply projects in the country of Iran. This implies the need for comprehensive consideration of the negative environmental impacts of dams at downstream areas. Accordingly, the present study was conducted to investigate the relationship between land use patterns of Lower Karkheh River Basin and changes in the water quality parameters. The goal was to check if there is any statistically significant relationship between land use patterns and changing trend of river water quality.

2. Material and methods

2.1. Study area

Karkheh River is one of the permanent rivers in western Iran with an average discharge of 177 m^3/s. It is the third largest river in Iran (Mohammadpour et al., 2008). The river is stretched over an area of about 51,337 km^2 within the eastern longitudes of 46° 06'-49° 10' and the northern latitudes of 30° 58'-35° 58'. It originates from the middle and southwestern regions of the Zagros Mountains and eventually, after a distance of approximately 1,900 km along the north-south direction, flows into the Hooral-Azim and Hurolhavizeh Wetlands in the southwest of Khuzestan Province (Fig. 1).

2.2. Functional scope of Karkheh Dam

The scope of this study limits to the downstream basin of Karkheh Dam, which covers an area of about 4621 km^2 (462,100 ha). The studied buffer, up to a distance of 5 km from its periphery on both sides of the river, had an area of over 1753 km^2 (175300 ha). The average water flow (mean discharge) in Karkheh River at the dam site (Paypol Station) was about 219.84 m^3/s in pre-construction phase within the statistical period of 1992-1994 and 20.76 m^3/s in post-construction phase at the Susangerd Station (downstream of the river at the entrance to the Hooralizim Wetland) within the statistical period of 2009-2014.

The climate of the region is dry and warm. In late fall, the study area witnesses the onset of the rainy season that continues until early spring. It should be note that the dam has begun to function since 2001 (Heidarzadeh et al., 2019).

2.3. Material

This study is a descriptive-inferential research. The basic layers include the topographic map at the scale of 1:25000 (prepared from Cartographic Center of Khuzestan Province), the map of land resources at the scale of 1:250000 (prepared from Soil and Water Research Institute), and geological map at the scale of 1:100000 (prepared from Geological Survey and Mineral Explorations of Iran).

The meteorological data, including precipitation, temperature, and evaporation, were collected from the rain gauge, climatology, and synoptic stations in the study area and the adjacent areas. Moreover, the statistics in the environment, natural resources, water resources, watershed management, and agriculture reports of the dam prepared by the employers of the relevant bodies were gathered and used. The Landsat satellite images of the years 1992, 1995, 2003, 2008, and 2013 were used to prepare the maps of land use change and land cover (Fig. 2). Literature reviews and expert opinions showed that the 5-year time intervals would lead to appropriate results in monitoring land use changes. The pattern of dry and wet years in the region was also another important criterion was considered in the selection of these intervals. A database was created in the ARC GIS 9.3 to process and analyze the descriptive and thematic data (maps). The analyses were done in Arc GIS v. 9.3, SPSS v. 17, ENVI v. 4.8, Erdas Imagine v. 2013, and Google Earth. Table 1 shows the specification of the satellite images used.

2.4. Detection of land use changes

In order to detection the pattern of land use changes over a period of 20 years, the land use maps of the intervals 1992, 1995, 2003, 2008, and 2013 were prepared from the Landsat satellite images of the years 1992, 1995, 2003, 2008, and 2013, the detail of which is discussed in the following:

Preprocessing of the satellite images: To detect land use changes, a panchromatic band with a resolution of 15 was used, and after providing the required information, the executive work of this research was done as follows: In order to pre-process the images, first the dimensions of all the pixels were changed to 60 m. Then, geometric, atmospheric, and topographic corrections were applied to all images. For the geometric correction, first, the 15-meter bands of TM sensor, with an error of 0.38 pixels, were registered on a topographic map with a scale of 1:25000, and then, it was used to geo-reference the Landsat images using the image-to-image registration method (Jafari et al., 2007).

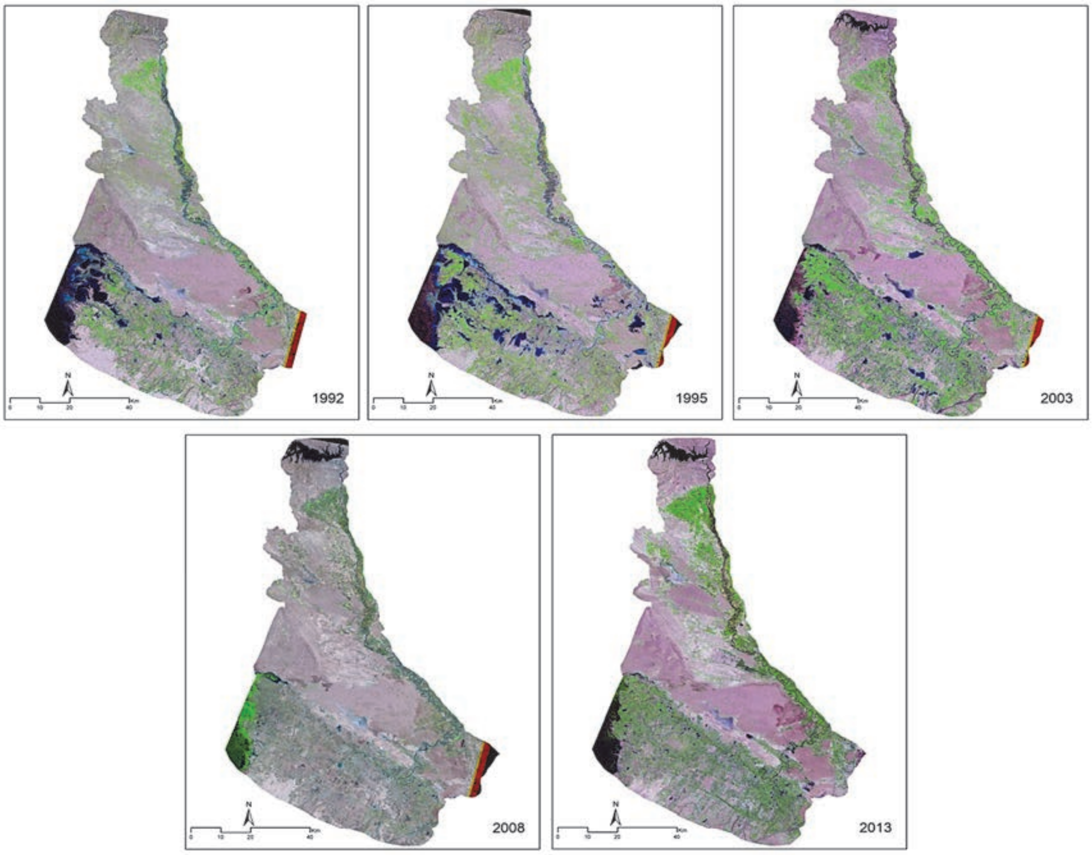

Fig. 2. Landsat satellite images of Lower Karkheh River Basin in the years 1992, 1995, 2003, 2008, and 2013

Since the satellite images were acquired at different times, the atmospheric correction of Dark subtraction was also applied to them in the ENVI v. 4.8 software (Lunetta and Edvidge, 1999).

For topographic corrections, a 1:25000 scale topographic map was used to produce the Digital Digit Elevation Model (DEM) of the study area at a pixel size of 60 m, and then, the correction was performed using Lambert model in Erdas Imagine v. 2013 software (Riano et al., 2003).

Processing of the satellite images: After preprocessing the satellite images, the processing step was initiated, in which the different land use classes were classified on the images of different years.

The prominent land use classes in the study area were identified using the side information, topographic maps, and field visits. The classification was done by supervised classification method in Erdas Imagine software. This method is based on the selection of training sample points by the user and field visits. The selection of training points was done using tasseled cap transformation method, field visits, and Google Earth. At the end of this step, the land use classes of rangelands, woody rangelands, sand dunes, barren lands, and agricultural lands (rain-fed and irrigated farm-fields) were detected on the images (Fig. 4).

Change detection: After preparing the land use maps of the different intervals, they were pairwisely compared using Change Detection command in ENVI software. Accordingly, the conversion of different land uses over the period under study was detection quantifiably.

2.5. Water quality analysis

Water quality data, including physical and chemical parameters of Karkheh River, were gathered from Paypol, Abdul Khan, Hamidieh, and Susangerd Hydrostatic Stations (respectively at the upstream and downstream areas of Karkheh Dam) (Fig. 1). The data belonged to the five time intervals; two periods (1984-1992 and 1992-2000) before the dam construction and three periods (2000-2004, 2004-2009, and 2009-2014) thereafter. These water parameters were measured by Khuzestan Water and Power Organization and Tamab Company; the average of which in each period was considered and included in the analysis. The analysis of these parameters was performed using correlation tests and regression models in Excel and SPSS software packages. Table 2 presents the measured water variables in Lower Karkheh River Basin.

3. Results and discussion

3.1. Changing trend of the river quality at downstream of Karkheh Dam

Table 3 gives the periodic average values of the measured and recorded data in the five periods before and after the construction of the Karkheh Dam at the hydrometric stations of Paypol, Abdulkhan, Hamidiyeh, and Susangerd. The statistical analysis of these data showed that except for pH and Sodium Adsorption Ratio (SAR) parameters other water quality parameters have increased over the periods under study. As the table suggests, the lowest Electrical Conductivity (EC) level was related to the pre-construction statistical period and the highest value was recorded at Susangerd Station (downstream of the dam) in the period after the dam construction (2009-2014). Increasing trend of Total Dissolved Solids (TDS), from the river upstream areas towards the downstream areas at the Susangerd Hydrometric Station, revealed the entrance of the drained effluent into the river. This may be due to the expansion of the irrigated agricultural lands along the river course and development of agricultural activities in the area after the dam construction. The same goes true for the other water quality parameters. The results of comparing the periodic mean values of each of the studied parameters showed that the difference between all of the parameters was significant at the confidence interval of 95% ($p = 0.05$).

3.2. Changing trends of land uses in the Lower Karkheh River Basin

According to the interpretation of the Landsat ETM + satellite images, the land uses in downstream portion of the Karkheh Dam include rangelands, woody rangelands, sand dunes, barren lands, and agricultural lands (rain-fed and irrigated farm-fields). The irrigated agriculture, with an area of 3800 ha (constituting 40% of the total area of the basin) and woody rangelands, with an area of 43 ha (including 0.45% of the total area of the basin) accounted for the largest and smallest land use areas, respectively (Fig. 3). The change detection results at five time intervals before and after the dam construction, using interpretation of Landsat TM and ETM^+ satellite images, available reports, and field studies, showed that there are 6 types of land uses in the area under study, including rain-fed agriculture, irrigated agriculture, rangeland, woody rangeland, sand fields, and barren lands. Analyzing the areas covered by each land use type in the lower basin of the dam in pre- and post-construction phases showed a rising trend in the area of the irrigated and rain-fed agricultural lands (Table 2). This is related to the conversion of barren lands, and woody and non-woody rangelands into the agricultural lands, as well as, the expansion of sand fields (Table 2 and Fig. 5). The mean area covered by each of the land use types before and after the dam construction was significant at the 99% confidence interval ($p = 0.01$). In the time intervals studied, the greatest changes were detected respectively in the agricultural land use types (irrigated and rain-fed) and sandy areas, while the land use types of woody and non-woody rangelands experienced the lowest changes over the period of concern (Table 4, Fig. 3).

3.3. Effect of the periodic land use changes on the water quality parameters and their relationships

The effect of periodic changes in the area of each land use type in pre- and post-construction phases on the water quality parameters (based on the index of periodic mean values of the measured parameters) was investigated using the correlation test. According to the results, a significant correlation was found at the 95% and 99% confidence intervals (p-values = 0.01 and 0.05) between the periodic changes in the area of land use types (irrigated agricultural lands, barren lands, and woody and non-woody rangelands) and periodic changes in the mean values of water quality parameters, including EC, Total Suspended Solids (TSS), pH, Na%, HCO_3^{-1}, Cl^{-1}, SO_4^{-2}, Ca^{+2}, Mg^{+2}, Na^{+1}, and SAR, except for the water acidity (pH) parameter, which lacked periodic changes. The correlation between the periodic changes in the area of "barren lands" and "non-woody and woody rangelands" was negative, while the correlation between the periodic changes in the area of "irrigated and rain-fed farmlands" and "non-woody and woody rangelands" was positive.

In other words, increasing the extent of irrigated agriculture as a positive consequence of the construction of Karkheh Dam is a factor for increasing the amount of water quality parameters in the lower basin of Karkheh Dam as a negative environmental consequence of the dam construction (Table 5).

Table 2. Details of the water quality analysis in Lower Karkhe River Basin

No.	*Water variable*	*Unit*	*Method of measurement*	*Measurement tool*	*Season of sampling*
1	pH			Electric pH meter	Spring
2	EC	μmho/cm		EC meter	Spring
3	TDS	mg/L	Gravimetry	0.0001g Lab Digital Analytical Balance Weighing Precision Scale	Spring
4	SAR	mg/L		AAS*	Spring
5	Na	mg/L	Colorimetry	AAS	Spring
6	Mg	mg/L		AAS	Spring
7	Ca	mg/L		AAS	Spring
8	SO_4	mg/L	Colorimetry	AAS	Spring
9	Cl	mg/L	Electrochemical method	Chlorine Analyzer	Spring
10	HCO_3	mg/L		Titration	Spring

*Note: * Atomic Absorption Spectrophotometer*

Table 3. Mean value of water parameters before and after the dam construction in the studied stations, downstream of Karkheh Dam

Water Parameters	*Period (Phase)*	*Paypol*	*Abdul Khan*	*Hamidieh*	*Susangerd*	*Changing trend*
EC (µ mho/cm)	Pre-construction	728.18	1151.89	1410.43	1701.51	Increasing trend
	Post-construction	1164.02	1313.01	1545.97	2024.40	
TDS (mg/L)	Pre-construction	631.34	786.79	905.68	1075.62	Increasing trend
	Post-construction	772.37	880.77	997.19	1331.55	
pH	Pre-construction	8.08	8.1	8.05	8.07	Decreasing trend
	Post-construction	7.86	7.94	7.85	7.92	
Na%	Pre-construction	39.46	41.18	41.33	42.00	Increasing trend
	Post-construction	42.39	44.62	44.94	48.75	
SRA (mEq/**L**)	Pre-construction	2.52	2.56	3.34	3.45	Decreasing trend
	Post-construction	2.95	3.11	3.84	4.76	
Na (mEq/**L**)	Pre-construction	4.15	4.25	6.43	7.22	Increasing trend
	Post-construction	4.84	5.31	7.01	10.04	
Mg (mEq/**L**)	Pre-construction	2.63	2.48	3.35	3.46	Increasing trend
	Post-construction	2.84	2.73	3.73	4.14	
Ca (mEq/**L**)	Pre-construction	4.12	4.12	5.15	5.29	Increasing trend
	Post-construction	5.06	4.93	5.46	6.49	
SO_4 (mEq/**L**)	Pre-construction	4.11	4.60	6.05	6.31	Increasing trend
	Post-construction	4.87	5.23	6.95	8.68	
Cl (mEq/**L**)	Pre-construction	4.55	4.78	6.13	7.07	Increasing trend
	Post-construction	5.63	5.82	7.02	9.99	
HCO_3 (mEq/**L**)	Pre-construction	3.11	2.38	2.61	2.45	Increasing trend
	Post-construction	3.32	2.8	2.83	2.84	

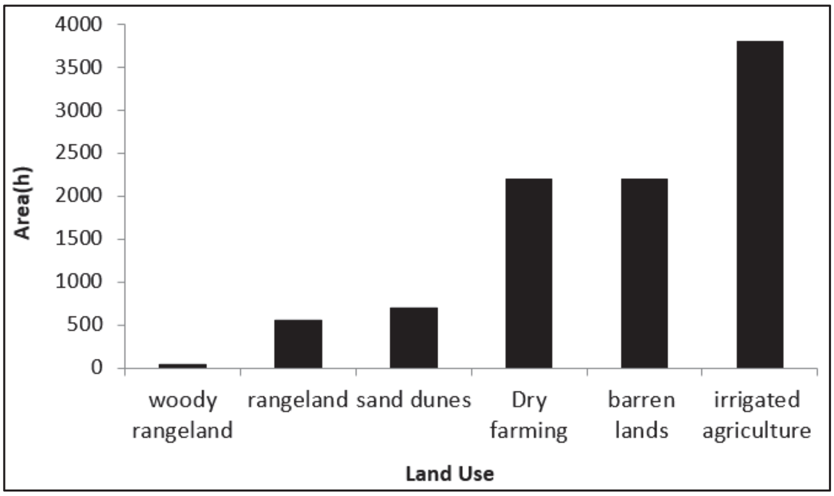

Fig. 3. Area of different land uses in Karkheh River Basin during the research period

Table 4. Areas covered by all land use types during 5 time intervals ending to the hydrological stations, downstream of the Karkheh Dam(area based on km^2)

Land use	*Station*	*1991*	*1995*	*2003*	*2008*	*2013*	*Changing trend*
Barren lands	Paypol	2800	2700	2500	2400	2200	Decreasing trend
	Abdul Khan	12000	10000	5600	5000	4200	Decreasing trend
	Hamidieh	19600	15000	9000	6000	5800	Decreasing trend
	Susangerd	5500	5000	1400	2000	2100	Decreasing trend
Sand dunes	Paypol	100	200	3000	410	700	Increasing trend
	Abdul Khan	200	7500	7000	6900	6300	Decreasing trend
	Hamidieh	7100	3600	3000	6600	3200	Decreasing trend
	Susangerd	700	600	2300	2500	2000	Increasing trend
Irrigated agriculture	Paypol	400	700	1100	3300	3800	Increasing trend
	Abdul Khan	2200	2900	9800	11200	14700	Increasing trend
	Hamidieh	1600	4700	12700	16500	27200	Increasing trend
	Susangerd	2800	4600	9100	10200	11800	Increasing trend
Dry farming	Paypol	1600	2400	1500	2100	2200	Increasing trend
	Abdul Khan	10200	7600	7500	10300	11700	Increasing trend
	Hamidieh	8500	10500	9800	10400	12900	Increasing trend

	Susangerd	7500	6700	6100	6500	6800	Increasing trend
Rangeland	Paypol	3600	3000	1000	700	557	Decreasing trend
	Abdul Khan	18300	17000	15600	13000	10000	Decreasing trend
	Hamidieh	21200	20500	20000	18600	10100	Decreasing trend
	Susangerd	7200	6600	4700	3600	2500	Decreasing trend
Woody rangelands	Paypol	1000	500	400	590	43	Decreasing trend
	Abdul Khan	6400	4300	3800	2900	2400	Decreasing trend
	Hamidieh	2100	5800	5600	2000	900	Decreasing trend
	Susangerd	1800	2000	1800	700	500	Decreasing trend

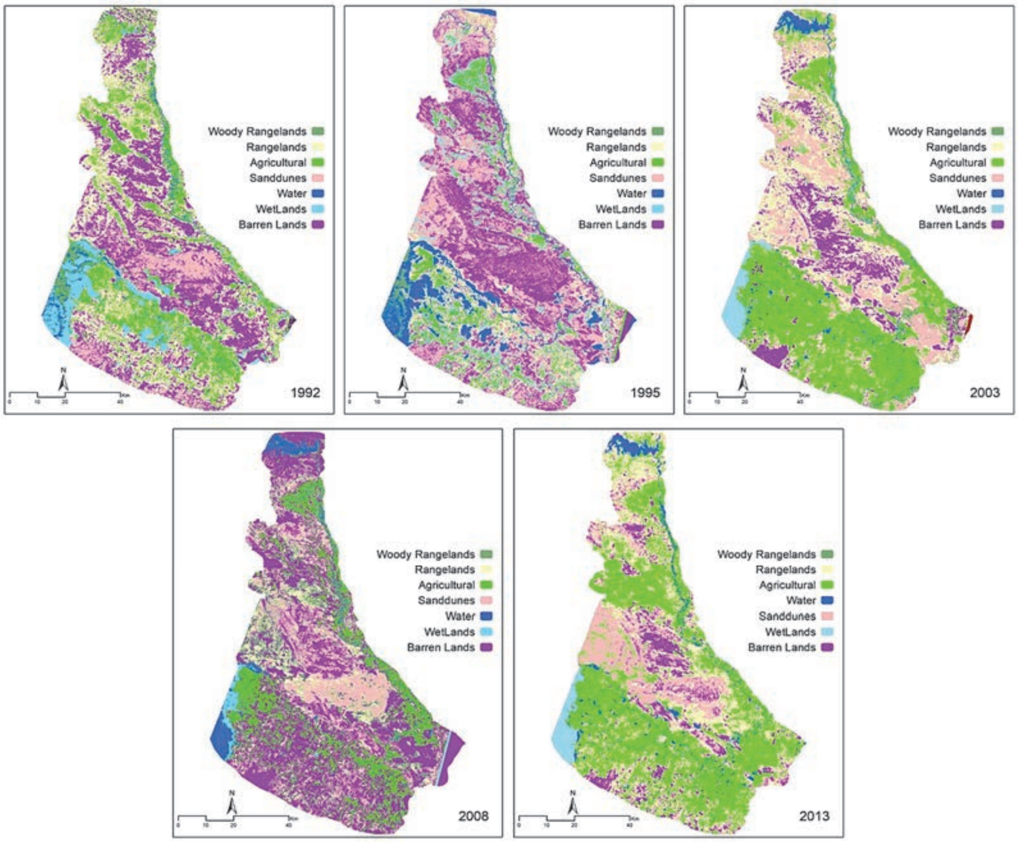

Fig. 4. Land use maps of Lower Karkheh River Basin in the years 1992, 1995, 2003, 2008, and 2013

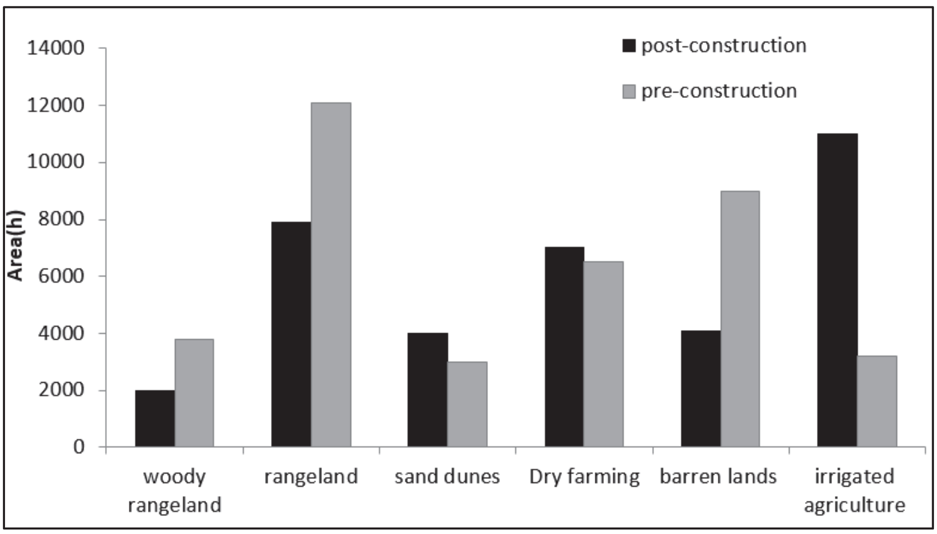

Fig. 5. A comparison on the average area of the different land uses in pre- and post-construction phases of Karkheh Dam

In order to study the relationship between those land use changes effective in the water quality changes, and determine the permissible changing extent of each land use type (as a tool and model for water quality management in the Lower Karkheh Dam Basin), multivariate regression models of ENTER (Table 6), Stepwise (Table 7), Backward (Table 8), and Forward (Table 9).

Fig. 6 shows the correlation obtained between Na and EC parameters and land use classes of irrigated lands and woody rangelands as an example.

The results of the four regression models for estimating the permitted changing extent of the land use types (irrigated and rain-fed agriculture and rangeland) are as follows:

a) **Enter model:** the model was used for characterization of the relationship between the water quality parameters and the effective land uses. The outputs were useful to predict the changing limits of each land use type in a way that would not cause the water quality parameters to fall beyond the permitted values for the intended land uses.

Table 5. Result of correlation test between land use changes and water quality parameters, downstream of Karkheh River at 5 time intervals

Land use		*Na%*	*SAR*	*Na*	*Mg*	*Ca*	*SO_4*	*Cl*	*HCO_3*	*PH*	*TSS*	*EC*
Barren lands	CC	-0.9*	-0.9**	-0.1**	-0.9**	-0.1**	-0.9 *	-0.1**	-0.1**	0.9*	-0.1**	-0.1**
	St	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Irrigated agriculture	CC	0.1*	0.1**	0.1**	0.1**	0.1**	0.1*	0.1**	0.1**	- 0.9 *	0.1**	0.1**
	St	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Rangeland	CC	- 0.9 *	-0.9*	-0.1**	-0.1**	-0.1**	- 0.9 *	-0.1**	-0.1**	-0.9 *	-0.1**	- 0.1 **
	St	0.09	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
Woody rangelands	CC	- 0.9*	- 0.7	- 0.7	- 0.7	- 0.7	- 0.9 *	- 0.7	- 0.7	- 0.7	- 0.7	- 0.7
	St	0.01	0.09	0.09	0.09	0.09	0.19	0.09	0.09	0.01	0.09	0.09

*Note: CC= Correlation Coefficient; St = Sig.; **: confidence levels of 99% and 95%*

Table 6. Area threshold prediction models for each of the land use types to manage water quality at the downstream of Karkheh Dam based on ENTER regression model

No.	*IV*	*DV*	*Model*	*R^2*	*R*	*Ad.R*	*α*	*p-value*
1	IL.DF.RL	EC	EC= - 698.73 -17.59 (IL)+138.41(DF) +53.55(RL)	1.000	1.00	1.000	0.01	> 95
2	IL.DF.RL	TDS	TDS = -5490.29-16.66(IL) + 117.49(DF)+40.61(RL)	1.00	1.00	0.998	0.03	> 95
3	IL.DF.RL	pH	pH=12.41+0.009(IL)-0.08(DF)-0.022(RL)	0.92	0.96	0.692	0.012	> 95
4	IL.DF.RL	HCO_3	HCO_3= -3.705+0.000005(IL)+0.104(DF)+0.04(RL)	0.99	0.99	0.968	0.01	> 95
5	IL.DF.RL	Cl	Cl= -110/44-0.34(IL)+2.13(DF)+0.8(RL)	0.97	0.98	0.898	0.01	> 95
6	IL.DF.RL	SO_4	SO_4= -89.224-0.262(IL)+1.714(DF)+0.679(RL)	0.97	0.98	0.901	0.01	> 95
7	IL.DF.RL	Ca	Ca= -28.03(IL)+0.56(DF)+0.23(RL)	0.99	1.00	0.99	0.02	> 95
8	IL.DF.RL	Mg	Mg= -14.055-0.04(IL)+0.3(DF)+0.11(RL)	0.99	0.99	0.98	0.01	> 95
9	IL.DF.RL	Na	Na= -91.40-0.26(IL)+1.761(DF)+0.68(RL)	0.98	0.99	0.94	0.012	> 95
10	IL.DF.RL	SAR	SAR= -33.92-0.08(IL)+0.65(DF)+ 0.25(RL)	0.99	0.99	0.97	00.011	> 95
11	IL.DF.RL	Na%	Na%= -143.48-0.44(IL)+3.35(DF)+1.23(RL)	0.87	0.93	0.50	0.03	> 95

**R2: correlation coefficient, R: coefficient of determination, Ad.R: adjusted correlation coefficient, α: confidence interval, p-value: confidence level, DV: dependent variable, IV: independent variable, land use, RL: rangeland, IL: irrigated land, DF: Dry farming*

Table 7. Area threshold prediction models for each of the land use types to manage water quality at the downstream of Karkheh Dam based on Stepwis regression model

No.	*IV*	*DV*	*Model*	*R2*	*R*	*Ad.R*	*α*	*p-value*
1	IL.DF.RL	HCO_3	HCO_3 = 1.763 +0.021(IL)	0.96	0.98	0.955	0.001	> 99
2	IL.DF.RL	TDS	TDS = -320/248 + 24/059(DF)	0.91	0.95	0.883	0.01	> 95
3	IL.DF.RL	pH	pH = 9.583 – 0.031(DF)	0.9	0.95	0.876	0.01	> 95
4	IL.DF.RL	Ca	Ca = 2.346 + 0.054(IL)	0.89	0.94	0.865	0.01	> 95
5	IL.DF.RL	Mg	Mg = 0.055 + 0.062(DF)	0.89	0.94	0.845	0.01	> 95
6	IL.DF.RL	Na	Na= 2.904 + 0.061(IL)	0.88	0.93	0.842	0.01	> 95
7	IL.DF.RL	EC	EC= 125.424 + 25.138(IL)	0.85	0.92	0.806	0.02	> 95
8	IL.DF.RL	SO_4	SO_4= 3.082 + 0.052 (IL)	0.84	0.91	0.791	0.02	> 95
9	IL.DF.RL	SAR	SAR=-2.421 + 0.111(DF)	0.82	0.91	0.771	0.03	> 95
10	IL.DF.RL	Na%	Na%= 9.571 + 0.648(DF)	0.77	0.88	0.704	0.04	> 95
11	IL.DF.RL	Cl	Cl= -4.989 + 0.218 (DF)	0.77	0.88	0.700	0.05	> 95

**R2: correlation coefficient, R: coefficient of determination, Ad.R: adjusted correlation coefficient, α: confidence interval, p-value: confidence level, DV: dependent variable, IV: independent variable, land use, RL: rangeland, IL: irrigated land, DF: Dry farming*

Table 8. Area threshold prediction models for each of the land use types to manage water quality at the downstream of Karkheh Dam based on Backward regression model

No	*IV*	*DV*	*Model*	*R2*	*R*	*Ad.R*	*α*	*p-value*
1	IL.DF.RL	pH	pH= 9.58 – 0.03(DF)	0.90	0.95	0.87	0.01	> 95
2	IL.DF.RL	Mg	Mg = -0.05 + 0.06 (DF)	0.89	0.94	0.85	0.01	> 95
3	IL.DF.RL	EC	EC = -6398.73 – 17.59(IL) + 138.41 (DF) + 53.55(RL)	1.00	1.00	1.00	0.01	> 95
4	IL.DF.RL	HCO_3	HCO_3= -3.556 + 0.101 (DF)	0.99	0.99	0.984	0.01	> 95
5	IL.DF.RL	TDS	TDS= -549.29 + 117.49(DF) + 40.61(RL)	1.00	1.00	0.99	0.03	> 95
6	IL.DF.RL	Na	Na= -21.5 + 0.41(DF) + 0.2(RL)	0.98	0.99	0.97	0.03	> 95
7	IL.DF.RL	SO_4	SO_4= -20.4 + 0.39(DF) + 0.2 (RL)	0.98	0.99	0.969	0.03	> 95
8	IL.DF.RL	SAR	SAR= -2.421 + 0.111 (DF)	0.82	0.91	0.77	0.03	> 95
9	IL.DF.RL	Ca	Ca= -15.584 + 0.320 (DF)	0.97	0.98	0.95	0.03	> 95
10	IL.DF.RL	Na%	Na%= -9.571+ 0.648 9DF)	0.77	0.88	0.70	0.04	> 95
11	IL.DF.RL	Cl	Cl= -4.989 + 0.218(DF)	0.77	0.88	0.70	0.04	> 95

**R2: correlation coefficient, R: coefficient of determination, Ad.R: adjusted correlation coefficient, α: confidence interval, p-value: confidence level, DV: dependent variable, IV: independent variable, land use, RL: rangeland, IL: irrigated land, DF: Dry farming*

Table 9. Area threshold prediction models for each of the land use types to manage water quality at the downstream of Karkheh Dam based on Forward regression model

No	*IV*	*DV*	*Model*	*R2*	*R*	*Ad.R*	*α*	*p-value*
1	IL.DF.RL	HCO_3	HCO_3= 1.763 + 0.021(IL)	0.96	0.98	0.95	0.00	> 99
2	IL.DF.RL	TDS	TDS= -320.248 + 24.059 (DF)	0.91	0.95	0.88	0.011	> 95
3	IL.DF.RL	pH	pH= 9.583 – 0.031(DF)	0.90	0.95	0.876	0.012	> 95
4	IL.DF.RL	Ca	Ca= 2.346 + 0.054(IL)	0.89	0.94	0.865	0.014	> 95
5	IL-DF-RL	Mg	Mg=-0.055 + 0.062(DF)	00.89	0.94	0.854	0.016	> 95
6	IL-DF-RL	Na	Na= 2.904 + 0.061(IL)	0.88	0.93	0.84	0.018	> 95
7	IL.DF.RL	EC	EC= 125.424 + 25.138(DF)	0.85	0.92	0.806	0.025	> 95
8	IL.DF.RL	SO_4	SO_4= 3.082 + 0.052(IL)	0.84	0.91	0.791	0.028	> 95
9	IL.DF.RL	SAR	SAR= -2.421 + 0.111(DF)	0.82	0.91	0.771	0.032	> 95
10	IL.DF.RL	Na%	Na%= 9.571 + 0.648(DF)	0.77	0.88	0.704	0.048	> 95
11	IL.DF.RL	Cl	Cl= -4.989 + 0.218 (DF)	0.77	0.88	0.700	0.049	> 95

**R2: correlation coefficient, R: coefficient of determination, Ad.R: adjusted correlation coefficient, α: confidence interval, p-value: confidence level, DV: dependent variable, IV: independent variable, land use, RL: rangeland, IL: irrigated land, DF: Dry farming*

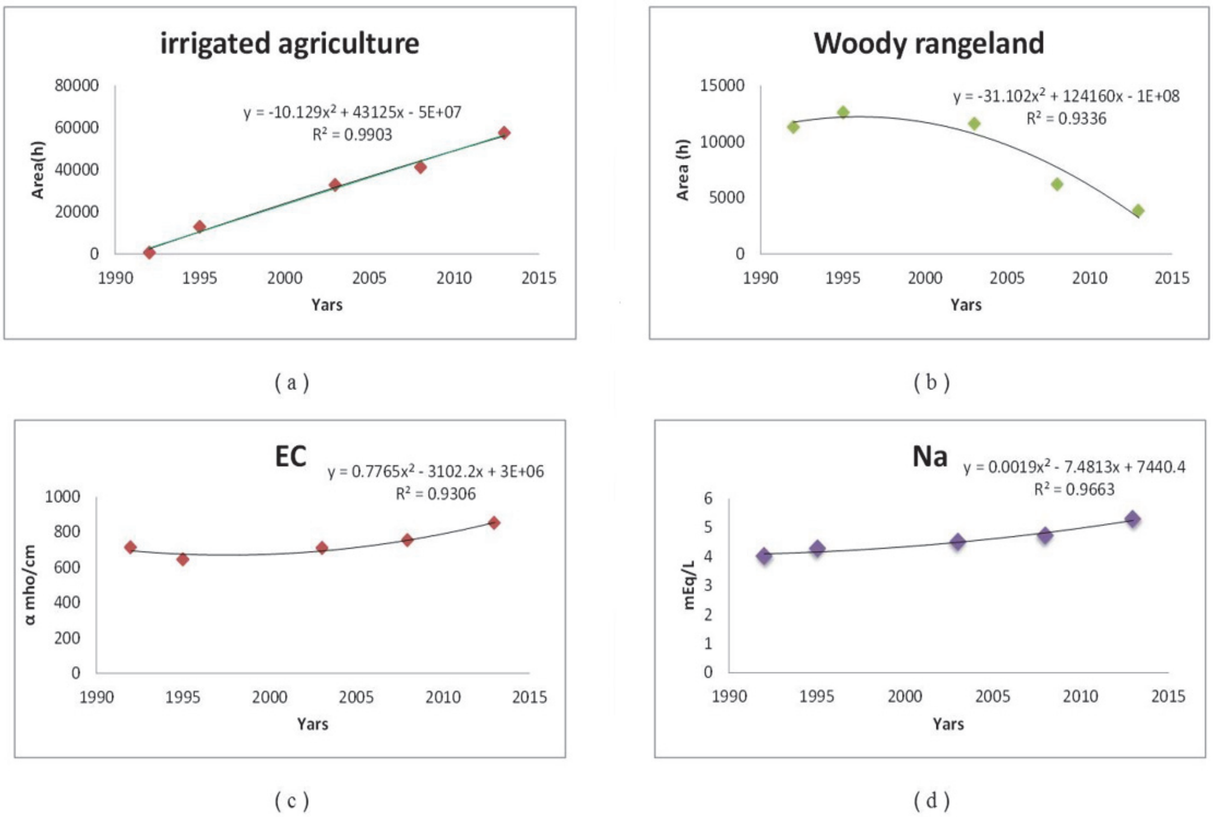

Fig. 6. Correlation obtained between Na and EC parameters and land use classes of irrigated lands and woody rangelands

In other words, this model specifies the maximum permissible extent of different land uses at downstream of the dam and the areas with similar conditions at the 5% confidence interval.

b) **Stepwise model:** the model was used with the purpose of identifying the most effective land use types on the declined quality of the river water at the lower dam basin and the areas with similar conditions at the 5% confidence interval.

c) **Backward model:** the model was used to determine the most preferred land use type affecting the river water quality within the lower basin of the dam and similar areas at the confidence level of 1%.

d) **Forward model:** the model was used to determine the most important and preferred type of land use effective in the reduction of the river water quality in the lower basin of the dam and similar areas at the confidence level of 5%.

According to the Spearman test, a significant correlation was found between the area of the irrigated farm fields and the changing quality of the water parameters. The results showed that after the dam construction, the extent of rangelands and barren lands decreased, unlike the irrigated lands that had an increasing trend. This has led to the economic growth and, consequently, social welfare in the region, as two positive consequences of dam construction in the study area. The periodic values of chemical and physical water parameters, including EC, TDS, SAR, Na%, HCO_3^{-1}, Cl^{-1}, So_4^{-2}, Mg^{+2}, Ca^{+2}, and Na^{+1}, have been increasing over the study period, compared to the time before the dam construction. After constructing the dam, the quality of Karkheh River has declined at downstream areas. The poorer quality of the water parameters has disturbed the balance of the river ecosystem at the downstream areas, which will have inevitable effects on the fauna and flora of the region (Cooper et al., 2017; Hallajian et al., 2018; Wijesundara and Dayawansa, 2011). The negative environmental consequences of the dam were also reported by Hallajian et al. (2018) and Azarang et al. (2017). Investigation of the correlation between the mean values of water quality parameters after dam construction and land use change showed that with an 8.2-time increase in the area of the irrigated lands at the downstream of the Karkheh Dam, the water quality of the river began to decline. The significant correlation between the changes in land use types and water quality parameters has been emphasized in other studies (Hallajian et al., 2018; Poff and Schmidt, 2016). The reason for the declined water quality in the Lower Karkheh Dam Basin was the conversion of natural habitats (rangelands) into the irrigated lands due to the inflow of agricultural effluents and their leaching and drainage over time. This is consistent with the results reported in the studies by Ahearn et al. (2005) and Chessman and Townsend (2010).

According to the studies by Taleb et al. (2004) and Xisto da Silva et al. (2020), construction of dams on rivers would increase the concentration of water quality parameters and result in a gradual decline in the water quality (over time), especially when the environmental water rights are not observed. These results were in line with the findings by Hallajian et al. (2018). Applying the regression models presented in Tables 6 to 9, it would be possible to plan for the optimization of the land uses in Lower Karkheh Dam Basin and similar catchments. Using the Enter model, it was determined that the maximum permissible area of the irrigated lands in the Lower Karkheh Basin should be 46% of the entire basin area, which should be regarded as the threshold limit for the allocation of lands to irrigated agriculture. It should be noted that this land use type accounted for approximately 76% of the entire area of the lower basin. The changes of this land use type were considered as the main reason for the declined water quality of the river at the downstream areas of Karkheh Dam. According to Mohammadpour et al. (2008), different land uses can be established around the dam, provided that suitable management measures are used.

4. Conclusions

The results of the four multivariate regression models showed that three land use types of irrigated agriculture, dry farming, and non-woody rangeland were the main reason for the changes in the concentration of the water quality parameters of Na%, SAR, Na, Mg, Ca, SO_4, Cl, HCO_3, pH, TDS, and EC. The development of the irrigated lands was the main reason for the poorer quality of the river water in terms of HCO_3, Ca, Na, EC, and SO_4 parameters.

Although the land use did not have any different preferential effects on the water quality parameters, it was recognized as the most important preferential factor in changing the concentration of HCO_3, Ca, Na, and SO_4 parameters. Since the relationships, in this study, were developed according to the environmental conditions of the Karkheh Dam, they must be validated and modified, if required, for the use in other areas.

Models often need to be modified because of the inconsistency of environmental conditions. Therefore, it is recommended to carry out similar studies in several basins located in the downstream of large dams and modify the relationships of each model to make the models more applicable and reduce probability errors.

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