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Quality Evaluation and Suitability Assessment of Surface Water of Nal Sarovar Bird Sanctuary, Gujarat, India

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ABSTRACT

The present study was conducted to determine the suitability of water of Nal Sarovar Bird Sanctuary (NSBS), a Ramsar Site of International importance, for human consumption, agricultural use, outdoor bathing and fish culture purposes.To examine the suitability of NSBS water, Water Quality Index (WQI) tool have been applied using different physico-chemical parameters. This study reveals that (i) water quality of central part of NSBS, is good for drinking purpose after treatment (ii) the water is safe for irrigation purpose (iii) good to moderately good for outdoor bathing purpose and (iv)unsuitable for fish culture.The Principal Component Analysis (PCA) has been carried out to check the compositional data structure and to determine the probable source of pollutants in the water of the study area.Management options such as introduction of organic farming, bio-gasification of invasive species, fencing around NSBS, continuous dredging and buffer zone development are suggested for sustainable development of NSBS.

Keywords: Nal Sarovar Bird Sanctuary (NSBS),Principle Component Analysis, Suitability Assessment, Sustainable Development, Water Quality Index

I. INTRODUCTION

Fresh water resources are limited and the access to fresh water is declining because of increase in pollution level [1] as well as severe competition among its users for drinking, domestic, industrial and agricultural purposes.To meet the increasing water demand of the burgeoning population,unusual water resources such as wetland water are used along with conventional sources of surface water like rivers, lakes and ponds. Wetlands are transitional zones that have an intermediate position between land and water ecosystems [2],[3]. Wetlands are the valuable productive ecosystems on the earth [4] and provide many important services to human society [5]. Ecosystem services provided by the wetlands mainly include: water for irrigation purpose; fisheries; non-timber forest products; water supply; and recreation. Other major services include: flood control, carbon sequestration, groundwater recharge, nutrient removal, toxics retention and biodiversity maintenance [6].However, they are also ecologically sensitive and fragile in nature [7],[6].Despitetheir valuable roles for water quality maintenance, wetlands are experiencing serious ecological problems and degradation. Wetlands are in filled, drained and converted to other landuse classes such as waste disposal site from decades [8],[9],[10],[11],[12]which damage the ability of wetlands in many aspects [13]. They have been deteriorated from centuries but their degradation or conversion (64-71%) is escalating at a faster rate now-a-days [14],[15]. This alarming degradation phenomenon is due to increasing population pressures and unsustainable economic growth.

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Gujarat is a semi-arid western part of India and a growing state in terms of population growth and economic activities. Therefore, there is a phenomenal pressure on existing fresh water bodies such as rivers and lakes andthere is a continuous requirement of more water for domestic, agricultural and commercial uses. Consequently, there is a growing need to explore other unusual sources of surface water especially wetlands. In Gujarat, Nal Sarovar Bird Sanctuary (NSBS) can serve as a better source of water to fulfil the enhancing need of water.

To determine the suitability of NSBS water for different uses, Water Quality Index (WQI) tool have been used for suitability assessment. Water Quality Index (WQI) tool have been applied using different physico-chemical parameters like EC, TDS, DO, BOD, COD, sodium, chloride, potassium, etc. The Principal Component Analysis (PCA) has been applied to check the overall compositional data structure of the water at the study area. The present study is a way forward to emphasize on environmental status of NSBS water. The aim of the study is to explore the scope of use of wetland water of NSBS for various purposes to fulfil future water demands. In addition, some management strategies are also suggested to protect the NSBS from anthropogenic activities as well for sustainability of NSBS.

II. MATERIAL AND METHODS

2.1 Study area

Nal Sarovar Bird Sanctuary(NSBS), a Ramsar site (site no. 2078) is located in the state of Gujarat, India[16]. The NSBS lies in outskirts of Ahmedabad district between the coordinates of 71˚58' 32" E to 72˚ 07' 21" E and 22˚41' 50" N to 22˚ 52 '21 " N (Fig. 1). The total area of NSBS is approximately 120.82 sq. km. and is being protected as Bird sanctuary by the State Forest Department of Gujarat. With the change of seasons, the wetland shows variation in shape and size. Most part of the wetland is shallow and muddy. Historically, the NSBS was an estuary and its formation occurred due to tectonic uplift, aeolian infill and increased sedimentation [17],[18].

2.2 Sampling and analysis of water samples

Surface water samples had been collected from eight selected sites (Fig. 1) using spot sampling procedure from NSBS in pre-monsoon season. The samples were collected in the pre-cleaned polythene bottles and then taken to the laboratory for examination using standard methodology of APHA [19]. Certain parameters such as temperature (C˚), pH, electrical conductivity (EC, μS/cm), hardness (mg/l), turbidity (NTU), total dissolved solids (TDS, mg/l), dissolved oxygen (DO, mg/l), salinity (ppt) and specific gravity (δt) had been analysed onsite by using multi-parameter water sampler (Horriba-U-52). The alkalinity (mg/l), biological oxygen demand (BOD, mg/l), bicarbonates (mg/l) and free carbon dioxide (mg/l) were determined by titration method. Chloride was analysed by argentometric method. Chemical oxygen demand (COD, mg/l) was determined by reflux method using potassium dichromate and potassium permanganate. Calcium and magnesium (mg/l) had been analysed by EDTA titrimetric method. Sodium and potassium (mg/l) were determined by gravimetric and colorimetric method respectively. Parameters such as sulphate (mg/l) and phosphate (mg/l) were measured by UV-VIS double beam spectrometer (model no. HALO DB-20).

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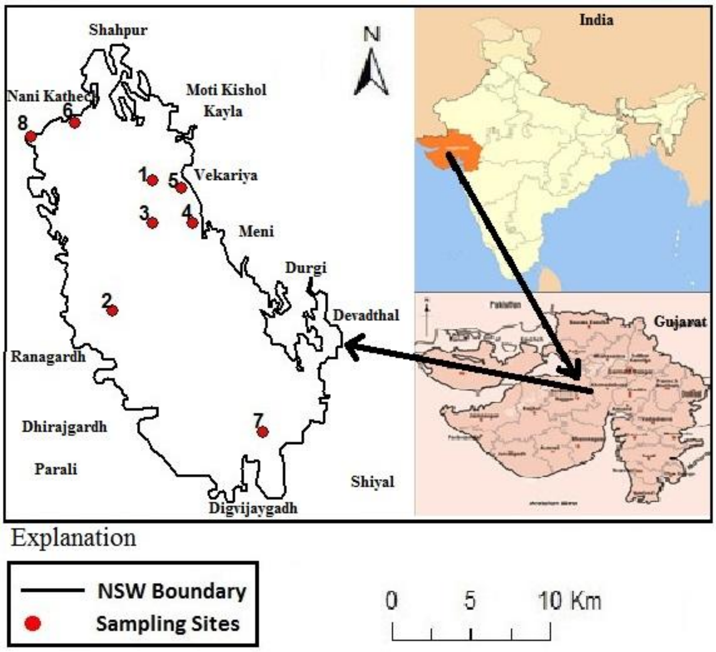

Fig. 1 Sampling sites of NSBS.

2.3 Water Quality Index (WQI) measurement

To get a comprehensive picture of quality of water required for different purposes, WQI is an important effective tool [20],[21],[22],[23],[24], [25]. WQI is a rating, which indicates the combined effect of different water quality parameters on the overall quality of water. Here, it is calculated to examine the suitability of water for human consumption, bathing, agricultural use and fish culture. In order to compute WQI, five steps are fallowed. Initially, each parameter is assigned a weight (w_i) as per its relative importance in overall quality of water for the purpose it is being used. Those parameters having much importance has been assigned a maximum weight of 5 in water quality assessment. Other parameters are allotted to a weight in between 1 to 4, depending on their respective importance in determination of water quality. In the second step the relative weight (W_i) is computed from the fallowing equation:

$$\mathbf{W_i = \frac{w_1}{\sum_{i=1}^{n} w_1}} \text{(1)}$$

Where, $W_i$is the relative weight and w_i is relative weight of each parameter (i^{th} parameter) and n is the number of parameters. In the third step the relative weight (W_i) is computed from the fallowing equation:

$$\mathbf{q_i = \frac{C_1}{S_1} \times 100} \text{(2)}$$

Where, q_i is the quality rating, C_i is the concentration of each parameter in each water sample. In equation (2) S_i is the Indian drinking standard for every chemical parameter in accordance with the guidelines of the BIS IS 2296[26].

To compute the WQI, for each chemical parameter the sub index (SI) is measured first. Thereafter, SI is used to determine WQI as per the fallowing equation:

$$\boldsymbol{SI} = \mathbf{W_i q_i} \qquad \text{(3)}$$

$$\boldsymbol{WQI} = \mathbf{\sum_{i=1}^{n} SI_i} \text{(4)}$$

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Where, SI_i is the sub index of i^{th} parameter, q_i is the rating based on concentration of i^{th} parameter and n is the number of parameters. The types of water are determined on the basis of the values of WQI. The computed WQI values are classified into seven categories as given in Table 1.

Table 1. Classification of WQI categories

WQI values	Categories
0-50	Excellent water
50-100	Good
100-150	Moderately good
150-200	Moderate
200-250	Moderately poor
250-300	Poor
300-400	Very poor
>400	Unsuitable

2.4 Principal Component Analysis method

The water quality of surface water is the composite of several interested parameters which undergo many local and temporal variations. Therefore, to understand the overall compositional data structure (in this case seven components, viz., HCO^-_3, Cl^-, SO^{2-}_4, Ca^{+2}, Mg^{+2}, Na^+ and K^+) and to separate as well as estimate the relative importance of the factors controlling the chemical composition of surface water, Principal Component Analysis(PCA) or Varimax-rotated R-mode factor analysis has been carried out [27],[28], [29],[30],[25]. Actually, principal components are the eigen vectors of a variance-covariance matrix. The methodology adopted from Davis [31]involves three steps (i) Standardization of the raw data in terms of a zero mean and a unit variance as well as computation of the variance-covariance matrix; (ii) computation of a set of mutually orthogonal principal component-axes (the elements in each axis referred to as 'loading') which are the eigen vectors of a variance-covariance matrix. The corresponding eigen values denote the proportion of variability accounted by the respective PC-axis; (iii) computation of a set of PC- scores for each of the Varimax-rooted factor PC-axis, corresponding to individual samples. Every PC-axis or factors(with high loading on one or more variables) may be representing an independent source of variation in the data matrix. These may give some clues to the processes that influence water quality by examining chemical associations defined by their loadings on factors [32]. Correlation coefficient matrix indicates the existence of several groups of significantly related parameters at 95% or more confidence level (TABLE 11).

III. RESULTS AND DISCUSSION

3.1 Water quality of NSBS

The results of physico-chemical analysis of surface water samples of NSBS is summarised in Table 2. The pH value has been obtained at the sampling sites, which showed fluctuations between values (9.95-8.53) with an average pH value of 8.99. It indicates that water is alkaline in nature. In natural water, higher pH value is due to high photosynthetic activity of green plants and algae. Electrical conductivity (EC, µS/cm) has also been determined on site. The high value (5.09 µS/cm) of EC is due the occurrence of ionic concentration of salts,

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discharge of some domestic and organic waste [33]. The average EC of the NSBS is also high which can be because of additional salts coming from the surrounding agricultural fields.

The total alkalinity from the maximum (2500 mg/l) to the minimum (1250 mg/l) value is the combined activity of carbonates and bicarbonates. This type of alkalinity is due to more accumulation of dead plants and animals remains and possibly because of domestic wastes [34]. The change in turbidity (NTU) values is because of fluctuating levels of solids in water. The presence of high values of turbidity (29.4 NTU) in the north side is due to the mixing of river water (River Brahmani) containing suspended matter such as organic and inorganic wastes. Therefore, which results in increase of turbidity, which in turn affects transparency. The high value of TDS (3200 mg/l) is due to accumulation of domestic waste water, silt deposits and organic matter coming through river Bhogava and river Brahmani in NSBS. In addition, certain quantity of dissolved solid materials come from agricultural soils surrounding the NSBS. Consequently, the increase in high concentration of TDS increases the nutrient status of NSBS which would result in eutrophication of water body [35],[36]. The result of hardness values from maximum (435 mg/l) to minimum (130mg/l) of different sites, indicate that NSBS water ranges from hard to very hard. The possible source of hardness are the salts coming from agricultural (fertilizers) and domestic wastes. In addition, they can be present because of the geology of the area. The higher concentration of bicarbonates (3050 mg/l) is the result of decomposition of more organic matter and possibly due to dissolution of atmosphere carbon dioxide in NSBS water.During the analysis, the presence of higher (8.77 mg/l) dissolved oxygen (DO) is due to less pollution and mixing of atmospheric oxygen. The occurrence of dead plants (macrophytes), organic matter decomposition and increase in temperature are the causes of low (4.12 mg/l) DO.The value of DO usually decreases in summer due to decomposition and increasing temperature.

Table 2. Chemical composition of surface water of NSBS

Parameter	Minimum	Maximum	Average
Temperature	30.3	35.2	32.7
pH	8.53	9.95	8.99
Total Alkalinity	1250	2500	904
Bicarbonate	305	3050	1103
Oxidation Reduction Potential(ORP)	78	320	228
Electrical Conductivity(EC)	1.84	5.09	4.13
Total Dissolved Solids(TDS)	1180	3200	3039
Turbidity	0.1	29.4	9.5
Dissolved Oxygen(DO)	4.12	8.77	6.56
Salinity	0.97	2.17	1.48
Specific Gravity	0.7	2.1	1.3
Hardness	130	435	227
Chloride	511	1320	863
Biological Oxygen Demand(BOD)	3.45	7.89	5.68
Chemical Oxygen Demand(COD)	4	40	12.5
Free Carbon Dioxide	26	132	64
Sulphate	221	579	415

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Phosphate	0.18	5.93	1.26
Nitrate	-	-	-
Sodium (Na^+)	371	3125	1079
Potassium(K^+)	25	140	71
Calcium(Ca^+)	14.4	48.0	24.6
Magnesium(Mg^+)	18	77	34

All the above parameters are in mg/l except temperature (°C), pH, Oxidation Reduction Potential (mV), Electrical Conductivity (mS/cm), Salinity (ppt), Specific gravity(δt) and Turbidity(NTU).

The high value of BOD (7.89 mg/l) is due to domestic and agricultural wastes coming from the catchment area of NSBS which agrees with the results reported by Hulyal and Kaliwal [37]. In addition, the high value of BOD could be decrease in water volume, increase in evaporation rate because of high temperature. Occurrence of higher values of COD in NSBS (40 mg/l) is because of biologically resistant organic matter. Besides this, the anthropogenic sources such as agricultural and domestic wastes in water body. The higher value of free carbon dioxide (132 mg/l) indicates more decomposition of organic matter during summer and respiration of organisms in NSBS. The lower value (26 mg/l) could be due to high photosynthetic activity at some sites which utilizes more free carbon dioxide [38]. The higher value (1320 mg/l) and lower value (511 mg/l) of chloride is reported from north-east and west side respectively. The presence of chloride is due to accumulation of domestic sewage contamination which includes human and animal wastes coming from the surrounding population. As per the results obtained the higher (5.93 mg/l) concentration of phosphate recorded might be due to discharge of sewage and dumping of domestic waste coming from the catch catchment area through river Brahmani etc. in NSBS. The other cause of phosphate in NSBS water can be due to discharge of detergent wastes and agricultural runoff, mostly containing phosphate fertilizers [39],[40]. Sulphate (415 mg/l) can be present due to dissolution of sulphur containing compounds naturally in water. Further, it may be present due to anthropogenic sources such as industrial wastes. Moreover, sulphate is also produced by oxidation of sulphites. Naturally, decaying plant and animal matter release sulphite in water. The possible anthropogenic sources of calcium (24.4 mg/l) in NSBS are from agricultural wastes and could be industrial also. The presence of calcium occurs in water naturally due to deposits of lime stone etc. Moreover, surface runoff discharges during rains. The occurrence of sodium (1079 mg/l) in NSBS water is because of mixing of various salts. The anthropogenic sources are agricultural wastes like fertilizers containing sodium and also sewage water. The presence of potassium is also due to runoff from agricultural fields containing potassium fertilizers surrounding the NSBS.

3.2 Suitability assessment of surface water of NSBS for various purposes using WQI

To check the water quality of NSBS for drinking, irrigation use and fish culture, WQI has been used. For this purpose, twenty two parameters were selected out of twenty three parameters.To analyse the suitability, eight surface water samples has been taken from the selected sites (Fig. 1). The fallowing twenty two parameters are pH, TDS, hardness, ORP, EC, turbidity, total alkalinity, salinity, specific gravity, DO, BOD, COD, free carbon dioxide, bicarbonate, chloride, sulphate, phosphate, nitrate, sodium, potassium, calcium and magnesium. These parameters have been selected because they have relevant threshold level for drinking, irrigation, bathing and fish culture and wildlife documented in BIS IS 2296, 1982[26].

3.3 Suitability assessment of surface water of NSBS for drinking purpose

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The fallowing selected parameters like pH, DO, BOD, TDS, total hardness, chloride, sulphate, calcium and magnesium are very important to assess the suitability of water for drinking use.To examine the WQI every parameter is assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purpose as prescribed in Table 3. For this purpose, the maximum weight 4 has been assigned to the parameters like pH, TDS, sulphate due to their higher relative importance in water quality assessment for drinking. The remaining parameters have weight 1 to 3 depending on their importance in drinking water quality determination.

Table 3. Relative weight of chemical parameters

Parameters	Indian Standard	Assigned weight	Relative weight
pH	6.5-8.5	4	0.173913043
DO(mg/l)	6	1	0.043478261
BOD(mg/l)	2	1	0.043478261
TDS(mg/l)	500	4	0.173913043
Total hardness as $CaCO_3$ (mg/l)	300	2	0.086956522
Chloride (mg/l)	250	3	0.130434783
Sulphate (mg/l)	400	4	0.173913043
Calcium(mg/l)	200	2	0.086956522
Magnesium (mg/l)	100	2	0.086956522
	Total Weight	Σw_i =23	ΣW_i =1

The WQI values obtained after analysis after computation showed moderate to moderately good water in NSBS (TABLE 4, Fig. 2). While as, for site 7 and 8 water has been found very poor and unsuitable for drinking purpose respectively. The overall quality of NSBS water is good for drinking purpose after necessary treatment process.

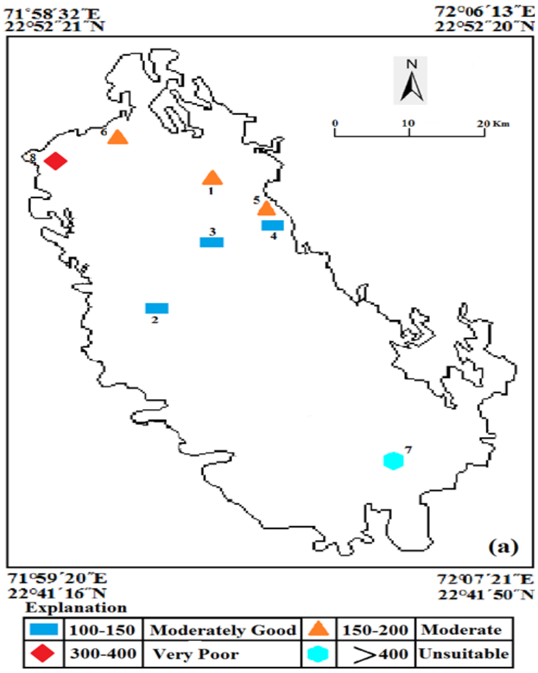

Fig. 2.Map of Water Quality Index for drinking purpose.

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Table 4. Calculation of WQI for drinking purpose

Site No.	WQI = ΣSI_i i= 1	Water type
1	174.25	Moderate
2	132.4	Moderately good
3	135.08	Moderately good
4	133.6	Moderately good
5	163.26	Moderate
6	186.87	Moderate
7	390.39	Very poor
8	403.44	Unsuitable

3.4 Suitability assessment of surface water of NSBS for irrigation purpose

The suitability of surface water of NSBS for irrigation is determined by (i) sodium absorption rate (SAR) and (ii) electrical conductivity (EC). For this, every parameter is assigned a weight (w_i) as per its relative importance in the overall quality of water for irrigation purpose (Table 5). The calculated relative weight (Wi) values of each parameter are also given in Table 5. To determine WQI of NSBS water for irrigation purpose, the maximum weight has been assigned to the parameter like conductivity, SAR, percentage of sodium and TDS due to their high control on agricultural production (Table 5). Other parameters have weight in between 1 to 3 depending on their importance in water quality determination.

Table 5. Relative weight of chemical parameters

Parameters	Indian Standard	Assigned Weight	Relative Weight
pH	6.0-8.5	3	0.115384615
Conductivity (micrmhos/cm at 25 Po PC)	2250	5	0.192307692
SAR	26	5	0.192307692
% sodium	60	5	0.192307692
TDS(mg/l)	2100	5	0.192307692
Chloride (mg/l)	600	2	0.076923077
Sulphate (mg/l)	1000	1	0.038461538
		Σw_i=26	ΣW_i=1

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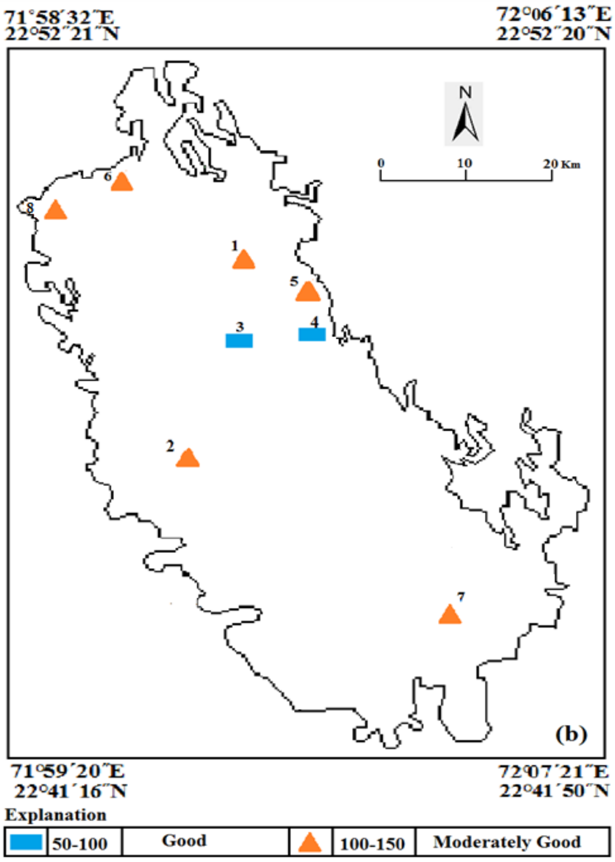

Fig. 3.Map of Water Quality Index for irrigation purpose.

Table 6. Calculation of WQI for irrigation purpose

Site No.	$WQI = \Sigma SI_i$ i= 1	Water type
1	115.179	Moderately good
2	102.602	Moderately good
3	93.03	Good
4	96.85	Good
5	122.272	Moderately good
6	125.725	Moderately good
7	225.406	Moderately poor
8	246.83	Moderately poor

From the WQI values as shown in the Table 6 clearly depicts that water is good to moderately good for irrigation purpose. Therefore, the overall quality of NSBS is safe for irrigation purpose except for sites 7 and 8 which are moderately poor (Fig. 3).

3.5 Suitability assessment of surface water of NSBS for outdoor bathing purpose

The fallowing parameters like pH, DO and BOD are very important to assess the suitability of water for human bathing. For this purpose, the maximum weight 4 has been assigned to the parameter like pH due to its higher relative importance in water quality assessment for bathing. From the above parameters like DO and BOD have weight 1 as per their importance in water quality determination (Table 7).

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The WQI values obtained as shown in Table 8 for NSBS reveals that the overall quality is good to moderately good for bathing purpose without any prior treatment (Fig. 4).

Table 7. Relative weight of chemical parameters

Parameters	Indian Standard	Assigned weight	Relative weight
pH	6.5-8.5	4	0.66666667
DO(mg/l)	5	1	0.16666667
BOD(mg/l)	3	1	0.16666667
		Σw_i=6	ΣW_i =1

Table 8. Calculation of WQI for outdoor bathing purpose

Site No.	WQI = ΣSI_i i= 1	Water type
1	142.99	Moderately good
2	99.95	Good
3	139.87	Moderately good
4	121.08	Moderately good
5	119.81	Moderately good
6	107.03	Moderately good
7	122.76	Moderately good
8	138.68	Moderately good

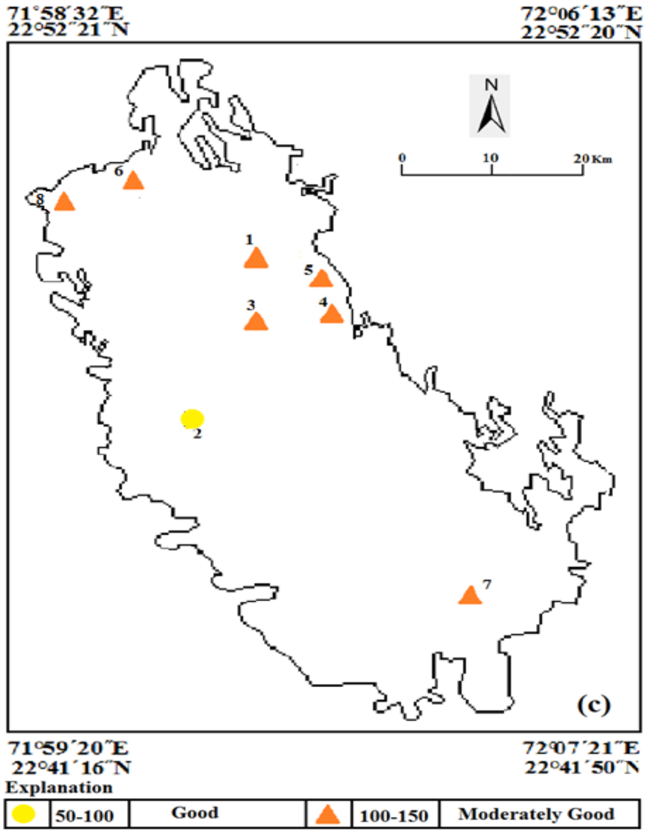

Fig. 4.Map of Water Quality Index for bathing purpose.

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3.6 Suitability assessment of surface water of NSBS for fish culture

The parameters are assigned a weight according to its importance in water. So, weight 5 has been assigned to the parameter like dissolved oxygen (DO) due to its maximum importance in water quality assessment for fish culture and wildlife propagation.Other parameters have weight in between 1 to 4 depending on their respective importance in water quality examination (Table 9). The WQI values computed for NSBS water is unsuitable for fish culture and wildlife. The overall quality of NSBS is not suitable for fish culture and wildlife as shown in Fig. 5.

Table 9. Relative weight of chemical parameters

Parameters	Indian Standard	Assigned weight	Relative weight
pH	6.5-8.5	4	0.30769231
Conductivity (micromhos/cm at 25PoPC)	1000	1	0.07692308
DO(mg/l)	4	5	0.38461538
Free Carbon Dioxide(mg/l)	6	3	0.23076923
		Σw_i=13	ΣW_i=1

Table 10. Calculation of WQI for fish culture purpose

Site No.	WQI = ΣSI_i i= 1	Water type
1	273.50	Poor
2	299.68	Poor
3	260.60	Poor
4	216.25	Moderately poor
5	431.79	Unsuitable
6	615.09	Unsuitable
7	439.55	Unsuitable
8	440.62	Unsuitable

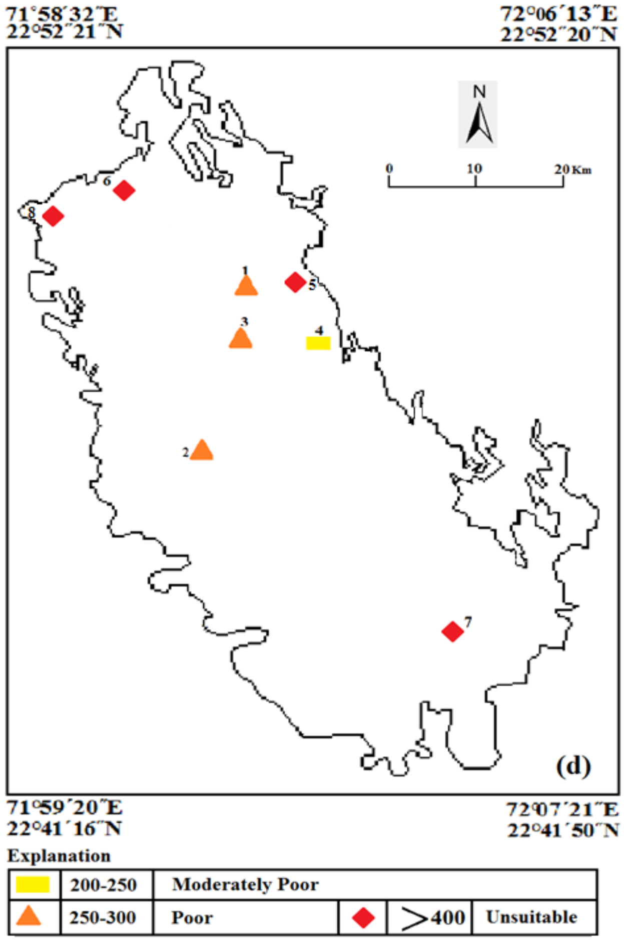

Fig. 5.Map of Water Quality Index for fish culture.

3.7 Principal Component Analysis

In this study, the first four factors such as TDS, Na, K and HCO_3 are selected to represent the dominant hydrochemical processes, which have helped in the formation of the present surface water chemistry without losing significant information. The output of the PCA (Table 12) reveals that the four eigenvalues together account for over 93% of the total variability of the combined population. Correlation coefficient matrix (Table 11) indicates the existence of several groups of significantly related parameters at 95% or more confidence level.

Results of PCA (Table 12) indicate that the first Principal Component (PC1), accounts for more than 36% of the total variance and has significant loading on TDS, Na, K, HCO_3, Cl, $SO_4$and moderately on hardness. It indicates that the dissolved solid of the NSBS water are mainly dominated by $KHCO_{3,}$ Na, SO_4 and Cl. The possible source can be sewage and industrial effluents as well as agricultural runoff carried by river Brahmani in north-west and river Bhogava in south discharge into NSBS. High loading of HCO_3 can be attributed to the CO_2 present in the rain water and soil. Mostly in wetlands like NSBS, oxidation of organic matter by microbes also generate CO_2 which may combine with water to form carbonic acid which on dissociation produces H^+ and HCO^{3-}. The hardness of water has been imparted by both Cl^- and HCO^{3-} indicating that the NSBS has both permanent (Cl) and temporary (HCO^3) hardness.

Table 11. Correlation coefficient matrix of chemical parameters of 8 surface water samples of NSBS

	pH	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	PO_4	Hardness	DO	BOD	COD	ORP	Turbidity	Salinity	CO_2
pH	**1.000**																	
TDS	**-.321**	**1.000**																
Ca	**.649***	**.650***	**1.000**															
Mg	**.101**	**.594**	**.569**	**1.000**														
Na	**-.307**	**.999***	**.625***	**.583**	**1.000**													
K	**-.422**	**.893***	**.483**	**.214**	**.896***	**1.000**												
HCO_3	**-.316**	**.997***	**.619**	**.545**	**.997***	**.922***	**1.000**											
Cl	**-.400**	**.964***	**.776***	**.695***	**.956***	**.790***	**.943***	**1.000**										
SO_4	**-.242**	**.991***	**.608**	**.599**	**.993***	**.872***	**.989***	**.934***	**1.000**									
PO_4	**-.119**	**.504**	**.745***	**.767***	**.481**	**.304**	**.479**	**.594**	**.492**	**1.000**								
Hardness	**-.467**	**.858***	**.641***	**.602**	**.856***	**.673***	**.834***	**.900***	**.827***	**.307**	**1.000**							
DO	**.137**	**.324**	**-.166**	**-.181**	**.335**	**.429**	**.365**	**.163**	**.371**	**-.376**	**.294**	**1.000**						
BOD	**.042**	**.351**	**.059**	**.017**	**.356**	**.352**	**.378**	**.218**	**.421**	**-.157**	**.370**	**.893***	**1.000**					
COD	**-.116**	**-.147**	**.348**	**.452**	**-.174**	**-.369**	**-.195**	**.091**	**-.219**	**.383**	**.149**	**-.431**	**-.320**	**1.000**				
ORP	**.210**	**.516**	**.257**	**.363**	**.510**	**.396**	**.525**	**.467**	**.559**	**.188**	**.457**	**.775***	**.801***	**-.005**	**1.000**			
Turbidity	**-.297**	**.489**	**.838***	**.684***	**.460**	**.326**	**.466**	**.611**	**.453**	**.962***	**.360**	**-.333**	**-.125**	**.504**	**.221**	**1.000**		
Salinity	**-.630***	**.654***	**.814***	**.604**	**.637***	**.446**	**.613**	**.811***	**.582**	**.458**	**.872***	**-.041**	**.072**	**.532**	**.275**	**.585**	**1.000**	
CO2	**-.618**	**.301**	**.737***	**.485**	**.274**	**.180**	**.268**	**.499**	**.205**	**.593**	**.495**	**-.413**	**-.268**	**.777***	**-.054**	**.742***	**.818***	**1.000**

**** indicates statistically significant correlation between variables at 95% confidence level***

The second Principal Component (PC2)has high loading on Mg, PO_4 and turbidity and moderate loading on COD, CO_2 and Ca (Table 12). Possible source of magnesium (Mg) is from fertilizer application and cattle grazing/feeding. The other sources of PO_4 may be from sewage runoff and surrounding agricultural fields. Turbidity is caused by erosion of materials from contributing water sheds. The possible source of COD can be wastewater from industrial origin. Free CO_2 is generated from microbial activity and decaying vegetation. Ca as well as Na are occurring naturally in surface water. The third Principal Component (PC3) has high loading on pH, CO_2 and salinity. Whereas, moderate loading on Ca, COD and hardness as shown in Table 12. Hardness of water is present mostly by calcium. High loading on pH and CO_2 indicates that the free CO_2 combines with surface water to form carbonic acid which further dissociates H^+ and HCO^{3-} as stated earlier. Possible sources of salinity could be sewage water and high rate of evaporation of wetland water. Since the water table is at or very close to the ground surface, bringing salts to the surface where it is left behind as the water evaporates. The fourth Principal Component (PC4) have high loadings on ORP, BOD and DO. High concentration of DO, BOD and ORP indicates a natural process whereas ORP values indicates potential of water for reducing Fe, Mn and NO_3 due to high DO concentration.

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Table 12. Principal Component Analysis using 8 surface water samples

Rotated Component Matrix(a)				
	Component			
	1	2	3	4
pH	-.328	.216	-.851*	.245
TDS	.914*	.271	.183	.226
Ca	.481	.511	.597	-.044
Mg	.330	.868*	.064	.122
Na	.922*	.249	.164	.228
K	.931*	-.057	.161	.141
HCO_3	.928*	.227	.158	.237
Cl	.808*	.414	.349	.168
SO_4	.916*	.268	.088	.275
PO_4	.358	.858*	.081	-.204
Hardness	.655*	.223	.527	.351
DO	.280	-.369	-.123	.862*
BOD	.252	-.174	-.029	.881*
COD	-.480	.648*	.546	-6.17E-005
ORP	.287	.274	-.062	.885*
Turbidity	.301	.807*	.306	-.146
Salinity	.385	.406	.787*	.142
CO_2	.057	.532	.796*	-.185
% eigen value	36.699	22.441	18.196	16.116
Cum %	36.699	59.140	77.336	93.451

**Variable with statistically significant loading*

IV. CONCLUSION

The present study reveals that the water quality of NSBS shows variation in physico-chemical characteristics at different locations.On the basis of the suitability of NSBS water for human consumption, agricultural use, outdoor bathing and fish culture purposes by their WQI values, it can be classified into 8 categories namely (1) excellent, (2) good, (3) moderately good, (4) moderate (5) moderately poor, (6) poor, (7) very poor and (8) water unsuitable for use. The overall water quality of central part of NSBS, is good for drinking purpose after treatment and the water is safe for irrigation purpose too. Though the NSBS water is good to moderately good for outdoor bathing purpose, it is not suitable for fish culture. Sodium chloride content of NSBS water is very high and it indicates that drainage of sewage water and industrial effluents into NSBS.PCA reveals that (i) dissolved solid of the NSBS water are dominated by $KHCO_3$, Na, SO_4 and Cl and the possible source are sewage and industrial effluents, agricultural runoff from river Brahmani in north-west and river Bhogava in south, (ii) fertilizer application and cattle grazing/feedings are the possible source of PO_4 andMg, (iii) Hardness of NSBS water is mostly due to calcium and (iv) salinity could be due to sewage water and high rate of evaporation of wetland water. Some of the important sustainable management options suitable for NSBS are (i) introduction of organic farming around NSBS using the dead and decomposed plant species of NSBS, (ii) bio-gasification of *Prosopis* and other such invasive species, (iii) fencing around NSBS, (iv) continuous dredging to combat the sedimentation problem and flood management and (v) buffer zone development around NSBS to protect it from further degradation.

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