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RESEARCH PAPER

Sustainability-based Conservation Approach to Assess the Health and Quality Condition of Aquatic Ecosystems using bed Sediment Oxygen Demand Rate and its Associated Factors
(Case study: Darreh-rood River, Aras Basin, Moghan Region, NW-Iran)

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ABSTRACT
Bed Sediment is a dynamic and complex material that plays an important role in the aquatic ecosystems and provides habitat from a highly various community of organisms. To address the major issue, this study, which its substantive subject done for the first time in Iran, aimed to assess the current status of Darreh-rood river's health and quality using SOD rate and its associated factors including Texture, fine-PSD, TOC and TP of bed sediments along with some basic field parameters of river-water. All required samples were collected from 10 sampling points in due course. SOD data with regard to related factors were calculated and analyzed. The rates of SOD ranged from 0.69 to 1.57 g O_2/m^2/day. Moreover, this index was classified in varied quality domains. Afterwards, a predictive equation was determined among SOD rate and its associated parameters using MATLAB software. Finally, the Results showed that the river quality and health suitability in research area are in categories slightly clean and slightly degraded, in targeted zones during the study period. Also, the increase in TOC and TP concentrations together with a decrease in sediment particle size was led to an increase in SOD-rate accordingly. In conclusion, the consequences of this study under Survivability-based Adaptive Management (SAM) perspective can be used as a rapid diagnostic tool to support water policy decision-makers and other stakeholders to promote the best practices for protecting the health conditions of riverine systems, focusing on selecting the appropriate points for discharging the wastewaters into the receiving water-bodies.

KEYWORDS: SOD rate, SAM approach, Aquatic Ecosystem, River Health, Moghan Region

INTRODUCTION

Rivers are the most important water sources that play a key role in providing the water needed for various activities such as human living, agriculture production, industry purpose, drinking-use and survival of the ecosystem, so that most of the water resources planning in countries is based on the potential of these valuable water-bodies (Ashayeri & Karbassi, 2014). With the rapid development of industry and agriculture, intense anthropogenic activities have broken the original ecological balance, and have affected the structures and roles of the river ecosystem beside the significant pressures imposed (Moghimi, 2009). These sources as an essential part in the water-cycle also have key functions such as electricity generation, flood risk control, water supply, food production, aquifers' recharging, sediment transport, and sightseeing along with

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acting as drainage channels for surface water (Allan and Castillo, 2007; Pan et al., 2012a). Discharge of various pollutants from point and non-point sources into water bodies has many negative effects on their environment and in return, active restoration of them will require a lot of time, money and efforts (Bernhardt et al., 2007).The improper use of pesticides and chemicals in agriculture together with the discharge of nutrients from various sources disrupt the balance of dissolved oxygen in the rivers(Berg et al., 2017).River-bed sediments as a sink of complex and dynamic materials are effective in providing habitat for a very diverse community of living organisms as well as in understanding the changes in their associated ecosystems and in reflecting key biogeochemical processes over a period of time (Cardoso et al., 2019). These sediments have a great variety in size, chemical compounds as well as geometric forms and shapes (Mudroch & Macknight, 1994; Ziadat, 2004).The oxygen demand of bed sediments and benthic organisms makes up a main part of the oxygen consumption rate in the rivers. This demand is mainly due to the transport and deposition of organic matters, which may be generated from sources outside the system such as particulate matters, debris/detritus, drainage-water, wastewater, effluents, sewage, or from local materials inside the system(Zhongqiao Li et al., 2015).A strong relationship has also been resulted between the benthic-based bio-indicators such as macro-invertebrates, nutrient enrichment, and the health quality situation of river-water (Mezgebu et al., 2019; Musonge et al., 2020). Benthic invertebrates living in the riverbed sediments along with bioavailability of organic matters can also produce a high rate of oxygen demand (USEPA, 1997; Walker and Snodgrass, 1986). Therefore, Sediment Oxygen Demand (SOD) rate includes both the Biological SOD (B-SOD), and the chemical SOD or C-SOD (Chau, 2002; Hu et al., 2001). Conceptual model of DO depletion and its relevant reactions (Lee G.F. & Lee A.J., 2007) has been illustrated in figure 1. It has been reported that the SOD with a significant effect on the oxygen budget of a river system, accounted for more than half of the total oxygen demand in some water systems, hence, this rate should not be underestimated (Liu et al., 2012). Large differences in SOD measurements with different chambers have been noted and this also has been recognized to differences in the chamber fluid mechanics (Joseph Lee et al., 2000).In a study carried out by researchers from USA (Doyle & Rounds, 2003; Doyle & Lynch, 2005), the rates of SOD ranged from 0.3 to 2.9 g O_2/m^2/day with a median value of 1.8 g O_2/m^2/day, and the overall median rate of SOD was used in water-quality assessment models for the entire study reach. Algal bloom was also identified most likely as the largest and important source of labile organic matter in occurrence of hypoxia. In one research on Santubong river in South Korea (Yee et al., 2011), the results showed that SOD rates ranged from 4.5 to 9.8 g O_2/m^2/day. It was demonstrated that the SOD values were significantly higher near aquaculture sites. In addition, total phosphorus and total organic carbon of the sediments accounted for about 96% of the total changes in SOD. The average values of SOD in a study in USA on the Arroyo Colorado River (Matlock et al., 2007) varied from 0.13 to 1.2 g O_2/m^2/day, and the results revealed that the sites with high sediment deposition potential had high SOD value. A research study concerning the benthic-based oxygen demand of Tercero River in Argentina (Chalimond et al., 2019) showed that the SOD rates in mineral and sandy bed materials ranged from 0.040 to 0.484 gO_2/m^2/day. Further, some factors such as sediment features, water flow rate or velocity, temperature, and wastewater disposal concluded as influencing factors on the variations of SOD rates.

Given the major points addressed above, this study aimed to assess the health condition of Darreh-rood River using sediment and benthic-based features. It focused on measuring and analyzing the Sediment Oxygen Demand rate and its associated factors, considering Survivability-based Adaptive Management (SAM) approach to the discharge points along the receiving water-body.

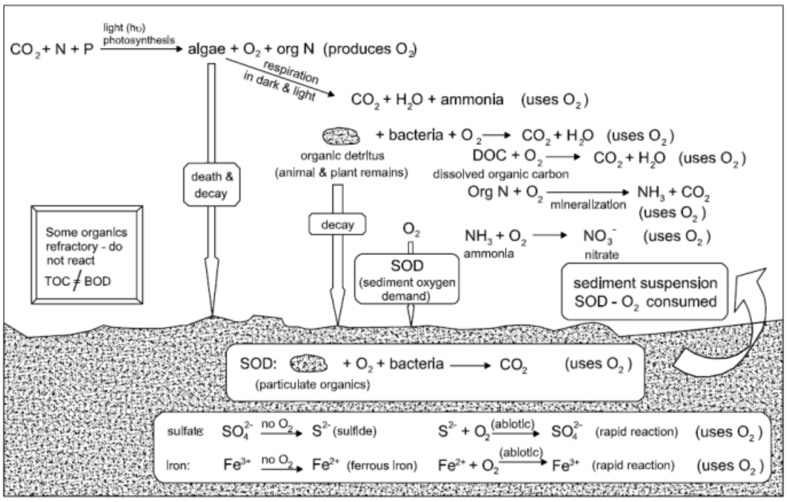


Fig. 1. Conceptual Model of DO Depletion Reactions
[Adapted from: Lee, G. F., Jones-Lee, A. (2007)]

MATERIAL AND METHODS

The study area (Darreh-rood river sub-basin) is located in northwest of Iran, Aras Basin and Moghan Region (Fig.2). Main stream of the river is started and fed at the confluence point where the two tributaries Ahar-chai and Qarah-sou merge together. This river eventually flows into the Aras River. The river basin lies at latitude 47º 10' to 47º 50' in East and longitude 38º 45' to 39º 30' in North, covering an area of about 14580 km^2 with main stream channel about 134.5 km in length. To conduct the research, ten sampling stations (S1-S10) were selected along the River and its tributaries (Fig.2) based on their accessibility and proximity to the discharge of point and non-point sources (UNEP/WHO, 1996). All required sediment and water samples were collected from the sampling points in early September 2017. According to the long-term meteorological data, the mean annual rainfall and temperature values in the study area are 270 mm and 14.3°C respectively (Ir-MoE, 2010-2015), and the river basin is occupied by about 5% forests and orchards, 32% farmland, 62.8% rangeland/pastures, and 0.2% other uses. Also, based on the USA soil taxonomy handbook, types of the soil within the study area are categorized in four classes: Entisols, Inceptisols, Mollisols, and Aridisols . From the stratigraphic point of view, volcanic, andesitic and igneous sedimentary rocks are the main types observed in the region. In addition, detrital deposits cover and make up a large part of the study area (Ashayeri, 2014).

There are several in-situ and laboratory methods for measuring the rate of SOD in water-bodies (USGS, 2003-2016; USEPA, 1985), most of which involve the system of employing the specific chambers. The method used in this study was based on the specialized laboratory chamber technique. The reason for focusing on laboratory methods was to be able to conduct the experiments in a highly controlled condition. The laboratory procedure also is generally more accurate over field measurements because of its replications and variations of components (Chau, 2002). The accuracy of these measurements relies on the ability of the chamber to simulate natural conditions, including temperature, turbidity and flow (Boynton et al., 1981). Moreover, climatic factors, cost, difficulty with the apparatus, and lack of standardization make in-situ measurements impractical for many investigators (Bowman and Delfino, 1980). With the aim to eliminate some of the shortcomings or limitations observed in previous studies, some modifications and additional possibilities were included in the chambers designed and constructed for this research (Fig.3). Additionally, other main reason for utilization of a modified chamber was to maintain the minimum disturbance possible to the sediment and its biological community under the same ambient conditions including the flow velocity of the water inside the chamber. For this research, after preparing the SOD chambers to start the measurement process, Oxygen depletion rates were measured. Such values were recorded every 5-minute, and a representative dissolved oxygen slope was established at each station accordingly. Then, the rate of SOD was developed by plotting the elapsed time versus the dissolved oxygen readings during the required course (2- 4 hours) in the chamber for each site (Fig.4). A brief description of the chambers used in this research (Fig.3) along with the results of how to operate the devices and to read the DO depletion rates, is subsequently presented in the next section. For this study, the following equation (USGS, 2010) was used for calculating the sediment oxygen demand:

$$SOD_T = -1.44(V / A)^b$$

where SOD_T is the sediment oxygen demand rate, in grams per square meter per day, at water temperature T; factor V is the volume of water in the chamber or volume of the chamber, in liters; A is the area of the bottom sediment covered by the chamber, in square meters; b is the slope of the oxygen-depletion curve, in milligrams per liter per minute; and 1.44 is a units-conversion constant. SOD rates were corrected to 20^{o}C using a standard Van't Hoff equation:

$$SOD_{20} = \frac{SOD_T}{1.065^{(T-20)}}$$

where SOD_{20} is the sediment oxygen demand rate, in grams per square meter per day, at 20^{oC} and T is the water temperature, in degrees Celsius.

The relevant standard methods and guidelines for measurement of the SOD rate and its associated parameters used in this study are summarized in tables 1 and 2 below. Further, to achieve the accurate and precise results, the whole relevant Quality Assurance and Quality Control (QA/QC) procedures (UN/ECE, 2003; APHA, 2005) followed during the research. Some statistical methods (Shrestha & Kazama, 2007; Andrade Costa et al., 2020) such as hierarchical cluster analysis (HCA), regression analysis, correlation matrix, t-test based inferential statistics, criteria-based analysis focusing on permissible levels and standards' compliance aspects, together with the expert judgment (Brownstein et al., 2019) were used. All the statistical analyses were performed using the MATLAB software and SPSS-16 program.

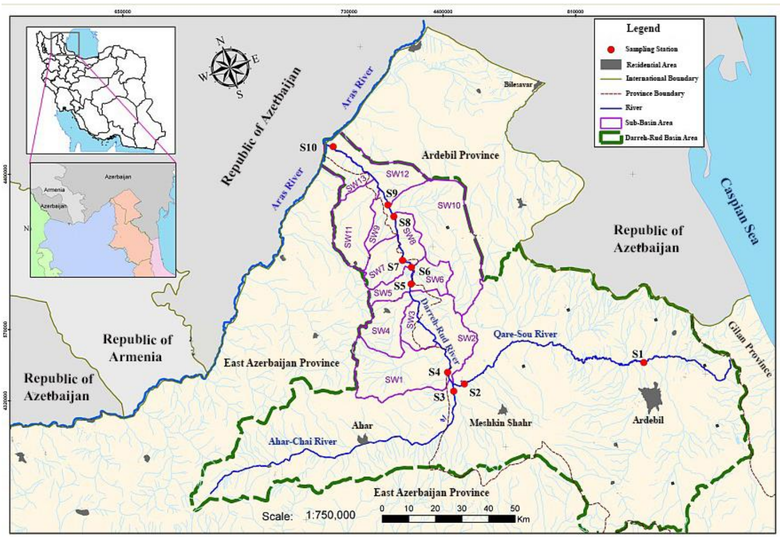


Fig. 2. Study Area and Location of Sampling Sites

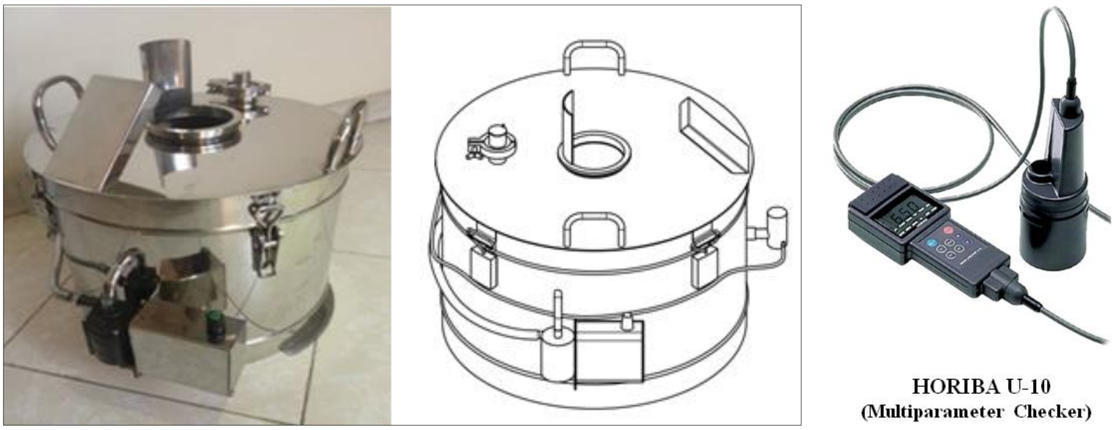


Fig. 3. SOD-meter Chamber (designed by the Principal Author: Azim Ashayeri), and Portable Multi-parameter Checker (manufactured by: HORIBA Ltd., Japan)

Table 1. List of SOD related parameters of the river bed sediments and standard methods or guidelines of measurement

Variable		Unit	No. of Stations	Frequency	Standard method/Guideline
PSD	Clay	%	10	1 [3 samples each site] Sampling Date: September 2017	▪ US-EPA, 1981 & 2001 ▪ UNEP/WHO, 1996 ▪ USGS, 2005 ▪ ASTM, 2014
	Silt				
	Sand				
Texture		Tex. name			
pH		s.u			
EC		dS/m			
OC & OM		%			
P (available)		ppm			
SOD		g O_2/ m^2/day			▪ USGS, 2005 & 2010 ▪ US-EPA, Ohio, 2012 ▪ ASTM, 2014

Table 2. List of the river water parameters and standard methods/guidelines of measurement

Variable	Unit	No. of Stations	Frequency	Standard method/Guideline
Temperature	°C	10	1 [3 samples each site] Sampling Date: September 2017	▪ Standard Method, APHA,2005 ▪ Manual of HORIBA U-10, 1991
pH	s.u			
Turbidity	NTU			
Salinity	%*			
DO	mg/l			
Discharge, Q	m^3/s			▪ USGS, 1982, Discharge Measurement ▪ HYDRO-BIOS RHCM, Current Meter

* pph (parts per hundred)

RESULTS AND DISCUSSION

Based on the aforesaid methodology, a modified and specialized SOD chamber along with a control device was used. After making preparations on the chamber to start the measurement, an initial rapid decrease in dissolved oxygen rate may occur within the chamber during the first 10 to 25 minutes of the experiment. This decrease may be due to the initial start-up of the pumps in circulating the water within the chamber, which may lead to re-suspension of the sediments in the water column for a short period of time until the suspended particles settled back to the sediment surface (USGS, 2005 & 2010). To overcome these limitations, and to achieve the best results, the following measures were taken: (1) selection and simulation of the chamber dimensions on a laboratory-based small scale in accordance with the hydrodynamic conditions of the river, in which the chamber enclosed a volume of 49.09 liters and exposed an area of 0.196 m^2 of sediment to the naturally circulating volume; (2) selection and installation of two proper types of the pumps with circulator (Peristaltic) and diffuser (water sprayer) roles on the suitable points of the chamber-wall along with their inflow and outflow pipes in order to establish the required good-mixing situation, similar flow and mixed velocity inside of the chamber and to eliminate the errors caused by the occurrence of sediment disturbance and re-suspension which may lead to abnormally increase in DO uptake; and (3) simulation of the river water flow velocity inside the chamber. For this purpose, an experimental study of the fluid mechanics of a SOD chamber was conducted in a laboratory model of the cylindrical type considering the three velocity components (vertical, horizontal/radial, and tangential) at 3 points on the effective line in the chamber. Flow velocity of these points measured by the Ultrasonic technology based micro current meter at different depths above the bottom of chamber, while the river flow velocity determined by the macro current meter (RHCM-Hydro Bios) using the 5-point methods across the water-body. To simulate the flow velocity, 2 above-mentioned pumps (circulator and water sprayer) installed at 2 proper points on the chamber-wall, while their positions and performances checked and controlled by a dimmer switch of electrical adaptor installed close to the pumps. Further, a rotameter as a QA/QC cross-check tool utilized for measuring the volumetric flow rate of the water inside the SOD chamber. Also, some other facilities such as a smart eye (for checking the sediment re-suspension and the pumps' performance), stabilizing support base (for the potable quality testing apparatus) and staddle base (for display LCD and data logger) provided on the chamber to ease up the operation and improve the performance of the device (Fig. 3). Further, after the rate of turbidity-changes inside the chamber reached a constant, it was assumed that the conditions for proper and effective reading of DO versus elapsed time were established and henceforth, the SOD rate at each chamber indicated the representative value at the relevant site (Fig.4).

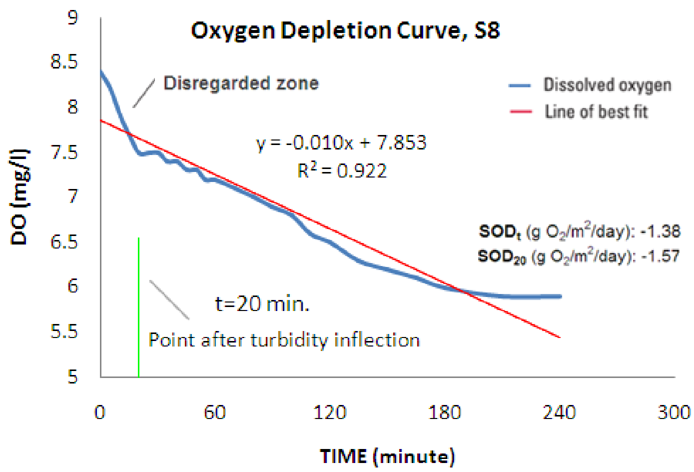


Fig. 4. Example Graph showing Dissolved Oxygen Depletion Curve

Considering the above-mentioned approach and required calculations, mean measured rates of the SOD in Darreh-rood river ranged from 0.69 to 1.57 g O_2/ m^2/day in the main stream and its tributaries during the study period (Table 3). Maximum rate of the SOD was found at S8 (Fig.2 & Fig.4) having a high proportion of fine–textured material with a higher content of organic matter in compared to the other sites. As already addressed, SOD is the rate at which dissolved oxygen is removed from the water-column in surface waters mainly due to the respiration of benthic organisms and decomposition of organic matter in the riverbed or bottom sediments.

Table 3. Results of the SOD rate measurements and other contributed parameters

Variable		Unit	Sampling stations [Sample Matrix: Sediment]									
			S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
PSD	Clay	%	14.16	11.18	4.21	7.42	5.32	3.59	3.13	9.07	1.53	4.38
	Silt		17.23	14.29	20.57	22.41	24.94	18.95	11.62	45.09	6.05	15.36
	Clay + Silt		31.39	25.47	24.78	29.83	30.26	22.54	14.75	54.16	7.58	19.74
	Sand		68.61	74.53	75.22	70.17	69.74	77.46	85.25	45.84	92.42	80.26
Texture		Tex.name	SL	SL	LS	SL	SL	LS	LS	L	S	LS
TOC		%	0.32	0.41	0.24	0.29	0.25	0.18	0.23	0.58	0.07	0.06
TP		ppm	5.1	7.9	5.6	4.2	4.9	3.8	3.2	10.3	1.2	1.9
SOD*		g O_2/m^2/day	**0.93**	**1.28**	**1.17**	**0.94**	**0.98**	**0.87**	**0.79**	**1.57**	**0.69**	**0.85**

***SOD rate: Mean value at 20 °C, SL: Sandy Loam, LS: Loamy Sand, L: Loam, S: Sand

To discuss the issue, in the following, the contributed factors affecting this rate are assessed and explained in detail. As shown in table 3, measured TP contents of the river bed sediments ranged from 1.2 to 10.3 ppm, the maximum value of which was observed in station 8. The main factors which influence the occurrence of this issue are the drain of agricultural runoff and effluents into this point of the river, the phosphorus pollution load resulting from non-point sources as well as the excessive use of P-fertilizers in agriculture and also the direct discharge of rural sewage/wastewater and effluents into the river system at this location. Results also revealed that there was a high significant positive correlation (0.965) between SOD_{20} rates and TP values in this study (Table 5). Measured TOC contents of the river bed sediments varied from 0.07 to 0.58 percentages as stated in table 3. Also, correlations between SOD_{20} and TOC were assessed. Results indicated that there was a significant positive correlation (0.882) between SOD_{20} rates and TOC percentage. SOD is the result of biological activity and chemical processes by which organic material is decomposed. Those nutrients and organic matters loading from exogenous sources may accelerate DO depletion and hypoxia (Zhang P. et. al, 2015). Oxygen depletion in connection with the sediment associated organic matter of the river bio-geochemical cycling under the oxidation process, partially depends on the sources of such materials (Collins, et al., 2017). In view of this point, the sources of these organic materials include deposits from streams, constituents added from point and non-point sources, and biotic deposits from stream biota (Rong et al., 2016; Hagy, 2004). Also, actual contributions of point and non-point source pollutions into the river can be determined based on the total flux partition across river sections (Rong, et. al, 2016). Considering the test-results of the TOC and in confirming the approach of other researchers addressed above on the topic, it was concluded that the main factors which influenced the variations of the TOC values were the same affecting the TP contents in this research. In addition, the roles of other factors such as croplands and agricultural organic solid waste, river-basin land erosion, relevant terrestrial sources, deposition of organic debris, land-derived particulate organic carbon and degradation of the river riparian zone along with disturbance of its treatment function in non-point source pollution control are also effective in this regard, as confirmed by the outputs already obtained from a detailed TMDL study on the darreh-rood river (Ashayeri, Azim, 2014). Further, the result of Hierarchical Clustering (Fig.5) also showed that the TOC and TP are the objects grouped within a cluster, on which are broadly similar to each other beside the SOD rate.

The results of fine-PSD (FP) in sediment's samples showed that the amount of particles finer than 63 microns (Clay and Silt) varied from 7.58 to 54.16 percentages as mentioned in table 3. In this regard, correlations between SOD_{20} and percentage of fine particles were assessed. Results showed that there was a strong positive correlation (0.838) between SOD_{20} rates and fine particles' percentage measured in this study. As reported in a previous study, the rates of oxygen depletion at the sediment-water interface vary, possibly depending on the composition of streambed material (USGS, 2010). Bed-sediments at sampling locations in the Darreh-rood River are consisted of clay, silt, sand, and to some extent gravel substrates along with organic materials as indicated in table 3. It is important to note that the particle size composition that dominated by silt and clay particles makes high level of organic carbon compounds which be adsorbed from the water. In other words, as smaller the particle size, larger is the surface area. Therefore, sediments with the higher share of clay and silt textures have also a higher surface area compared to sandy particles in absorbing the organic matter and nutrients. As stated in table 4, measured river water turbidity content varied from 13 to 53 NTU. Results indicated that there was not an acceptable correlation (0.127) between SOD_{20} rates and river water turbidity content. This means that the relationship between these two variables is interpreted in a negligible or very weak category. It is also noteworthy that a clear correlation between SOD rate and other parameters having transient/labile conditions was not found. Although turbidity showed a very weak correlation with the SOD rate, but the reading of its data during SOD measurement is used to identify the effective starting point of the oxygen depletion curve which determine the ‘disregarded zone’ (Fig.4). As shown in figure 5 and table 5, the data obtained from hierarchical cluster analysis (HCA) as well as the results of Pearson statistical analysis indicate a significant correlation between SOD rate and three associated factors including TP, TOC and fine-PSD. Additionally, statistical analysis of the SOD rates at ten sampling stations is presented in table 6.

Based on the results obtained, and considering the statistical analyses, three factors including TP, TOC and Fine Particles (FP) were considered as the principal variables to derive and present an empirical equation which can be used for estimation of the SOD rate in the region. Given to this point and using the correlation and regression programs of the MATLAB software, the following empirical predictive equation is recommended.

$$SOD_{20} = 0.537 + (0.143* TP) - (1.095* TOC) + (0.003* FP)$$

Table 4. Results of the River Water Analysis*

Variable	Unit	Sampling stations [Sample Matrix: Water]									
		S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Temperature	°C	18	20	22	21	22	22	23	22	22	24
pH	s.u	7.7	7.8	8.1	8.2	8.3	8.3	8.3	8.2	8.0	8.3
Turbidity	NTU	13	20	42	53	27	25	24	36	29	38
Salinity	% (pph)	0.02	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.04
DO	mg/l	7.3	7.7	8.1	8.3	8.1	8.2	8.0	7.9	7.8	8.0
Discharge, Q	m^3/s	0.21	0.58	0.34	0.82	0.67	0.56	0.52	0.49	0.61	0.64

***** The values contained in this table, with the exception of Turbidity content, were mainly used to simulate laboratory status with the natural conditions.

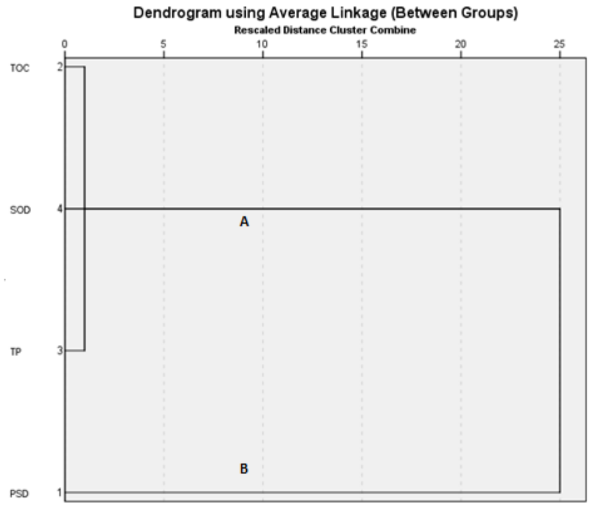


Fig. 5. Dendrogram of variables in river sediments

Table 5. Results of the Pearson correlation statistics (inclusive of the SOD and most effective factors)

Parameter	fine-PDS	TOC	TP	SOD
fine-PDS	1.000	0.860	0.857	0.838
TOC		1.000	0.960	0.882
TP			1.000	0.965
SOD				1.000

Table 6. Statistical analysis of the SOD rates at ten sampling stations

Sampling Station	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Number of samples	9	9	9	9	9	9	9	9	9	9
Mean value of SOD	0.93	1.28	1.17	0.94	0.98	0.87	0.79	1.57	0.69	0.85
Standard deviation of SOD	0.0883	0.1296	0.1617	0.0917	0.1155	0.1184	0.0876	0.2439	0.0922	0.1271
SOD range	0.78-1.08	0.96-1.38	0.89-1.34	0.82-1.08	0.79-1.12	0.72-1.05	0.68-0.94	1.24-1.88	0.54-0.85	0.64-1.06
μ_1= 0.7	*t-value*	*3.698199*		*The result is significant at $p < .05$.*						
Sig. level = 0.05	*p-value*	*0.002467*								
μ_2= 1.7	*t-value*	*-8.348051*		*The result is significant at $p < .05$.*						
Sig. level = 0.05	*p-value*	*< 0.00001*								

SOD at 20°C ($gO_2/ m^2/day$)

SOD-based categorization of the river health quality condition determined in this research is mostly similar to the ones have been previously conducted by the principal author on the same river focusing on combined effects of three methods including benthic-based bio-assessment, morphohydraulic indices and detailed TNL (Total Nutrient Load) study. Also, statistical analysis results together with the expert judgment were included (Table 6 & Fig.6). Consequently, the following classification method recommended for the river bed sediment's quality condition based on the SOD rates, especially for the shallow rivers with the same conditions (Table 7).

Table 7. River-bed SOD-based Quality Classification
[recommended by the principal author]

Quality Class	Quality Conditions	SOD_{20} Range ($g\ O_2/ m^2/day$)
A	Clean	<0.3
B	Moderately Clean	0.3 - 0.7
C	Slightly Clean	0.7 - 1
D	Slightly Degraded	1 - 1.7
E	Moderately Polluted	1.7 - 3
F	Polluted	3 - 7
G	Heavily polluted	>7

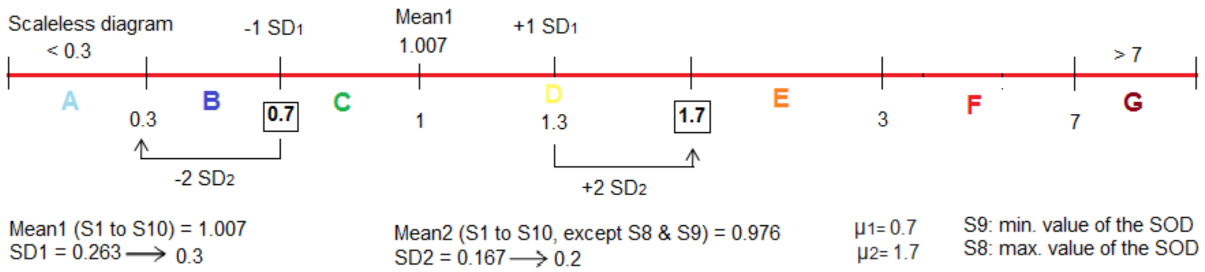


Fig. 6. Schematic classification of the SOD rates

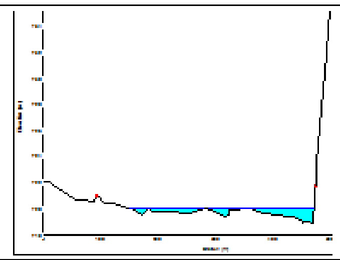
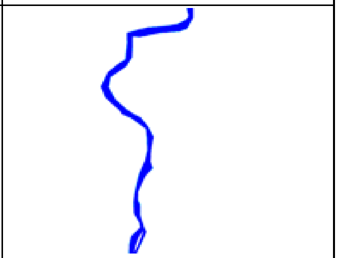
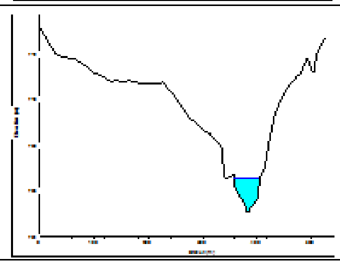
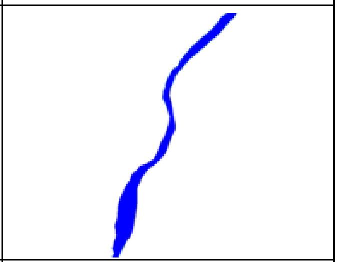
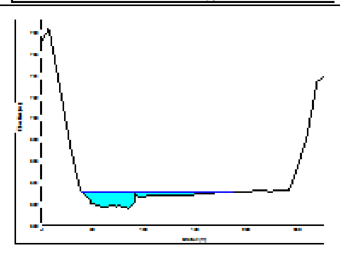
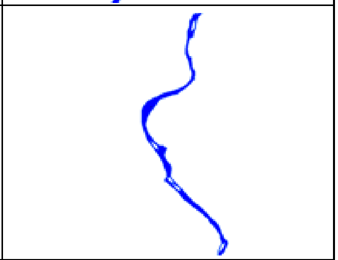
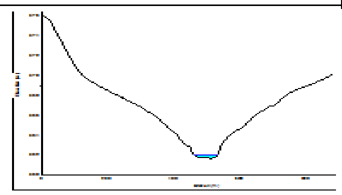
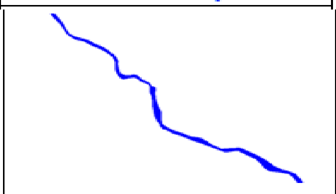
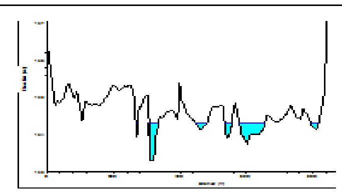
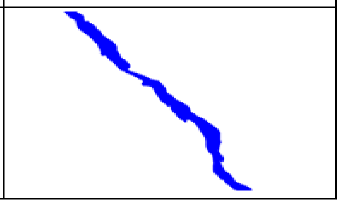
Given to this classification, Darreh-rood River is categorized in classes C (S1, S4, S5, S6, S7, S9, & S10) and D (S2, S3, & S8) which means slightly clean and slightly degraded, respectively. In stations whose quality class is being degraded, all the meaningful precautions and initiatives need to be considered for managing the discharge of effluents/wastewaters into the river system, ensuring the maintenance of river key functions alongside its ecological values. Therefore, it is highly notable that the burden of pollution not to be allocated and imposed more than the bearable load-capacity of the river in these stations.

In addition to the points mentioned above, it can be discussed that: as previous study in South Korea (Yee et al., 2011) has shown, nutrient-related factors such as TP and TOC have similarly played an effective and determinative role in SOD changes in this research. Further, the range of SOD rates (0.69 to 1.57 O_2/m^2/day) indicated that this set of data is mostly proportional to the scope (0.05 to 1 O_2/m^2/day) reported by the USEPA (1985) and also by the researchers in Argentina (Chalimond et al., 2019) for the rivers having the mineral and sandy bed sediments. In this regard, type of the Darreh-rood bed sediment material (mostly silt-clay and sandy) confirms the outputs emerged. This caused that the nutrient-based organic matters to be observed on the surface area of these fine particles in a higher rate compared to the course materials. One of the reasons for why the SOD rate in S8 is higher than other sites is that this site located in a zone with high erosion potential, as the available information from erosion map of the study area corroborates this point. This factor led S8 to be grouped in a high potential of sediment deposition while receiving the sub-basin runoffs, agricultural drain-waters and rural wastes. Therefore, this situation led to a high SOD value at S8, as the researchers from USA (Matlock et al., 2007) have already come to the same conclusion herein. Likewise the S8, stations S2 and S3 have also been prone to the features addressed above, but with a relatively low magnitude (Table 3).

On the basis of a general classification (U.S. EPA, 2003a; USGS, 2009), Darreh-rood River is categorized as a shallow watercourse (less than 2 m in depth). Thus, as it already concluded by some researchers (Ziadat & Berdanier, 2004) in relation to the shallow rivers, it can be discussed that the SOD rates in Darreh-rood play a role of driving factor in ambient DO deficits, so that the shallower the depth of the water column, the more essential SOD becomes in connection with ambient DO shortages considering the similar sediment characteristics. Furthermore, the organic matter in shallow water sediments is oxidized much more readily than that in deep water sediments, due to enhancing the aerobic degradation process. Besides, the relative influence of bottom decomposition on the water column is therefore greater in shallow systems compared to the deep waters.

From another perspective, effective planning for restoration of the rivers needs insight into the geomorphologic aspects of their systems and associated landforms, which consider the processes for the control of river channels' structure and dynamics. Further, stream biotic composition is deeply influenced by its physical habitat (Richards, Johnson & Host, 1996). Geo features also are imperative targets for conservation. Rivers represent an important emphasis on conservation of biological and geo-morphological values, and the biota often is reliant on their physical and chemical environment for survival and health purpose (Jerie, Houshold & Peters, 2003). In line with this viewpoint, Rosgen (1994) Geomorphic classification method inclusive of slope, channel patterns, cross-sectional character, dominant particle size of bed materials, and entrenchment was used to describe the Darreh-rood river form, condition, and potential behavior in order to assess the river health and its Geo-conservation value (Table 8).

Table 8. Geomorphic classification of the main stream, based on Rosgen method at level-I

ZONE	RIVER LENGTH (km)	SLOPE (m/m)	Width to Depth Ratio	RIVER TYPE	REPRESENTATIVE CROSS-SECTION VIEW	REPRESENTATIVE PLAN VIEW
1	0-12.9	0.004	90.8 - 148.5	C		
2	12.9-15.5	0.004	15.9 - 41.8	B		
3	15.5-23.4	0.004	77.1 - 112.7	C		
4	23.4-104.7	0.005	25.7 - 80.2	B		
5	104.7-134.5	0.004	39.4- 73.8	DA		

Under this technique, main stream of the Darreh-rood River has been mostly categorized in types of B, C and DA with dominant bed materials of silt-clay, sand and to some extent gravel, which mostly agreed with the SOD-based quality classification recommended in table 7 and figure 6. Therefore, with the aim of achieving the best possible result, it is recommended that the SOD-based river health study to be conducted beside the benthic bio-assessment and the watercourse geo-morphological characteristics.

CONCLUSION

As mentioned in the previous sections, sediment samples were collected from 10 locations in the Darreh-rood River to determine the rates of SOD and to study their trend along the river in order to assess the health and quality condition of the water-body. SOD was measured in laboratory scale using the specialized chambers designed and constructed by the principal author. Mean value of the measured SOD ranged from 0.69 to 1.57 g O_2/m^2/day during this study. In this regard, some of the much more significant findings to emerge from this study are as follows: (a) based on the results obtained, three factors including TP, TOC and Fine Particles (FP) were identified as the main variables affecting the SOD rate in this study due to the significant and strong correlation between them, so that the increase in TOC and TP concentrations together with a decrease in sediment particle size was led to an increase in SOD-rate accordingly; (b) it was resulted that the phosphorus is the key and more limiting factor in affecting the SOD rate in compared to other nutrients, as the detailed previous study (2014) on total nutrient load also outlined the same result. Therefore, the present study contributes additional evidence that demonstrates the significant association between TP values and SOD rates in the Darreh-rood river system; (c) proper method selection along with the suitable design of SOD measuring device, in accordance with the conditions of natural environment and the river type, play a very decisive role in achieving the appropriate and significant results; (d) rather than concluding that SOD rates differ among sites, it would be more reasonable to use the median SOD_{20} rate (0.935 g O_2/ m^2/day)as well as the predicted empirical equation for the entire study reach in river water-quality modeling and other relevant analyses in this region. Under this finding and considering the classification method defined and recommended in table 7 and figure 6, the health quality conditions of the river are interpreted in classes C (slightly clean) and D (slightly degraded); (e) from value engineering prospective, a comparison of costs including remuneration fee and reimbursable expenses in similar studies of river health quality condition indicates that the use of sustainability-based indices is about 3 to 5 times more cost-effective on average than the physicochemical analyses in detail, especially in the inception phase (identification, pre-feasibility and feasibility stages) of the research projects. Hence, it is recommended that the SOD-based investigations alongside the benthic bio-assessment technique (like the macro-benthos and invertebrates) and geo-morphological survey to be included in the work plan of the qualitative studies of water bodies under the umbrella of SAM approach; (f) to achieve a better outcome in assessing the health and survival conditions of the water-bodies with an emphasis on shallow rivers beside their vulnerability capacity, it is preferable that the sampling trips to be conducted during stressful season inclusive of low-flow, post-harvest and pre-wet (before the first major flow event) periods. In order to comply with this objective, all required samples were collected in early September 2017 in this research; (g) from the author's point of view, the dissolved oxygen value and its demand rates from the analysis of running river water provide a transient and temporary picture of the survival and health situation of water-body, while the SOD rates as well as the related benthic-based biological analyzes reflect a long-term and appropriate picture of the conditions; (h) one of the remarkable point is that the rate of oxygen removal by the bed sediments has a crucial role in the response of water bodies to wastewaters discharge, so that the results can be a great help in managing the drain-waters and effluents, focusing on how to select the suitable discharge sites along the river, taking into account the vulnerability and assimilative capacity of the receiving watercourse. Thus, SOD rate can also be considered as a useful index in waste-load allocations in rivers especially in the study region; (i) expert judgment under the umbrella of required deep knowledge and skills is also recommended as a key tool for valid statistical and scientific analyses; and (j) to sum up, the consequences of this study under Survivability-based Adaptive Management (SAM) approach can be used as a rapid diagnostic tool to support water policy decision-makers and other stakeholders to promote the best practices for improving and protecting the health situations of riverine systems. Finally, further researches need to examine more closely the links between SOD rate and health condition of the river ecosystem in the future.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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