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Evaluation of Aydughmush River water quality using the National Sanitation Foundation Water Quality Index (NSFWQI), River Pollution Index (RPI), and Forestry Water Quality Index (FWQI)

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ABSTRACT

In rivers, water flowing results in dilution and decomposition of pollutants faster than standing water. Water quality index (WQI) is a tool to reflect the composite influence of different water quality parameters. WQI is a fast and simple manner to show water quality from the point of view of a special consumption such as human consumption etc. Therefore, in this study, the water quality of the Aydughmush River evaluated by the National Sanitation Foundation Water Quality Index (NSFWQI), Forestry Water Quality Index (FWQI), and River Pollution Index (RPI). This study surveyed the parameters of the NSFWQI and RPI including dissolved oxygen percentage, temperature difference, biochemical oxygen demand (BOD), fecal coliform bacteria, turbidity, total suspended solids, pH, and phosphate. In addition, 22 parameters were measured for FWQI calculating. These parameters were measured at eight stations for one year (2010–2011). The results showed that water quality of Aydughmush River is within the "Medium" category according to the NSFWQI and the "Negligibly polluted" class based on RPI. The overall water index was in the borderline at all the stations but it was excellent at station D based on FWQI. According to this study, the results of NSFWQI and FWQI are consistent with each other but RPI index has different results.

Keywords: Aydughmush River; Water Quality Index; NSFWQI; RPI; FWQI

1. Introduction

In water quality monitoring programs, many parameters are evaluated. Various types of specialized knowledge are required to interpret the obtained results [1,2]. In environmental monitoring programs, such as water quality monitoring, reporting results to managers and the public is a main objective. Reporting of obtained results to relevant organizations and comparing them with water quality guidelines presented by international organizations are the usual approaches taken by water quality monitoring plan in

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Iran and other countries. A qualitative comparison of the measured parameters with standard values can give information about the water resources. However, in most cases, managers and the public do not need to be aware of the detailed results of studies or monitoring programs. Moreover, they may not have the essential ability to explain the results [3,4]. Therefore, it is necessary to show monitoring results in terms of impact on public health and the environment, industry, agriculture, and recreation. One solution to this challenge is to evaluate water quality based on specified indices and reporting the results by defined criteria [4].

A water quality index (WQI) combines obtained data from water quality parameters and gives a fast and understandable explanation. In addition, a WQI gives an only value (similar to a score) to ease shown water quality in the definite site and time based on several usual water quality parameters [4,5]. Water quality indices that use easily can show water quality in specific area quickly and powerfully.

National Sanitation Foundation Water Quality Index (NSFWQI) [4], Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), and Oregon Water Quality Index (OWQI) are some of the river water quality indices developed by organizations and used by many researchers (6). In these indices, water quality parameters compare to regulatory standards and give a value to the water quality of a source [6].

Among water quality indices, the NSFWQI is most widely used by some researchers [1,4,5,7]. The NSFWQI was developed to give a standardized method for comparing the water quality of various water bodies. The River Pollution Index (RPI) is another common WQI. RPI is an integrated indicator used to find the level of pollution of the river [2,3]. Industrialization and human activities in the basin were the main reasons for the declining of water quality [7].

This study was conducted due to the vastness of the Aydughmush River Basin and the importance of awareness about the water quality of the river and possible pollution. Our purpose was to check the water quality of the Aydughmush River using the NSFWQI, Forestry Water Quality Index (FWQI), and RPI.

1.1. Study site

The studied area is the Aydughmush River located in the Sefidrud basin in northwest of Iran (Fig. 1). It has a basin area of 1,802 km^2. Its longitude and latitude are 46˚53´ to 47˚45´E and 36˚45´ to 37˚23´N, respectively. Aydughmush River with 80 km in length is the largest river in the Aydughmush Basin. It originates in northwest Iran, flows eastward, and enters Aydughmush dam. The Aydughmush basin and Aydughmush River are shown in Fig. 1. The annual discharge of the Aydughmush River is 170 million m^3 and the basin precipitation is about 378 mm.

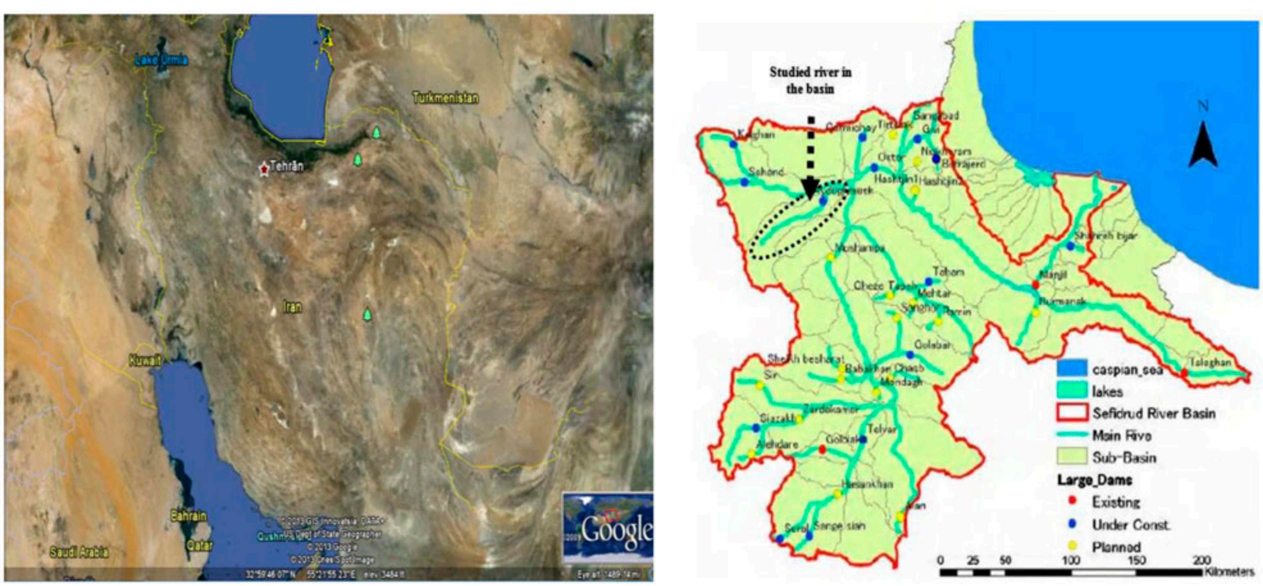

Fig. 1. Over view of Aydughmush River location in Sefidrud basin, in Iran [8].

2. Materials and methods

2.1. Sampling stations

After visiting of the region, eight stations along the river were selected. The location of each station is presented in Table 1. In this studied river, water quality was evaluated using NSFWQ and FWQ indices. In addition, RPI was selected to manifest and understand the tendencies of water pollution. Particularly, one of the tasks pioneered in this study is the use of two different types of river indices from which we get water quality and river pollution, simultaneously.

2.2. National Sanitation Foundation Water Quality Index

These nine parameters for NSFQWI calculating include dissolved oxygen (DO, mg L^{-1}), biochemical oxygen demand (BOD_5, mg L^{-1}), nitrate (NO_3^-, mg L^{-1}), phosphate (PO_4-P, mg L^{-1}), fecal coliform bacteria (CFU/100 mL), turbidity (NTU), total solids (TS, mg L^{-1}), temperature change from 1 mile upstream (°C), and pH. For NSFQWI calculating, weighting factor of each parameter has been used. For weighting factor determination, scientists were asked to graph the level of water quality ranging from 0 (the worst) to 100 (the best) from the raw data, (e.g. pH values 2–12), first. The curves drawn were averaged to get a weighting curve for each parameter. Results of the nine parameters are compared to the curves and a numerical value, or "Q-value," is obtained. After the Q-value is obtained, it is multiplied by a "weighting factor," based on that test's importance in water quality. The nine resulting values are then added to arrive at an overall WQI.

The NSFWQI ranges are divided by five quality classes including very bad (0–25), bad (25–50), medium (50–70), good (70–90), and excellent (90–100). Each of the NSFWQI parameters has its own weighting factor (W_i) which describes the importance of the effect of each parameter in the calculation. The weighting factor for each parameter has been presented in Table 2.

Table 1
Geographical characteristics of studied river

Sampling stations			
Name	Latitude	Longitude	Symbol
Bodaq Beyg	37° 14′ 26.2′′	47° 30′ 6.5′′	A
Tavaq	37° 12′ 38 ′′	47° 28′ 59 ′′	B
Qezeljeh qeshlaq	36° 35′00′′	47° 42′00′′	C
Qalèh-ye hoseynabad	37° 10′	47° 15′	D
Korja	37° 6′ 30′′	47° 8′ 24′′	E
Qurt Yemaz	37° 7′ 7 ′′	47° 11′	F
Qareh Kandi	38° 7′	45° 1′	G
Peyk	36° 58′	43° 3′	H

Table 2
Weighting factor for each parameter in NSFWQI calculation [1,9]

Index parameter	W_i of each parameter	Index parameter	W_i of each parameter
Dissolved oxygen (DO)	0.17	Turbidity	0.08
Fecal coliform (FC)	0.15	Suspended solids (SS)	0.08
pH	0.12	Temperature	0.1
Total phosphates (TP)	0.1	Biochemical oxygen demand (BOD_5)	0.1
Ammonia nitrogen (NH_3-N)	0.1		

2.3. The River Pollution Index

Environmental Protection Administration of Taiwan applied the RPI in combination with the water quality data for categorizing the water quality monitoring stations into appropriate groups. Obtained results using this index were able to show the characteristics and extent of pollution for each group, which will be a valuable reference for managing stream pollution, as well as water quality monitoring along a river [3]. The RPI can be used to determine stream pollution based on the four water quality parameters including dissolved oxygen (DO), biochemical oxygen demand (BOD_5), suspended solids (SS), and ammonia nitrogen (NH_3-N) presented in Table 3. Eq. (1) is used for RPI calculation. In this equation, "S_i" is the index score and it is selected based on Table 3. Each of the quality parameters is ultimately converted to a four-state quality sub-index [10,11].

$$\mathrm{RPI} = \frac{1}{4}\sum_{i=4}^{4} S_i \quad (1)$$

The RPI value ranges from 1 to 10. Finally, the RPI index is classified into four pollution categories (unpolluted, negligibly polluted, moderately polluted, and severely polluted).

2.4. Forestry Water Quality Index

The FWQI calculation is done for three kinds of usages: (a) Drinking Water Quality class: in this class, there are drinking, recreation, irrigation, and livestock watering uses. (b) Aquatic Water Quality class: aquatic life and wildlife protection uses are in this class. (c) Overall Water Quality: in this class, there are all the usages encompassing, the protection of human health, aquatic ecosystems, wildlife, etc. For each usage, there is a standard value which is used to compare the attainment of water quality objectives, coming from EPA Quality Guidelines and Guidelines for Iranian Drinking Water Quality. There were conclusions of the 21 physical/chemical variables inputted in FWQI, which are: alkalinity, conductivity, hardness, pH, TDS, TSS, turbidity, calcium, chloride, potassium, sodium, sulfate, ammonia, DO, nitrate(it), total phosphorus, barium, cadmium, iron, zinc, and temperature.

The FWQI is attained by using variances in three ways that are F_1 (scope), F_2 (frequency), and F_3 (amplitude). Described FWQI formulation in this paper is based on the Canadian Water Quality Index 1.0—Technical Report (CCME 2001).

$$\mathrm{FWQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \quad (2)$$

Then obtained FWQI values converted into rankings by using the categorization scheme are presented in Table 4.

In Eq. (2), F_1 is the number of objectives that not met as a percentage of the number of objectives checked. For a period of one year, F_1 is calculated by summing the number of objectives that not met in that year, dividing by the total number of objectives evaluated that year, and multiplying by 100. For a given type of WQI determination, if n is the number of objectives (variables) which do not meet a water quality standard in a specified period and if N is the total number of objectives measured in that period, then F_1 is determined according to Eq. (3).

$$F_1 = \left(\frac{n}{N}\right) \times 100 \quad (3)$$

F_2 is measured as a percentage of the several times the objectives that are not met in a given time period, of all instances the objectives are checked during that

Table 3
Parameters and classification of RPI [9,10]

Index parameter	Water pollution classification			
	Unpolluted	Negligibly polluted	Moderately polluted	Severely polluted
Dissolved oxygen (DO)	>6.5	4.6–6.5	2–4.5	<2
Biochemical oxygen demand (BOD_5)	<3	3–4.9	5–15	>15
Ammonia nitrogen (NH_3-N)	<0.5	0.5–0.99	1–3	>3
Suspended solids (SS)	<20	20–49	50–100	>100
Index score (S_i)	1	3	6	10
RPI value	<2	2–3	3.1–6	>6

Table 4
FWQI range, classification, and their descriptions

FWQI ranges	Water quality classification based on each range	Description of each class
95–100	Excellent	There is not any risk or threat for a specific use close to natural or pristine level
80–94	Good	There is a small degree of risk or threat and conditions rarely depart from the natural or wanted conditions
65–79	Fair	That may be a single use (Drinking, Aquatic, Recreation, Irrigation, or Livestock) not overall, for a short time interrupted, and conditions sometime depart from the natural or wanted conditions
45–64	Borderline	Several uses are threatened or impaired and more than one use may be temporarily interrupted
0–44	Poor	When conditions usually depart from natural or wanted levels, as well as most uses are at risk or threat and also several uses may be temporarily interrupted

period. For a given type of WQI determination, if m is the several times the objectives that do not met the water quality standard or guideline for the use and if M is the number of times the objectives (variables) are measured, then F_2 is calculated by Eq. (4), as follow:

$$F_2 = \left(\frac{m}{N}\right) \times 100 \quad (4)$$

Amplitude or F_3 is symbolic of the greatest amount of failed tests that do not meet their objectives. Three consecutive steps are required for F_3 calculation. In first step, excursion should be calculated using two approaches (a): when the test value does not exceed the objective and (b): when the test value does not fall below the objective.

(a) $\text{Excursion}_i = \left(\frac{\text{Failedtestvalue}}{\text{Objective}_j}\right) - 1$

(b) $\text{Excursion}_i = \left(\frac{\text{Objective}_j}{\text{Failed test value}}\right) - 1$

Then in the second step, the normalized sum of excursions (NSE) should be calculated. NSE is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both of them meeting objectives and not meeting objectives).

$$\text{NSE} = \frac{\sum_n^{i=1} \text{excursion}_i}{\text{Number of test}}$$

F_3 is calculated using two former steps results and by using Eq. (5).

$$F_3 = \left(\frac{\text{NSE}}{0.01\text{NSE} + 0.01}\right) \quad (5)$$

Samples are taken at a depth of 30 cm below the water surface at each sampling station. The composite samples were examined following the Standard Methods for water and wastewater examinations for each parameter [12]. Samples were collected between 9 and 11 am on the first week of every month throughout one year (August 2010–July 2011).

3. Results and discussion

Monthly data were collected at eight water quality-monitoring stations in the Aydughmush River from August 2010 to July 2011. During the data collection period, if incomplete or incorrect water quality data were caused by occasional errors at some water quality monitoring stations, they were deleted. In short, 96 correct water samples were acquired. NSFWQI and RPI values for each sampling station are presented in Tables 5 and 6 that used the annual average of the NSFWQI and RPI values for each station and each quality parameter.

As it is clear from Table 5 and Fig. 2, river water quality in all the sampling stations was classified as "medium" (NSFWQI = 51–70). However, the value of the index at station D (NSFWQI = 72.51) was classified as "good."

Table 5
Results of NSFWQI values calculated for water quality of each station

Parameters in NSFWQI	Weighting factor	NSFWQI for each station							
		A	B	C	D	E	F	G	H
		W_iI_i values							
DO	0.17	10.03	3.06	5.1	9.69	8.84	10.88	8.16	12.41
FC	0.16	10.4	10.24	9.6	10.4	10.4	8.96	5.76	10.08
pH	0.11	8.03	8.8	8.03	8.03	8.8	7.26	8.03	8.47
BOD	0.11	7.26	7.37	10.56	10.78	8.58	10.56	6.16	7.59
ΔT	0.1	5	4.5	3.4	5.3	4.5	3.4	3.6	4
TP	0.1	6	6	4.2	7.9	4.9	8.2	9	4.4
NO_3^-	0.1	9.7	9.5	9.7	9.7	9.7	9.7	9.6	9.6
Turbidity	0.08	5.12	4.96	6.16	6.72	6.56	6.96	5.2	5.28
TS	0.07	1.4	1.4	1.4	3.99	1.4	1.4	1.4	1.4
NSFWQI		62.94	55.83	59.05	72.51	63.68	67.32	56.91	63.23

Table 6
RPI values for the sampled stations

Station	Parameter concentration (mg/L)				S_i				RPI
	DO	BOD	TSS	NH_3-N	DO	BOD	TSS	NH_3-N	
A	7.00 ± 1.1	3.20 ± 0.51	26.85 ± 1.01	0.55 ± 0.019	1	3	3	3	2.5
B	3.10 ± 0.55	3.06 ± 1.09	28.20 ± 1.89	0.39 ± 0.029	6	3	3	1	3.25
C	4.30 ± 0.43	0.85 ± 0.06	14.44 ± 0.79	0.55 ± 0.11	6	1	1	3	2.75
D	7.00 ± 0.2	0.50 ± 0.07	9.00 ± 2.19	0.45 ± 0.009	1	1	1	1	1
E	6.20 ± 1.52	0.22 ± 0.01	10.17 ± 0.82	0.39 ± 0.038	3	1	1	1	1.5
F	6.50 ± 0.68	0.90 ± 0.05	6.63 ± 2.54	0.25 ± 0.12	3	1	1	1	1.5
G	5.30 ± 1.05	5.00 ± 1.01	25.50 ± 0.74	0.12 ± 0.068	3	1	3	1	2
H	7.40 ± 0.41	2.70 ± 0.61	38.70 ± 4.01	0.40 ± 0.021	1	6	3	1	2.75

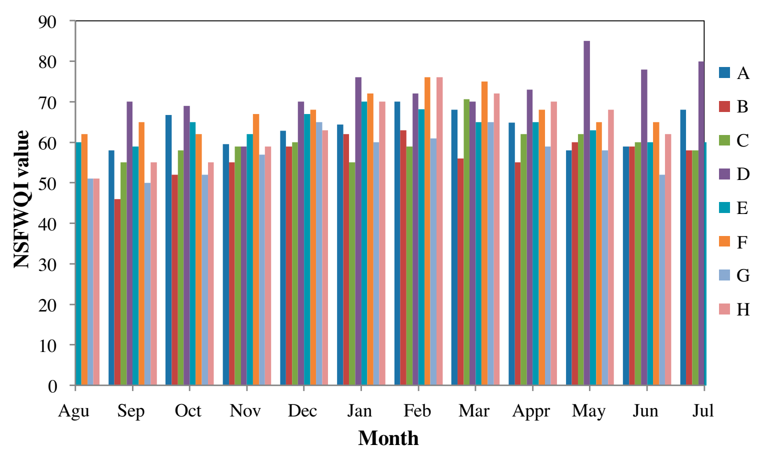

Fig. 2. Monthly NSFWQI values for each station.

As the results showed, based on NSFWQI, water quality at all the stations except station D (good class) is classified as "medium." The higher value of NSFWQI for D station is due to the low values of BOD and fecal coliform, as well as higher dissolved oxygen than that of the other stations. Table 5 shows that the DO levels at A, F, and H are higher than that of D, the BOD levels at D are actually the highest, and

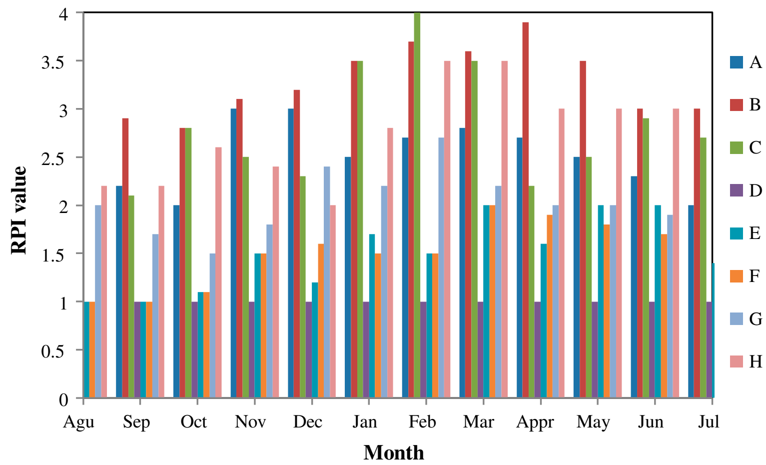

Fig. 3. Monthly RPI values for each station.

the fecal coliform counts at A, D, and E are both equal and the highest ones, while NSFWQI values are close to each other. This may be indicative that the NSFWQI does not fit with the studied area and/or it fits but the weights we gave to the constituents of WQI are not suitable for our studied system. Inadequate sample size and failure of the annual average of the NSFWQI values to discriminate between the different stations can be other reasons to inappropriate this index. We think the weights of used NSFQWI formula is not suitable, and there is a need to design new WQI with suitable weighting factor, but in general indices which use the weighting factor provided the best results for the indexation of the general water quality.

One of the most widespread economic activities of residents in Aydughmush basin is animal husbandry. According to the waste (solid and liquid) production per head, livestock waste is considered as one of the major sources of pollution of rivers (fattened cattle produce 10.59 tons of waste per year and dairy cows produce 15.24 tons per year [13]). Waste production amount is varied from one place to another, but assuming that waste production rates in present study area equal those reported by Hutchison et al. [13]. Livestock waste and wastewater containing it can deteriorate river quality. Livestock waste has ammonia nitrogen. Dissolved and inorganic form of nitrogen is ammonia that by consumption of dissolved oxygen turns into the most reduced form of nitrogen in aqueous solution. Notice that the NSFWQI does not include ammonia nitrogen while RPI dose includes it; so, in this case, RPI is more capable in pollution determination than NSFWQI. As the role of livestock waste on river water quality is very complex, a special study should be designed to verify its role on river pollution.

As shown in Fig. 2, maximum and minimum of NSFWQI values were in February and August, respectively (68.15 vs. 55.37).

The calculated RPI values are shown in Table 6 and Fig. 3. According to the obtained results based on the RPI classification, the water quality at three stations (D, E, and F) is classified as "unpolluted" water and only one station (B) was "Moderately polluted" (RPI = 2.75). As shown in Fig. 3, maximum and minimum of RPI values were in February and September, respectively (2.71 vs. 1.72).

The river water at station B is classified as moderately polluted, while at stations A, F, G, and H are negligibly polluted (Table 6). According to the RPI

Table 7
FWQI values and their classification for the sampled stations

Data summary	Overall	Drinking	Aquatic	Recreation	Irrigation	Livestock
FWQI	63	59	100	100	82	100
Categorization	Borderline	Borderline	Excellent	Excellent	Good	Excellent
F_1 (scope)	33	40	0	0	25	0
F_2 (frequency)	22	21	0	0	16	0
F_3 (amplitude)	50	54	0	0	12	0

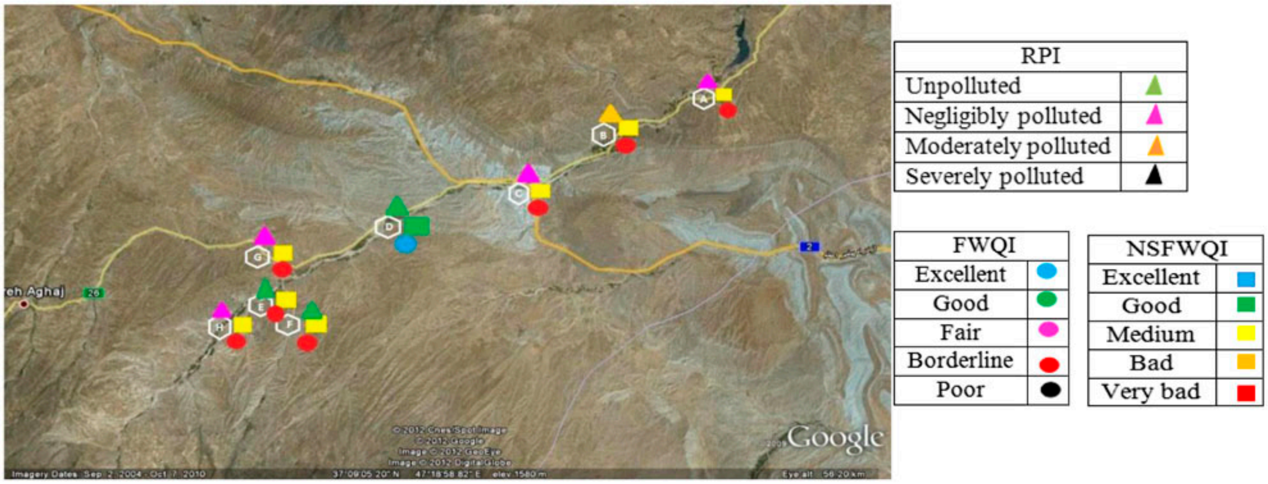

Fig. 4. Exploit Aydughmush River basin and overall water quality indices.

values listed in Table 6, station B should be exhibiting much lower water quality because NH_3-N has the highest weight ever in the RPI.

No water quality parameters of B station tend to have high concentration, if water-monitoring station B based on each water quality parameter is judged only for DO classified in a moderately polluted category while based on BOD and SS, it is classified in negligibly polluted category; and when judged based on ammonia nitrogen (NH_3-N) it can be classified into unpolluted category.

The FWQI were evaluated for overall use, drinking, aquatic, recreation, irrigation, and livestock water use. Table 7 summarizes the FWQI for overall use, drinking, aquatic, recreation, irrigation, and livestock water use, respectively. The overall water index was in borderline at all the stations except for D where it was excellent (Fig. 4). The lowest FWQI value pertains to drinking water use among all of the water uses.

As shown in Fig. 4, the results of used indices for evaluating NSFWQI and FWQI have more accordance. RPI uses the multiplicative collective function of uniform scores for a number of water quality parameters to show river health, while FWQI and NSFWQI assesses quality of water against guidelines for freshwater life. Therefore, NSFWQI and FWQI have the same approach and application. A recent study [14] showed that by using some FWQI procedure analyses, the specific problematic parameters that may be contributing towards lowering the index values can be identified.

Using the FWQI information in comparison to other used indices, it is possible to determine parameters having the largest excursion from the guideline, parameters exceeding the most times, and therefore parameters driving the index. This will assist in validating the index against real data and help in identifying parameters, or guidelines. The method which is used in FWQI is the most sensible method in a data-set with low values, because these take more weight than those with high values. In FWQI calculation, all factors are taken into account based on the data and their relation to the objectives. With this concept focusing on the objectives, the agents must worry more in improving the environmental conditions.

4. Conclusion

Because overall water quality and pollution in rivers are complicated by large-scale development and pollution, therefore, in this research, three indexes were used to assess the overall water quality of the river. It is trusted that the use of NSFWQI, RPI, and FWQI meet the objectives of management systems in execution.

FWQI entails adequate sensitivity for observance of guidelines. It is recommended in cases where there are enough sampling stations and sampling frequency. When a few specific parameters are used for water quality assessing, the use of NSFWQI is preferred.

The RPI is as same as NSFWQI with the difference that all used parameters have equal value in index calculation without weighting rate. The concentration of total phosphorus has not been considered as a parameter to stream pollution in RPI.

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