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Research Paper

Evaluation of water quality and physicochemical parameters of pitlakes in the Raniganj coalfield for potential reuse in domestic, irrigation, and aquatic life support

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ABSTRACT: *The study presents a detailed analysis of the physicochemical parameters of pitlakes' water to identify the its suitability for potential uses for domestic (drinking), irrigation, and aquatic life support. The study covers several pitlakes in the Raniganj coalfield area, West Bengal, India. An in-depth comparative study of physicochemical parameters of the water and water quality index (WQI) for domestic, irrigation, and aquatic life was performed for each site for pre-monsoon, monsoon, and post-monsoon seasons. The calculated WQI demonstrates that the pitlakes in this area have very poor water quality for domestic use. However, it can be a good choice for irrigation as the mean WQI for irrigation ranges from 4.4 to 23.1 for these sites. A rigorous study of salinity, and electrical conductivity, SAR, %Na, RSC, chloride toxicity, Kelly's ratio, and permeability index were determined and Wilcox diagrams were created to ascertain the uses of the water for irrigation. The WQI for aquatic life was calculated to provide a comprehensive understanding of the quality of pitlake water for aquatic life and it is found to be of poor quality. From our study, it can be concluded that the water resources of pitlakes in Raniganj coalfield area are of poor quality for domestic purposes and aquatic life, but has good potential to be used for irrigation use.*

KEYWORDS: *Pitlake, WQI, Irrigation, domestic use, Aquatic life, Physicochemical parameters.*

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I. INTRODUCTION

Pitlake ecosystem is a unique man-made ecosystem created by mining activity and also is a reservoir of huge water resources [1]. Among different mining methods, surface mining is the most common method used in coal production. After mining the pit, if left abandoned, over time it leads to the creation of these artificial water bodies [2,3]. Pitlakes are characterized by a narrow and deep shape, absence of a littoral zone, and are bounded by high rock walls. [4,5]. Since pitlakes are created due to mining activities, the water quality becomes a matter of concern. They often exhibit water quality issues which include low pH levels, elevated metal concentrations, and high levels of suspended and dissolved particles [6–8]. The applications of pitlake's water are limited and are generally used by local people for domestic use only. As a result, a huge water resource remains unused [1,9,10]. One of the main causes of this is the lack of thorough understanding of the water's quality and its possible applications for drinking, irrigation, household usage, pisciculture, etc.

Raniganj coalfield area (RCF), India is one of the most significant coal production sites and contributes significantly to the total coal production of India. A huge number of of pitlakes have been generated in the region due to coal mining. It is also very significant due to the livelihood dependency of local people. Over the past two decades, researchers have studied the environmental, ecological, and socioeconomic aspects of these pitlakes in RCF. A comprehensive and integrative study of pitlakes' water for reuse in domestic, irrigation, and aquatic life support remains underexplored. Initial study and research on the water quality of the pitlake in RCF were conducted by A.K. Singh and his research team [11]. Although their study covered physicochemical parameters and analysis of water quality to use in domestic and irrigation purposes, the study did not cover the water quality indices for different uses. In addition to that, that study didn't focus exclusively on understanding the usability of pitlake water. Later, Goswami et al. and Gupta et al. in 2013 have investigated the health impact of mining and created an inventory of pitlakes in this region [12,13]. Subsequently research group of Dr. D. Palit have published several research works on water quality and physicochemical parameters of water and sediment [5,9,14–21]. However, none of the studies explicitly covered the usability of the pitlake water for irrigation and aquatic life support, though those analysis are equally important. In the meantime, some discrete research studies were done on the aquatic life, including fish, phytoplankton, and rofifer diversity [21–23]. While some progress has been made, no previous study has offered a comprehensive assessment and usability of pitlake water in the RCF region incorporating WQI, Wilcox diagrams, SAR, %Na, and physicochemical analysis, coupled with explicit evaluations of the pitlake for use in domestic, irrigation, and aquatic life support.

Our study was performed with the motive of determining the uses of pitlakes' water for irrigation, domestic use and aquatic life using water quality and physicochemical parameters analysis. It also emphasises comprehending how water quality varies seasonally. This integrated and comparative approach to reuse-oriented water quality assessment sets this work apart from all prior research studies and have the potential to contribute substantially to environmental management, policy planning, and pitlake rehabilitation strategies in post-mining landscapes.

II. MATERIAL AND METHODOLOGY

2.1. Study Site

Our present study focuses on a detailed analysis of the water quality of the pitlake ecosystem of Raniganj coalfield area and its usability for drinking, aquatic life and irrigation purposes. Seven pitlakes (Fig.1) from the Raniganj coalfield area (RCF) of Paschim Bardhaman district of West Bengal, India were selected with that objective (Table 1). It is a crucial coal mining site in West Bengal and contributes significantly to the total coal production of India [16,24]. All the sites that were selected for study, were created due to mining activity and are under Eastern Coalfield Limited. The details of the study sites that were examined are shown in Table 1.

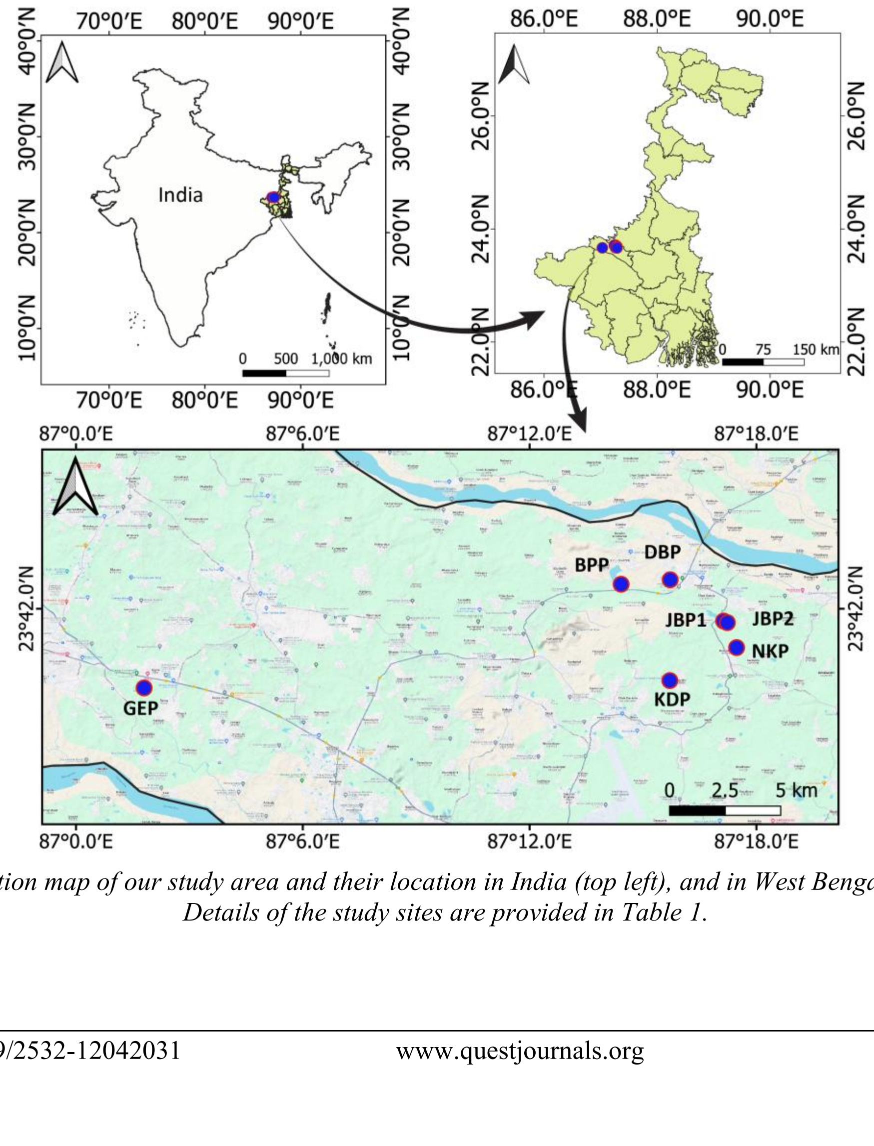

Fig1. Location map of our study area and their location in India (top left), and in West Bengal (top right). Details of the study sites are provided in Table 1.

Table 1: Study sites with detailed geographical information.

Sl No.	Name of the pitlake	Short name	Location	Block	Nearest village/town
1	Dalurbandh	DPP	23°42′46.0″N and 87°15′43.1″E	Pandabeswar	Dalurbandh
2	Belpahari	BPP	23°42′38.9″N and 87°14′25.2″E	Pandabeswar	Belpahari
3	Joyalbhanga-1	JBP1	23°41′40.5″N and 87°17′07.9″E	Pandabeswar	Joyalbhanga
4	Joyalbanga-2	JBP2	23°41′38.0″N and 87°17′13.8″E	Pandabeswar	Joyalbhanga
5	Nagrakonda	NKP	23°40′58.4″N and 87°17′28.5″E	Pandabeswar	Nagrakonda
6	Kumardihi	KDP	23°40′06.1″N and 87°15′42.5″E	Pandabeswar	Kumardihi
7	Gunjan ecological park	GEP	23°39′54.4″N and 87°01′48.1″E	Jamuria	Sripur

2.2. Sampling and Analysis

To perform a detailed analysis of the water quality and physiochemical parameters, water samples were taken from the study sites during the pre-monsoon, monsoon, and post-monsoon seasons in the year 2022-2023. The pre-monsoon, monsoon and post-monsoon samples were collected during the month of April-May, July-August, and October-November, respectively. Before collecting the water samples, the sample bottles are cleaned properly to remove any residual contamination and substance. Water samples were collected from three random sampling stations of each site in one-litre containers during morning hours following standard protocol. After collection, the bottles were labelled properly to avoid any form of confusion and errors. GPS meter was used to obtain coordinate data (Table 1) of each site to precisely identify each site. The water samples were kept cool while transported by car to the laboratory where the samples were analyzed. Temperature, pH, total dissolved solids (TDS), and electrical conductivity (EC) were measured on-site using Eutech Oakton multi-parameter tester immediately after collection. The samples for dissolved oxygen (DO) and biological oxygen demand (BOD) analysis were collected in BOD bottles and sealed properly following standard guidelines to prevent any bubble formation. The DO samples were fixed immediately after collecting the sample with manganous sulfate and alkaline iodine azide. The rest of the analysis were conducted in the laboratory following the standard protocol of APHA [25]. Total alkalinity, total hardness, bicarbonate, calcium and magnesium were measured using titrimetric techniques. The argentometric method was utilized to measure the amounts of chloride. The Azide-modified Winkler method was used to quantify dissolved oxygen and biological oxygen demand. Five-day BOD tests were performed for this study. The flame photometric method was followed to estimate sodium and potassium concentrations. Nitrate and phosphate were measured using the spectrophotometric method.

2.3. Data Analysis

The water quality index (WQI) was calculated using Brown's weighted arithmetic index method [26] for domestic (drinking), irrigation and aquatic life. The Water Quality Index (WQI) was calculated from physicochemical data. The parameters chosen for the calculation of WQI are selected based on their significance in evaluating water quality. The selected parameters can differ based on the purpose that is being considered. The average values of each parameter were calculated using the data obtained during the study period.

The water quality index (WQI) is calculated by dividing the sum of the products of the individual water quality values (Q_n) and their corresponding weights (W_n) by the sum of the weights (W_n).

$$WQI = \frac{\sum Q_n W_n}{\sum W_n}$$

Where:

Q_n:Quality rating of the nth water quality parameter

W_n:Unit weight of the nth water quality parameter

Quality rating (Q_n) for each parameter was determined using the equation:

$$Q_n = 100 \times \left(\frac{V_n - V_i}{S_n - V_i}\right)$$

Where:

V_n:Actual value of the parameter

V_i:Ideal value of that parameter. ($V_i = 0$, except for pH ($V_i = 7$) and DO ($V_i = 14.6$ mg/l))

S_n:Standard permissible value for the nth water quality parameter

Unit weight (W_n) was calculated using the formula:

$$W_n = \frac{K}{S_n}$$

Where:

K:Constant of proportionality, calculated using the equation:

$$K = \left[\frac{1}{\sum \frac{1}{V_s} = 1,2,\ldots,n}\right]$$

In addition to WQI, sodium adsorption ratio (SAR) and %Na (percent sodium) were calculated using standard formulas [27]. US salinity laboratory hazard diagram and Wilcox diagram were created to classify and predict the suitability of water for irrigation purposes. Also, residual sodium carbonate (RSC), Kelly's ratio (KR), and permeability index (PI) were calculated to have more insight [28]. Statistical analysis like box plots, line graphs, bar graphs, Wilcox diagrams were carried out using statistical data analysis software e.g. Minitab and MS Excel.

III. RESULT AND DISCUSSION

3.1. Water quality parameters

To understand the water quality of our seven study sites, we estimated and calculated different physicochemical parameters for each site in a systematic manner. These are temperature, pH, electrical conductivity, TDS, total alkalinity, total hardness, calcium hardness, magnesium hardness, calcium, magnesium, chloride, salinity, DO, BOD, sodium, nitrate, and phosphate. The obtained values for the physicochemical parameters are given in Table 2.

Table 2: Seasonal variation in physicochemical parameters of pitlakes (Unit: mg/L except Temperature (°C), pH, EC (µS/cm))

Parameters	**Pre-monsoon**				**Monsoon**				**Post-monsoon**			
	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
Temperature	36.5	34.6	38.3	1.4	33.9	33.2	34.7	0.6	25.5	24.9	26.0	0.4
pH	8.28	7.67	8.98	0.57	6.69	6.21	7.01	0.30	7.39	6.99	7.92	0.35
Conductivity	534	193	801	227	512	184	779	222	541	190	790	219
TDS	292	97	401	114	331	107	486	134	307	91	458	128
Total alkalinity	216.7	110.0	323.3	77.8	183.6	100.0	288.3	67.4	207.9	106.7	316.7	72.0
Total Hardness	176.9	54.3	306.5	74.6	166.5	45.5	291.9	73.9	189.1	52.8	325.6	81.5
Ca^{2+}	44.0	15.0	103.8	29.5	40.8	14.0	99.9	28.5	49.2	16.7	112.8	32.2
Mg^{+}	16.3	3.3	34.1	9.6	15.8	1.5	32.8	10.6	16.1	2.6	37.3	11.1
Dissolved Oxygen	6.7	4.3	7.8	1.3	7.5	5.6	8.5	1.1	6.5	4.0	7.6	1.3
BOD	1.6	0.7	2.8	0.8	1.6	1.1	2.4	0.5	2.1	1.6	3.0	0.6
Chloride	31.6	14.7	63.5	16.3	24.6	11.8	51.5	13.8	36.8	16.0	74.4	19.6
Sodium	20.9	10.4	42.5	10.8	16.9	7.3	34.5	9.1	24.4	12.1	47.2	12.1
Potassium	6.5	3.4	12.1	3.1	5.8	2.7	11.8	3.0	8.1	3.4	15.8	4.2
Phosphate	0.044	0.027	0.063	0.014	0.038	0.023	0.053	0.010	0.046	0.033	0.064	0.010
Nitrate	1.671	1.121	2.360	0.510	1.895	1.182	2.540	0.513	1.773	1.093	2.475	0.541
Bicarbonate	216.7	110.0	323.3	77.8	183.6	100.0	288.3	67.4	207.9	106.7	316.7	72.0

Boxplots in (Fig. 2) give a detailed understanding of the range and seasonal variations of each parameter. Each plot in Fig. 2 shows the median, skewness, dispersion and outliers of different water quality parameters. Analyzing all the parameters, it can be summarized that pre-monsoon season showed higher temperature, alkalinity, and bicarbonate levels. This was due to high evaporation, increased temperature, and stagnant water conditions. The monsoon season recorded the lowest values for most parameters due to dilution by rainfall and run-off. The post-monsoon season exhibited higher conductivity, TDS, hardness, and BOD. Stabilization and reduced water levels had increased the concentration of dissolved substances.

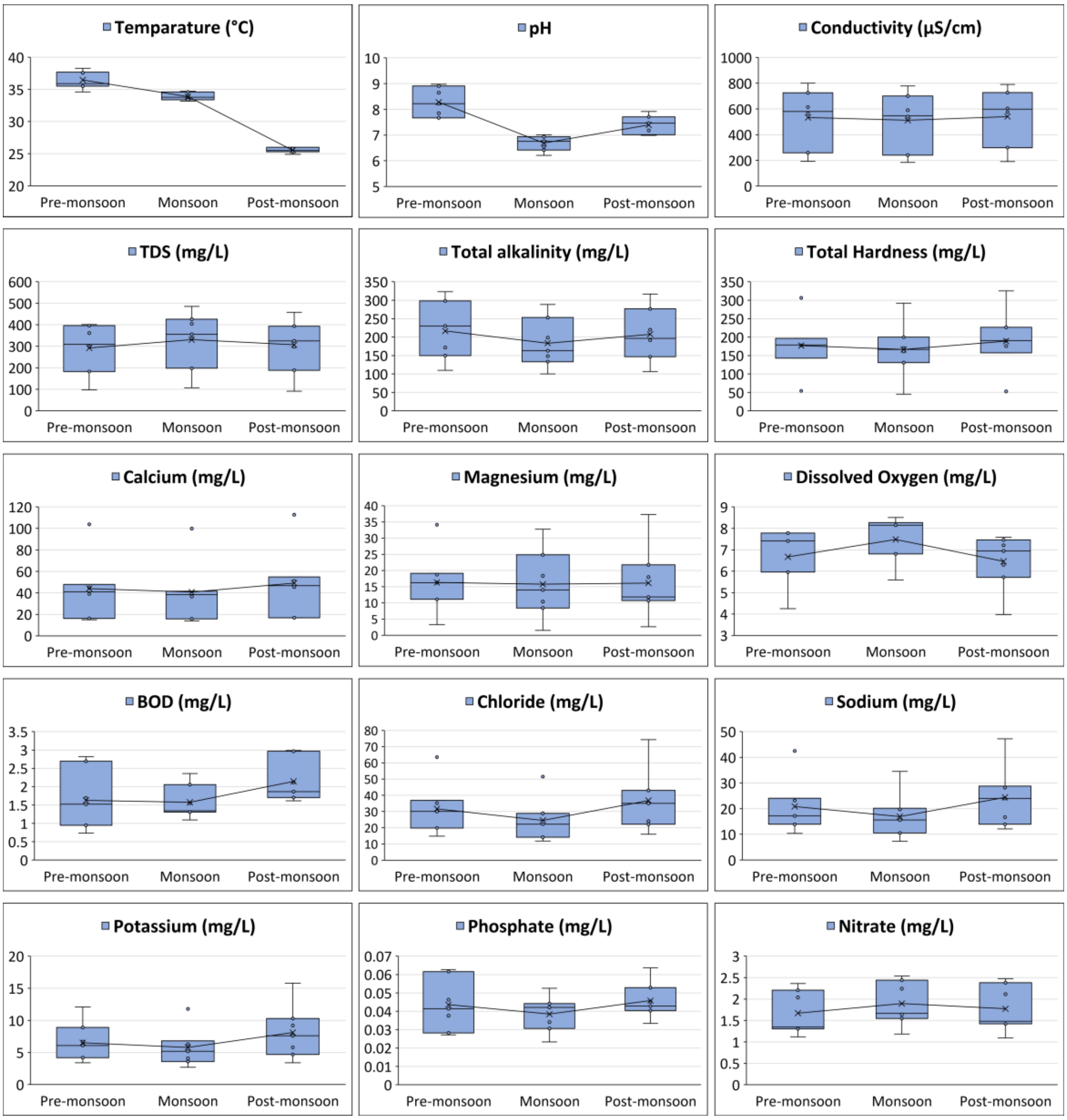

Fig.2: Boxplot showing the range and variation of different physicochemical parameters among different seasons.

3.2. Water quality index for domestic utilization

Polluted drinking water is one of the main reasons for waterborne diseases. So, regular monitoring of water quality is a good practice. The WQI is a very convenient method to understand pollution status of water for both specialists and non-specialists. It also helps the policy-makers to make better decisions [26,29]. During the field surveys, it was observed that water in our pitlakes was used by local people for several domestic purposes. This is the main water source for them. The WQI values were calculated for seven sites in three seasons to understand the level of safety to be used for domestic purposes. Twelve parameters i.e. pH, electric conductivity, TDS, total alkalinity, total hardness, calcium, DO, BOD, chloride, sodium, phosphate, and nitrate were used for calculating WQI values for each site and for each season. In this study, the standard values of the physicochemical parameters were obtained from the Bureau of Indian Standards (BIS) and the Indian Council of Medical Research (ICMR) and then relative weight for each parameter was calculated to obtain WQI values. The range of WQI value along with the health status is provided in Table 3.

Table 3: Status categories of WQI (Brown et al. 1972).

Water Quality Status	WQI
Excellent	0 – 25
Good	26 – 50
Poor	51 – 75
Very Poor	76 – 100
Unsuitable	>100

The mean WQI values for domestic use were found to be 78.7, 66.8, and 85.9 for pre-monsoon, monsoon, and post-monsoon seasons, respectively as shown in Fig. 3(a). It indicated that water quality degraded and became poor during pre-monsoon and post-monsoon seasons and got better in monsoon season. The WQI values for each site as shown in Fig. 3(b) during pre-monsoon, monsoon and post-monsoon seasons were also calculated. The detailed values of WQI for each site in three different seasons (Table 4). The WQI values of each site showed similar seasonal variation except for BPP site. The general trend showed a relatively better water quality during monsoon season. From our data and observation, we can conclude that the water of pitlakes must not be used for domestic purposes without proper purification.

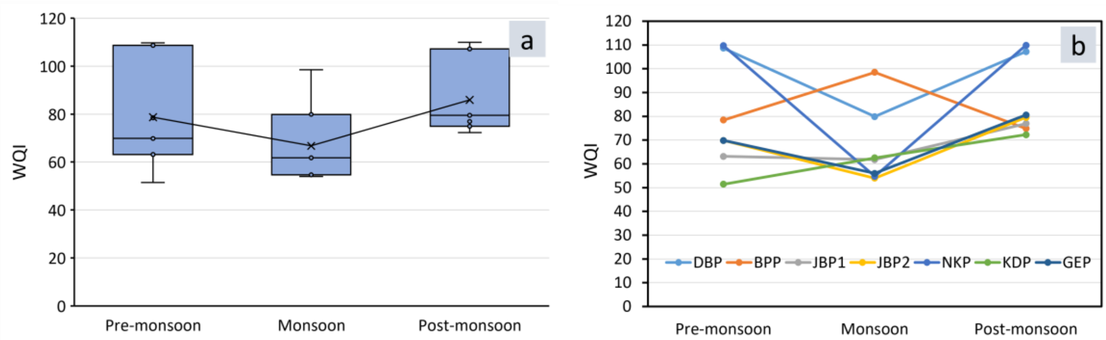

Fig.3: Seasonal variation of WQI for domestic use. (a) Boxplot showing the range and variation of WQI for domestic use in different seasons (b) Line graph showing the change of WQI for domestic use in different sites in different seasons.

Table 4: WQI and its categorization for domestic, irrigation, and aquatic utilization in different sites and seasons

Season	Study Site	WQI Domestic		WQI Irrigation		WQI Aquatic	
Pre-monsoon	DBP	108.6	Unsuitable	16.3	Excellent	56.9	Poor
Pre-monsoon	BPP	78.4	Very Poor	13.0	Excellent	76.7	Very Poor
Pre-monsoon	JBP1	63.2	Poor	22.4	Excellent	62.5	Poor
Pre-monsoon	JBP2	69.8	Poor	23.1	Excellent	67.9	Poor
Pre-monsoon	NKP	109.7	Unsuitable	21.3	Excellent	77.0	Very Poor
Pre-monsoon	KDP	51.4	Poor	12.4	Excellent	75.8	Very Poor
Pre-monsoon	GEP	69.8	Poor	9.4	Excellent	47.5	Good
Monsoon	DBP	79.9	Very Poor	9.8	Excellent	55.6	Poor
Monsoon	BPP	98.5	Very Poor	12.9	Excellent	75.7	Very Poor
Monsoon	JBP1	61.8	Poor	4.4	Excellent	47.9	Good
Monsoon	JBP2	54.0	Poor	5.1	Excellent	54.6	Poor
Monsoon	NKP	54.7	Poor	5.4	Excellent	64.4	Poor
Monsoon	KDP	62.5	Poor	8.1	Excellent	73.0	Poor
Monsoon	GEP	56.0	Poor	7.1	Excellent	45.2	Good
Post-monsoon	DBP	107.2	Unsuitable	8.3	Excellent	53.7	Poor
Post-monsoon	BPP	74.9	Poor	5.1	Excellent	71.7	Poor
Post-monsoon	JBP1	76.9	Very Poor	13.1	Excellent	56.0	Poor
Post-monsoon	JBP2	79.5	Very Poor	6.4	Excellent	56.1	Poor
Post-monsoon	NKP	109.9	Unsuitable	12.5	Excellent	73.5	Poor
Post-monsoon	KDP	72.3	Poor	6.3	Excellent	71.6	Poor
Post-monsoon	GEP	80.6	Very Poor	8.0	Excellent	46.3	Good

3.3. Suitability for irrigation use

3.3.1. WQI for irrigation

The WQI values for irrigation were determined using the same method [26] considering eleven parameters i.e. pH, electrical conductivity, Total dissolved solids, TSS, calcium, magnesium, chlorides, sodium, sodium adsorption ratio (SAR), phosphate, and nitrate. The standard values of the physicochemical parameters were obtained from FAO (Food, Agriculture Organization, UN), 1985 [30]. WQI values for irrigation varied from the range of 4.4 to 23.1 indicating excellent quality of water for irrigation. Mean values of WQI for irrigation were 16.9, 7.5 and 8.5 during pre-monsoon, monsoon, and post-monsoon seasons, respectively. The values of WQI for irrigation for each site and season are provided in Table 4. Our study suggests that water was excellent for irrigation use throughout the season, and got even better during monsoon and post-monsoon seasons.

Apart from WQI analysis, the suitability for irrigation needs to be evaluated based on four basic criteria. These are the total amount of soluble salt which is also known as salinity hazard, the relative proportion of sodium to calcium and magnesium ions which is also known as SAR, RSC, and excessive amount of any element [30]. Wilcox (1955) and US Salinity Laboratory Staff (1954) have given several irrigational speciations to understand the suitability of water for irrigation [27,31]. In our study, we have considered those specifications, especially SAR, %Na, and EC, and used the Wilcox diagram to understand the suitability for irrigation purposes.

3.3.2. Salinity hazard

When excess salt is present in the soil, this leads to physiological drought conditions in which the osmotic pressure of soil solution is so high that despite the presence of water in the soil, plants fail to uptake it [30]. The total soluble salt can be measured either by measuring actual salt or by measuring electrical conductivity [32]. We have measured electrical conductivity (μS/cm) using a multiparameter tester. Studies have shown that EC levels below 750 μS/cm generally have no detrimental effect on plants, but a range of EC between 750 to 1500 μS/cm has an effect on sensitive plants, and EC about 1500 μS/cm has an adverse effect on plant growth [27,33]. The EC of the water of our study sites varied between 184 and 801 μS/cm.

3.3.3. Sodium and salinity hazards

Several results have shown that high salinity has led to the reduced growth of plants [27,32]. High salt changes the quality of soil and alters the permeability, infiltration rate, soil structure, and tilth of soil. All these impact the vegetation. This plant growth is important for any mining site for reversing the landscape in the previous vegetative state. These also positively help in improving the soil and water quality, groundwater recharge, and preventing soil erosion [32]. So, if the water from the pitlake is found to be suitable for irrigation, it will be of great use in improving the landscape of the mined area.

3.3.4. SAR calculation

SAR is used to evaluate whether water is suitable for use in agricultural irrigation. [34]. The high level of sodium ions adsorbs onto the cation exchange sites of soil. As a result, soil aggregates tend to break down. It also seals the pores of soil which make water flow difficult and the plants are not able to absorb the soil water. The level of sodium ions is estimated by comparing it with the total cation content, especially calcium and magnesium ions. So, a higher level of sodium creates a sodium hazard and hence is undesirable [30]. The SAR is the measure of sodium concentration relative to the total calcium and magnesium concentration, where all concentrations are in meq/L [27]:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}$$

SAR values between 0 to 6 indicate good water quality, values between 6 to 9 indicate doubtful and values more than 9 indicate unsuitable water quality for irrigation [35]. Mean SAR values in our study were 0.69, 0.59 and 0.8 for different seasons (pre-monsoon, monsoon, and post-monsoon). So, all the sites have good water quality for irrigation (Fig. 4).

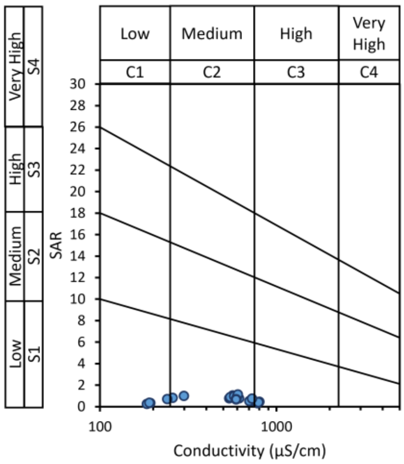

Fig.4: Wilcox diagram showing the electrical conductivity and SAR for different study sites and classification of the irrigation water based on US salinity laboratory diagram.

3.3.5. Alkali and salinity hazard

The EC value is considered as alkali hazard and the SAR value is considered as salinity hazard. For alkalinity hazard, the EC value was categorized into four groups: low with EC value less than 250 μS/cm, medium with EC value from 250 to 750 μS/cm, high with EC value from 750 to 2250 μS/cm and very high with EC value more the 2250 μS/cm. High salinity hazard i.e. high SAR value has an influential impact on soil quality and irrigation. The soil's permeability and infiltration are reduced by the high SAR value [27,36].

In our study, the SAR values were between 0.24 and 1.14, which represented the good quality of irrigation water. The range of EC in our study sites was found to be from 184 to 801 μS/cm. EC is maximum during post-monsoon season and minimum during monsoon season. When the results of our study sites of different seasons were plotted in the Wilcox diagram of alkali hazard and salinity hazard, we found that the majority of our water quality falls under C2-S1 (medium salinity and low sodium water) and very few fall in C1-S1 (low salinity and low sodium water) and some C3-S1 (high salinity and low sodium water) (4). As the alkalinity hazard was low for water pitlake water, this water had the potential to be used for irrigation and revegetation of the landscape. However, plants with high salt resistance will be more appropriate because the salinity hazard was medium to high [27,37].

3.3.6. %Na calculation

Sodium is considered the most hazardous among the soluble constituents of water for irrigation [32]. The relative amount of sodium in comparison to total cation gives us ideas about the detrimental effect of sodium on plants. %Na is one such parameter that helps to calculate the relative amount of sodium in comparison to the total cation present in the water [38], and calculated using the following equation (unit: meq/L)[33]:

$$\%Na = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \times 100$$

%Na values below 20 were considered as excellent, between 20 to 40 were considered as good, between 40 to 60 were considered as permissible, between 60 to 80 were considered as doubtful and more than 80 were considered as unsuitable [35]. Our study suggests that mean %Na values were 24.4, 22.1 and 25.8 for pre-monsoon, monsoon, and post-monsoon seasons, respectively (Fig. 5). Values indicated that on water was of excellent to good quality in all our study sites.

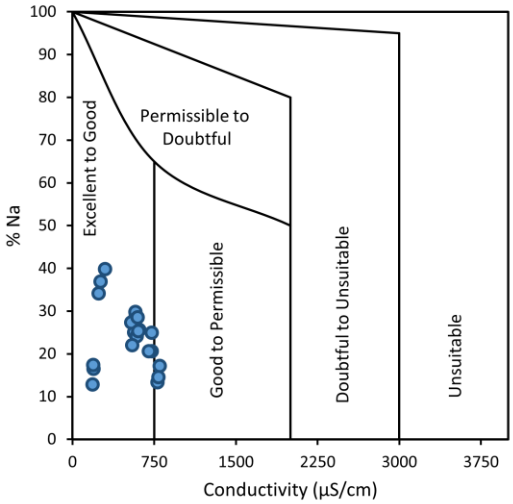

Fig.5: Plot of sodium percentage and electrical conductivity (Wilcox 1955) for classification of water for irrigation uses.

3.3.7. Carbonate and bicarbonate concentration

If the amount of carbonate and bicarbonate is high, the calcium and magnesium have a tendency to precipitate out. This leads to an increase in relative sodium proportion and SAR value. This in turn increases sodium value. The impact of the presence of carbonate and bicarbonate can be measured by simply calculating residual sodium carbonate(RSC) [28,30]. The RSC can be measured by using the following formula where all the concentration is in meq/L unit [27]:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

Generally, RSC<1.25 meq/L is considered as safe for irrigation and an RSC>2.5 is considered as unsuitable [39]. Our study has shown the value of RSC range was between -1.76 to 1.37. So, the water quality of all of our study sites was suitable and safe for irrigation.

3.3.8. Chloride toxicity

Studies have shown that chloride levels less than 70 mg/L, are safe for all plants [39]. In our study, we observed our chloride levels to be 31.6, 24.6, and 36.8 mg/L for pre-monsoon, monsoon, and post-monsoon seasons, respectively. So, all the sites had chloride levels less than 70 mg/L which is under permissible limit.

3.3.9. Kelly's ratio (KR)

The formula used to determine Kelly's ratio, as presented by Kelly in 1963, is as follows [40,41]:

$$\text{Kelly's ratio (KR)} = \frac{Na^+}{(Ca^{2+} + Mg^{2+})}$$

Here, all ion concentrations are reported in meq/L. A KR number less than 1 indicates that the water is of good quality for irrigation. On the other hand, a KR value of more than 1 denotes that the water is unsuitable for agricultural applications due to alkali risks [36]. The result showed that the Kelly's ratio for all the study throughout all the seasons was less than 1 indicating good water quality for agricultural purposes.

3.3.10. The Permeability Index (PI)

The permeability index is determined using the following formula (concentrations are in meq/L) [28,36]:

$$PI = 100 \times \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+}$$

PI readings greater than 75 indicate water of excellent quality for irrigation. PI readings ranging from 25 to 75 suggest favourable water quality for irrigation. However, PI<25 indicates that water utilized for irrigation is unsuitable [36]. Our study showed that the mean PI values were 69.3, 69.1, and 66.6 for pre-monsoon, monsoon, and post-monsoon seasons, respectively. So, the value of PI remains in the favourable range. In case of Gunjan Ecological Park pitlake PI values were over 75 during three seasons with values of 128.4, 141.1, and 127.6 suggesting excellent water quality for irrigation.

3.3. Suitability for aquatic life

Five parameters i.e. pH, TDS, DO, chloride, nitrate, were considered for the calculation of WQI to check the level of suitability of water for aquatic life. Standard values of the parameters were taken from CCME [34,42]. The mean values of WQI for aquatic life were found to be 66.3, 59.5 and 61.3 for pre-monsoon, monsoon and post-monsoon seasons, respectively. The overall range varied from 45.2 to 77.0. It indicated that water was good to poor depending on the sites and seasons. The water quality improved a little during monsoon reason which was also the case for domestic use and irrigation. Rain-induced increases in the water column are the cause of this. The WQI values for aquatic life for each site in different seasons are given in Table 4.

3.4. Comparative analysis WQI for domestic, irrigation and aquatic life

Comparative analysis of WQI in Fig. 6(a) showed that the majority of WQI value for domestic ranged from poor to unsuitable and WQI for aquatic life ranged from good to poor quality. However, the WQI for irrigation had a very promising result based on the parameters taken. The water must be used for domestic work after necessary treatment. The WQI for irrigation fell in the excellent categories. WQI values for aquatic life were much better in GEP. WQI showed a similar kind of trend for domestic, irrigation and aquatic life throughout the seasons as shown in Fig. 6(b). The WQI was comparatively worse during the pre-monsoon season and comapratively better during the monsoon season.

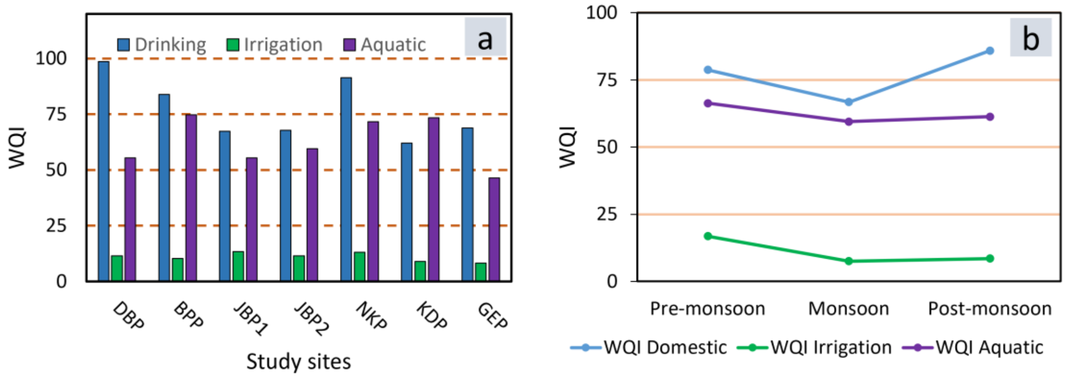

Fig.6: Comparative WQI for drinking, irrigation and aquatic life support (a) Comparative WQI for drinking, irrigation and aquatic life in different study sites. Mean value of WQI for different seasons has been considered for each study site (b) Comparative WQI for drinking, irrigation and aquatic life in different seasons. Mean value of WQI for different sites has been considered for each season.

Our study assesses the surface water of key pitlakes of RCF and highlights the potential use of this huge water resource. It provides a multi-dimensional assessment of physicochemical water parameters across pitlakes and evaluates their suitability for domestic, irrigation, and aquatic life support uses. This is achieved through WQI computation, Wilcox diagram, %Na, SAR, and other irrigation-relevant indicators. WQI study concluded the unsuitability of pitlakes' water in this region for domestic use. It requires necessary treatment and disinfection before using for domestic purposes. The WQI values for irrigation were found to range from 4.4 to 23.1, indicating excellent water quality for irrigation use. The Wilcox diagram and all the other analyses confirmed the suitability of the pitlakes' water for irrigation use. The WQI values for aquatic life showed a mixed result, ranging from good to poor, depending on the sites and seasons. The seasonal variation of the water quality for domestic, irrigation and aquatic life had a similar trend. The quality was generally found to be worse during pre-monsoon and was better during the monsoon season. Hence, Pitlakes' water in Raniganj coalfield zone can be of great utility to the community because of its good potential for utilization in irrigation and revegetation of the mining area. Pitlakes are a good option for ecological restoration and can compensate for the damages caused by mining.

REFERENCES

[1] Soni A, Mishra B, Singh S. Pit lakes as an end use of mining: A review. Journal of Mining and Environment 2014;5:99–111. https://doi.org/10.22044/jme.2014.326.

[2] Blanchette ML, Lund MA. Pit lakes are a global legacy of mining: An integrated approach to achieving sustainable ecosystems and value for communities. Current Opinion in Environmental Sustainability 2016;23:28–34. https://doi.org/10.1016/j.cosust.2016.11.012.

[3] Lund MA, Blanchette ML. Closing pit lakes as aquatic ecosystems: Risk, reality, and future uses. WIREs Water 2023;10:e1648. https://doi.org/10.1002/wat2.1648.

[4] Kalin M, Cao Y, Smith M, et al. Development of the phytoplankton community in a pit-lake in relation to water quality changes. Water Research 2001;35:3215–25. https://doi.org/10.1016/S0043-1354(01)00016-1.

[5] Palit D, Mukherjee A, Gupta S, et al. Water quality in the pit lakes of raniganj coal field, west bengal, india. Journal of Applied Sciences in Environmental Sanitation 2014;9:1.

[6] Gammons C, Harris L, Castro J, et al. Creating Lakes from Open Pit Mines: Processes and Considerations, Emphasis on Northern Environments. Geological Engineering 2009.

[7] Akburak S, Kul AA, Makineci E, et al. Chemical water parameters of end pit lakes in abandoned coal mines. Arabian Journal of Geosciences 2020;13:569. https://doi.org/10.1007/s12517-020-05598-y.

[8] Dzhangi TR, Atangana E. Evaluation of the impact of coal mining on surface water in the Boesmanspruit, Mpumalanga, South Africa. Environmental Earth Sciences 2024;83:159. https://doi.org/10.1007/s12665-024-11431-6.

[9] Palit D, Kar D. A Contemplation On Pitlakes of Raniganj Coalfield Area: West Bengal, India. In: Jhariya MK, Banerjee A, Meena RS, et al., editors. Sustainable Agriculture, Forest and Environmental Management, Singapore: Springer; 2019, p. 517–71. https://doi.org/10.1007/978-981-13-6830-1_15.

[10] McCullough CD, Schultze M, Vandenberg J. Realizing Beneficial End Uses from Abandoned Pit Lakes. Minerals 2020;10:133. https://doi.org/10.3390/min10020133.

[11] Singh AK, Mahato MK, Neogi B, et al. Quality Assessment of Mine Water in the Raniganj Coalfield Area, India. Mine Water and the Environment 2010;29:248–62. https://doi.org/10.1007/s10230-010-0108-2.

[12] Goswami DS. Environment Management in Mining Areas (A Study of Raniganj and Jharia Coal Field in India). Global Journal of Human-Social Science Research 2013.

[13] Gupta S, Palit D, Mukherjee A, et al. Inventory of pit lakes in raniganj coal field, west bengal, india. Journal of Applied Technology in Environmental Sanitation 2013;3:55.

[14] Palit D, Roychowdhury S, Mukherjee A, et al. Determinants of pitlake usage in raniganj coalfield region, west bengal: Implications for sustainable use. International Journal of Innovative Research in Engineering & Management (IJIREM) 2016;3:72–6.

[15] Palit D, Kar D, Roychoudhury S, et al. Water quality assessment of pit-lakes in raniganj coalfields area, west bengal, india. International Journal of Current Research and Review 2017;9:10–5.

[16] Palit D, Mondal S, Chattopadhyay P. Analyzing Water Quality Index of Selected Pit-Lakes of Raniganj Coal Field Area, India. Environment and Ecology 2018;36:1167–75.

[17] Mondal S, Palit D. Evaluation of water quality using water quality index of pit lakes, raniganj coal field area, west bengal, india. Research Journal of Life Sciences, Bioinformatics, Pharmaceutical and Chemical Sciences 2019. https://doi.org/10.26479/2019.0503.44.

[18] Palit D, Chaudhury AR. Contributions of Pit Lakes to the Socioeconomic Status: A Case Study of the Raniganj Coal Field Area. Environmental and Sustainable Development Through Forestry and Other Resources, Apple Academic Press; 2019.

[19] Palit D, Mukherjee A, Kar D, et al. Determinants of Pitlake Usage in Raniganj Coalfield Region, West Bengal: Implications for Sustainable Use. International Journal of Innovative Research in Engineering and Management 2020;3:72–9.

[20] Mondal S, Palıt D, Hazra N. Rotifer diversity in coal mine generated pit lakes of raniganj coal field area, west bengal, india. Journal of Limnology and Freshwater Fisheries Research 2021;7:115–27. https://doi.org/10.17216/limnofish.777321.

[21] Mondal P, Banerjee A, Palit D. Water quality of selected pitlakes of raniganj coal fields, west bengal, india. Indian Journal of Applied & Pure Biology 2023;38:1563–74.

[22] Saha D, Saha A, Saha NC. Seasonal variation of heavy metals and fish diversity in different open cast coal mine pits of satgram and kajora areas, raniganj, west bengal, india. BioscBiotechResComm 2020;13. https://doi.org/10.21786/bbrc/13.4/90.

[23] Saha D, Keshri JP, Saha NC. Comprehensive study on raniganj coalfield area, india: A review. Ecology, Environment and Conservation 2022;28:S387–98.

[24] Manna A, Maiti R. Geochemical contamination in the mine affected soil of Raniganj Coalfield – A river basin scale assessment. Geoscience Frontiers 2018;9:1577–90. https://doi.org/10.1016/j.gsf.2017.10.011.

[25] APHA. Standard Methods for the Examination of Water and Wastewater, 20th Edition. APHA American Public Health Association; 1998.

[26] Brown RM, McClelland NI, Deininger RA, et al. A Water Quality Index — Crashing the Psychological Barrier. In: Thomas WA, editor. Indicators of Environmental Quality, Boston, MA: Springer US; 1972, p. 173–82. https://doi.org/10.1007/978-1-4684-2856-8_15.

[27] Wilcox LV. Classification and Use of Irrigation Waters. U.S. Department of Agriculture; 1955.

[28] Nag SK, Das S. Quality Assessment of Groundwater with Special Emphasis on Irrigation and Domestic Suitability in Suri I & II Blocks, Birbhum District, West Bengal, India. American Journal of Water Resources 2014;2:81–98. https://doi.org/10.12691/ajwr-2-4-2.

[29] Jhariya DC, Khan R. Groundwater Quality Assessment for Drinking Purpose in Raipur City, Chhattisgarh Using Water Quality Index and Geographic Information System. Journal of Geological Society of India 2017:69–76. https://doi.org/10.1007/s12594-017-0665-0.

[30] Ayers RS, Westcot DW. Water quality for agriculture. Rome: Food and Agriculture Organization of the UN; 1985.

[31] Mosalem A, Redwan M, Abdel Moneim AA, et al. Implication of the Mining Activities on the Hydrogeochemical Imprints and Quality Assessment of the Groundwater in Wadi Asal and Wadi Queih, Red Sea Area, Egypt. Water Resources 2024;51:1076–93. https://doi.org/10.1134/S0097807824603807.

[32] Shinde V, Nandgude S, Singh M. Assessment of water quality around surface coal mine in India. Nature Environment and Pollution Technology 2013;12:215–24.

[33] Wilcox LV. The Quality of Water for Irrigation Use. Technical Bulletins 1948.

[34] Goher ME, Hassan AM, Abdel-Moniem IA, et al. Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. Egyptian Journal of Aquatic Research 2014;40:225–33. https://doi.org/10.1016/j.ejar.2014.09.001.

[35] Karakuş CB, Yildiz S. Evaluation for irrigation water purposes of groundwater quality in the vicinity of sivas city centre (turkey) by using GIS and an irrigation water quality index. Irrigation and Drainage 2019. https://doi.org/10.1002/ird.2386.

[36] Sahoo S, Khaoash S. Impact assessment of coal mining on groundwater chemistry and its quality from Brajrajnagar coal mining area using indexing models. Journal of Geochemical Exploration 2020;215:106559. https://doi.org/10.1016/j.gexplo.2020.106559.

[37] Kumari M, Rai SC. Hydrogeochemical Evaluation of Groundwater Quality for Drinking and Irrigation Purposes Using Water Quality Index in Semi Arid Region of India. Journal of Geological Society of India 2020:159–68. https://doi.org/10.1007/s12594-020-1405-4.

[38] Vasanthavigar M, Srinivasamoorthy K, Vijayaragavan K, et al. Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. Environmental Monitoring and Assessment 2010;171:595–609. https://doi.org/10.1007/s10661-009-1302-1.

[39] Zaman M, Shahid SA, Heng L. Irrigation Water Quality. In: Zaman M, Shahid SA, Heng L, editors. Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques, Cham: Springer International Publishing; 2018, p. 113–31. https://doi.org/10.1007/978-3-319-96190-3_5.

[40] Venugopal T, Giridharan L, Jayaprakash M, et al. Environmental impact assessment and seasonal variation study of the groundwater in the vicinity of River Adyar, Chennai, India. Environmental Monitoring and Assessment 2009;149:81–97. https://doi.org/10.1007/s10661-008-0185-x.

[41] Ramadhan OM, Al-Saffawi A-AY, Al-Mashhdany MHS. Assessment of Surface Water Quality for Irrigation using WQI model; A Case Study of Khosar and Tigris Rivers, Environmental Science, Agricultural and Food Sciences; 2018.
[42] Canadian Council of Ministers of the Environment. For the protection of aquatic life 2007. In: Canadian Council of Ministers of the Environment, editor. Canadian environmental quality guidelines, 1999, Winnipeg: Canadian Council of Ministers of the Environment; 2007.