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River Water Quality Assessment Using WRASTIC and Organizing Methods: A Case Study in Three Sub-Watersheds of Karaj River (Varangeh Rud, Doab, and Varian)

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Abstract

Water as an inevitable human need has encountered many problems during the last decades. One of these problems is water pollution. In recent years, water quality has been reduced in Karaj watershed as the most important source of drinking water in Tehran and surrounding areas. In the present study, three sub-watersheds were selected at the upper, middle and lower section of the main river of Karaj watershed called Varangeh Rud, Doab and Varian. In order to estimate and compare their pollution potential, two different methods including risk assessment (as a scientific method) and organizing (as an experimental-practical method) methods were applied. Out of the several risk assessment methods, only the WRASTIC Index method was used to estimate the risk of surface water sources pollution, particularly dams, and to weight the 7 main parameters of water pollution. Organizing method, in turn, involves several methods including ecological capacity assessment using GIS to determine the proportion between existing uses, analyzing the 10-year average of water pollution parameters for identifying the river water quality and SWOT analysis to determine threats and opportunities in the watershed water quality. Results showed little pollutant potential in all the three sub-watersheds, but based on the organizing method, there is little, average and very little pollution in Varangeh Rud, Doab and Varian sub-watersheds, respectively. Similar results were obtained using both methods. Hence, the organizing method, as an experimental method, can also be used for zoning the potential of water pollution in Karaj Dam watershed.

Keywords: Risk assessment; WRASTIC method; Pollutant potential; Ecological capacity assessment; SWOT

Introduction

Water is an issue which "pervades society". It is critical for long-term economic development, social welfare, and environmental sustainability. In recent years, there has been an increase in Awareness and concern about water pollution across the globe. Thus, new approaches towards achieving sustainable water resources management have been developed internationally [1]. Iran is characterized by an arid and semi-arid climate and Karaj Dam watershed is one of the most important sources of water supply in Tehran metropolitan. Due to the release of different types of pollutant in the studied area, pollution is increasing which is a subject of concern for related responsibilities these days [2,3]. Assessment, classification and studying the sources of pollutants in river watersheds and determining their pollutant potential is conducted by different methods or by a combination of methods [1,4]. Some of surface water pollution assessment methods are: Environmental change consensus building and resource management in the horn of Africa (ECOMAN) method [5], the practical method in California Department of Health Services (CDHS, 2000), United States Geological Survey (USGS) method [5] and Wastewater Presence, Recreational Impact, Agricultural Impact, Size of the Watershed, Transportation Avenues, Industrial Impact and Vegetative Ground Cover (WRASTIC) method. The WRASTIC method is used to systematically evaluate the pollutant potential of any surface water system throughout the United States. This Index is developed to evaluate and assess the capability of the study area against surface water pollution in hydrological systems that address specific characteristics of water distribution and land use (New Mexico Environment Department). WRASTIC, along with Geographic Information System (GIS), applied as an important tool for different classifications that following sub-watershed risk zoning, is able to provide management measures to reduce risk and effects.

The organizing method combined with ecological capacity assessment methods along with GIS to determine the proportion between accessible uses, analysis of the ten-year average of water pollution parameters for identification of the river water quality and SWOT analysis to study threats and opportunities of the watershed water quality are able to plan and prioritize required measures to control and reduce the pollution sources [6]. Studies by Mirzaei and Norouzian, are two types of research focusing on water pollution zoning in Zayandehrud River using WRASTIC index and FUZZY classification technique respectively. WRASTIC index showed that Zayandehrud watershed is in a high-risk class and the pollution increased significantly from station 1 toward the subsequent stations while the river water quality was reduced [7]. In a study by Norouzian et al. three unacceptable, moderate and acceptable classes of quality for Zayandehrud River were presented using FUZZY technique [8]. In another study, the risking rate zoning of pollutant sources in rivers and coastal areas of Guilan Province has been conducted by establishing a comprehensive pollutant rating system [9]. Several studies have been carried out on the studied area, including nitrite, nitrate and ammonia parameters measurement in the water behind the Karaj dam lake [10], presentation of an appropriate plan for monitoring the surface water quality of Karaj River watershed [11] and sanitary disposal of sewage in around villages [12], which often pointed out to independent issues and case studies. Two similar studies conducted in other countries are an investigation of water quality indexes in Ciambulawung River in Indonesia [13] and Sabarmati river in India [14] based on NSF-WQI index. The first study showed that the river water quality is good and the communities living along the river bank and micro-hydro power plant did not negatively affect the water quality in Ciambulawung River. However, the second study demonstrated that high anthropogenic activities, illegal discharge of sewage and industrial effluent, lack of proper sanitation, unprotected river sites and urban runoff were the main cause of deterioration of water quality in Sabarmati River.

In another study, the GIS technology, data management system, and computer models were used to evaluate the decentralized pollution sources in the state of Virginia watershed [15]. In the field of land use communication with water pollution, the Cow Bay watershed in Halifax, Canada, was investigated by the University of Nova Scotia. It is noteworthy to mention that to assess and improve the water quality of the watershed, the impact of land use on water pollution and reducing the quality of water was also analyzed [16].

As mentioned above, while there have been many attempts conducting water quality assessment and zoning by different kinds of methods, only a few addressed the capabilities of WRASTIC and organizing methods. Although it has been a relatively long period of time since these methods were first introduced, their capabilities in water quality assessment are yet to be investigated and compared. To this end, the present study attempts to address the effectiveness of WRASTIC and organizing methods, in order to determine and compare the pollutant potential in Varangeh Rud, Doab and Varian sub-watersheds in Karaj dam.

Material and Methods

Study area

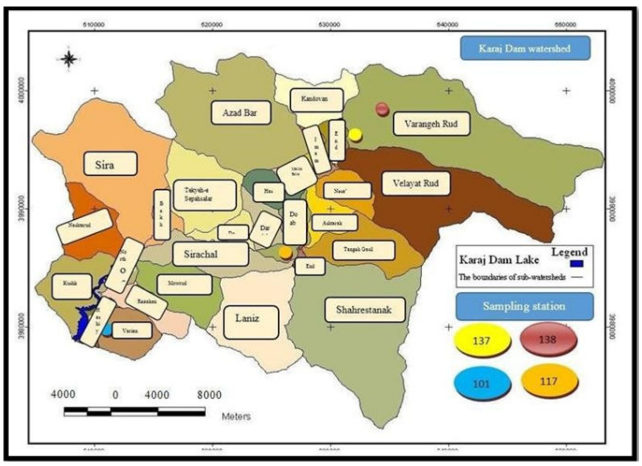

Figure 1: Map of Karaj dam watershed.

In this study, three sub-watersheds were investigated, at the upper, middle and lower section of Varangeh Rud, Doab and Varian, respectively. The below-mentioned figure shows three sub-watersheds with 4 sampling stations (101-117-137-138) in the study area (Figure 1) [17]. The sub-watersheds in Varangeh Rud, Doab, and Varian with areas of 123.05 Km^2, 12.52 Km^2, and 17.64 Km^2, respectively, were studied in terms of biophysical, social and economic conditions.

Moreover, Karaj dam watershed with 844.98 km^2 areas is located in the northeastern Karaj City. Based on the water distribution plans of the country, the dam is located in the central watershed, Karaj-Jajrood River sub-watershed and in the hydrologic unit of Tehran- Karaj. The highlands of Karaj Dam watershed are considered to be the water production platform of Tehran-Karaj plain. As the southern part of the plain is located in desert conditions, hence, this watershed is of vital importance [18].

WRASTIC method

WRASTIC is considered as a rating system for surface water systems. This method helps planners and managers in assessing the vulnerability and risk areas related to different pollution sources and is used at the first and basic stages of the resource planning and land use planning process.

In the WRASTIC method, 7 parameters as wastewater presence (W), recreational impact (R), agricultural activities (A), size of the watershed (S), transportation paths (T), industrial impact (I) and vegetation cover (C) are investigated. A value between 1 and 5 was determined for each parameter except for case I, which varies from 1 to 8. These parameters are identified by the vulnerability of the study area regard to the type of pollution, weighing and ranking. Also, the combination of mentioned parameters characterizes the surface water system vulnerability to pollution, which can be shown in a map.

The equation for determining the WRASTIC index for each surface area is as below:

WRASTIC Index=WRWW+RRRW+ARAW+SRSW+TRTW+IRIW +CRCW (1)

Where W is the weight and R is the rate factor.

In order to estimate the risk of water pollution by the WRASTIC index, the weight of each parameter, as well as the classification of the rates are required as shown in detail in the table (Tables 1 and 2) (New Mexico Environment Department).

Organizing method

Zoning and planning of the pollutant potential of Karaj watershed to reduce the pollution by organizing method are carried out in the three principal stages of the planning process including identification, analysis, and combination. In the identification stage, each zone is studied in biophysical resources, man-made environment, and pollutions forms. In the analysis stage, using various methods such as ecological capability assessment, analysis of water pollutant parameters and SWOT, role and impact of the uses and other environmental factors on the pollution of the watershed are determined. The final stage of the planning process, the combination, is able to plan for reducing pollution and improving the water quality, in which the most important pollutant issues and the relative pollutant potential of each sub-watershed are prioritized using details given in the table which has been prepared for this purpose.

Weight	Parameter	Rating	Category
1	Area	5	1942.50 km^2>
		4	388.50-1942.50 km^2
		3	155.40-388.50 km^2
		2	38.85-155.40 km^2
		1	38.85 km^2<
1	Transportation activity	5	The existence of a railway or inter-provincial route in the region
		4	The existence of a highway in the region
		3	The existence of a king way or any type of asphalt in the region
		2	The existence of incomplete ways in the region
		1	No transportation exist in the region
1	Vegetation coverage	5	0-5%
		4	6 -19%
		3	20 -34 %
		2	35 -50 %
		1	50>%
2	Recreational Impact	5	Motor activity is permitted in water
		4	No motor activity is permitted in water
		3	Local access is permitted by a vehicle in the area
		2	There is no access to the vehicle
		1	There are no recreational activities in the region
3	Agricultural Impact	5	There are 5 or more agricultural activities1 in the region
		4	There are 4 agricultural activities in the region
		3	There are 3 agricultural activities in the region
		2	There are 2 agricultural activities in the region
		1	There is 1 agricultural activity in the region
4	Wastewater Presence	5	There are sewage effects in the area, for this purpose a special disinfection system is in place
		4	The effects of sewage are evident in the region
		3	There are more than 50 disinfectant systems available
		2	There are fewer than 50 nasty systems available
		1	There is no sewage drain in the region
5	Industrial Impact	8	Have very wide Discharging industries or very heavy impact on the environment.
		4	Have large Discharging Industries or heavy impacts on the environment.
		6	Have moderate discharge industries or moderate environmental impacts
		2	Have little discharge industries or little impact on the environment.
		1	There is no industry in the environment

Table 1: Weighing and rating of effective parameters in the WRASTIC index.

Risk ratio	Vulnerability of the study area characteristics	Area	Study area percent	The rate of the study area characteristics
The risk with low impact and low probability of occurrence	Low	11-40	23	11-19
			18	20-28
			35	29-37
			23	38-46
The risk with low impact and high probability of occurrence	Moderate	40-70	>1	47-55
			0	56-64
			0	65-73
The risk with high impact and low probability	High	70-90	0	74-82
			0	83-91
The risk with high impact and high probability	Very high	90-100	0	92-100

Table 2: Vulnerability classification of area characteristics based on the percent of the study area and regional characteristic rate.

Discussion and Result

Estimation of water pollution risk using WRASTIC in three sub-watersheds

The below table presents the risk assessment of pollution in the three sub-watersheds studied using the WRASTIC method and Eq. (1). As shown in the table (Table 3), the values 30, 32, and 32 related to the sub-watersheds of Varangeh Rud, Doab and Varian, respectively, indicate a low risk of water pollution in these areas.

Application of WRASTIC in risk assessment of surface water pollution to study the water index quality and vulnerability has been reported in Zayandehrud River basin in Iran and Zhangji district, part of Huai River, in China. In the first study, the value of water pollution risk was obtained as 70 and the river was classified as bearing a high degree of vulnerability to water pollution, due to rapid urban development, excessive use of fertilizers in agriculture, and discharge of industrial and municipal wastewater into Zayendehrud [7]. In the second study, the value of water pollution risk was obtained as 58 and the river was classified as having a moderate degree of vulnerability to water storage pollution, low impact risk and high probability of occurrence, due to existence of plentiful villages and agricultural lands around the river, especially rice planting (New Mexico Environment Department).

Sub-watershed	Rating 7 parameters in WRASTIC method						
	Sewage	Recreational	Agricultural	Area	Transportation	Industry	Vegetation Coverage
Varangeh Rud	2	3	4	2	2	1	2
	WRASTIC Index=2 × 3+3 × 2+4 × 2+2 × 1+2 × 1+1 × 4+2 × 1=30						
Doab	2	3	4	1	5	1	2
	WRASTIC Index=2 × 3+3 × 2+4× 2+1× 1+5 × 1+1 × 4+2 × 1=32						
Varian	4	2	4	1	1	1	2
	WRASTIC Index=4 × 3+2 × 2+4 × 2+1 × 1+1 × 1+1 × 4+2 × 1=32						

Table 3: Estimation of water pollution risk in three sub-watersheds of Varangeh Rud, Doab and Varian using the WRASTIC method.

Results of organizing method

The ecological capacity assessment showed that the main potential capacity of the studied area in most studied zones were as conservation and expanded tourism in 2nd category, supportive forestry in 6th category, agriculture in 7th category and rangelands in 4th category and lacking centralized tourism capacity and development, respectively. At the moment, however, the major land uses are classified as rangelands, agriculture, forestry, and centralized tourism. Therefore, current land uses are not compatible with the capacity of the study area and only 25.42% of the capacity of the three studied sub-watersheds has acceptable land use, which will lead to further degradation and pollution of the study area. The user's disproportion percentages are 74.4%, 72.9% and 76.4% for Varangeh Rud, Doab and Varian, respectively. Subsequently, by comparing the ecological qualitative capacity of the three sub-watersheds and current uses, the major uses meet the capacity of the study area was in conservation with extensive recreation and conservation with supportive forestry. Also, assessment of pollution parameters in 4 stations (stations 137,138, 11 and 101 in

Varangeh Rud, Doab and Varian watersheds, respectively shown in map 1) demonstrated that only microbiological parameters, in particular, the thermophilic coliform 1976 MPN/100 ml and total coliforms with 6371 MPN/100 ml are several times more than standard and considered as the main causes of Karaj River pollution. It should be noted that these parameters indicate the arrival of refined sewage, non-refined sewage, and non-point pollutant sources.

To summarize the results, and consequently have an accurate assessment of the three sub-watersheds, the SWOT Tables were prepared for each pollutant potential. In these tables (Table 4), the weaknesses are the same issues that lead to threats (as the present study emphasizes on the identification of the pollutant areas, here, threats are particularly presented). Accordingly, 11 main issues related to the Karaj Dam watershed pollution (from A to P) with the relative pollution severity were shown in the range of 0-14 in the table.

In the below Table (Table 5) all sub-watersheds are evaluated in terms of the obtained issues. It should be noted that, for each issue, scoring is used in a single method in all areas; therefore, the grades in the rows and columns separately, are compatible with each other, can be added to each other and are relative, therefore the table addresses both the prioritization of issues and the prioritization of the zones. In the sum of columns, any issue with the highest score is considered to be the most important issue for water pollution of three sub-watersheds, and the total number of rows also shows the pollutant potential of the zones compared to each other, in watershed water pollution. As shown in the table, the highest priority of water pollution factors in all three sub-watersheds is the arrival of wastewater from rural settlements into absorbent wells and then to river water and land use change and the least priority to degradation due to mines activity and the presence of some of the population centers in the riverside. Also, according to the classification of the sum of values in very low (13-16), low (16-19) and medium (19-22) pollutant potential [6] and comparison of the sum, low, moderate and very low pollutant potential was achieved for Varangeh Rud, Doab And Varian sub-watersheds, respectively. Results of the present study are similar to those of Hossein Hashemi et al. In their studies, the researchers found that in the sub-watersheds of Velayat Rud, Shahr-e-Kark and Sierra, more than one-third of the total pollution arrived into reservoir of the dam and other sub-watersheds including Varangeh Rud, Doab and Varian had little contribution to Dam pollution.

Issue	Description	Evaluation method
A	Land use change (rangeland conversion to low yielding rain crops)	The more the conversion lands, the higher the score is.
B	The arrival of sewage from population centers around Dam (military and recreational centers) to the Dam	The only issue is causing score (1) in the zones, and if there is no problem, the score is zero to the area.
E	Unsanitary collection of wastes	
F	Construction of some population and activity centers in Riverside	
C	The arrival of sewage from rural settlements to absorbent wells and entering of gray wastewater to river water	The higher the sewage produced in the area, the higher the score is allocated to the area.
M	The destruction caused by my activities	The more pollutant centers in that issue, the higher the score for that issue in the area is considered
L	Presence of catering centers without wastewater treatment	
I	The existence of polluting service activities (small workshops) along the Karaj River	
N	Remains of tourists wastes in tourist centers	The density of tourist centers is considered in intensity according to (1) to (3)
O	Lack of disproportion use of existing potential land use	The disproportion of uses between 60% and 70%: score 1, between 70% and 80%, score 2, and upper 80%: score 3
P	High levels of erosion (drains, gardens and landscapes, roads and pastures)	The sediment between 4,000 to 10,000 tons (score 1) and between 10,000 and 16,000 tons (score 2)

Table 4 : The principal pollutant factors of Karaj Dam watershed and their evaluation.

Issues Zone Name	A	B	C	E	G	I	L	M	N	O	P	Total rows	Zones prioritization
Varangeh Rud	6	0	5	1	0	0	0	0	2	2	2	18	2
Doab	0	0	6	1	1	2	2	1	1	1	1	21	1
Varian	0	5	2	1	0	0	0	0	2	2	1	13	3
Total columns	6	5	13	3	1	2	2	1	5	6	4		
Issues prioritization	2	3	1	5	7	6	6	7	3	2	4		

Table 5: Evaluation of the issues for three sub-watersheds (zones) in order to prioritize them in SWOT method.

Conclusion

According to results of WRASTIC method, in risk assessment of water pollution throughout Varangeh Rud, Doab and Varian sub-watersheds of Karaj Dam, all have shown low pollution risk due to limited access to the sub-watersheds, lack of a specific industry, low area, as well as limited agricultural activities including agriculture, gardening, rangeland, and cattle grazing (consumer use), and the environment and recreation (non-consumable). In addition, Varian is not permanently inhabited. Regard to permitted motor activities, as not allowed throughout the main river of Karaj dam, and also Jeep route has not been developed in most areas, therefore, the transport activity rates are low in the region which will lead to a low rate of water pollution in the region.

Moreover, in Organizing method, Varangeh Rud sub-watershed with low pollutant potential (with pollutant production sources such as sewage of rural settlements, agricultural pesticides and fertilizers), Doab with mean pollutant potential (with pollutants such as rural settlements sewage, Catering centers without sewage treatment, pesticides and fertilizer caused by agricultural land and gardens, polluting service activities such as car repair, petrol stations and mines) and Varian with very low pollutant potential (with pollutant sources such as rural settlements sewage around the dam and agricultural pesticides and fertilizers), are known in Karaj Dam watershed compared to each other. Comparison of these two methods presented almost similar results. Consequently, Varangeh Rud in both methods has low pollutant potential; Doab sub-watershed has shown low and mean pollutant potential in WRASTIC and organizing methods, respectively. Besides, Varian subwatershed has shown low and very low pollutant potential in WRASTIC and organizing methods, respectively.

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