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Surface Water Quality Assessment In Bhokardan Area Of Jalna District, Maharashtra State

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Ambient or environmental water quality includes the water quality of lakes, rivers and oceans. The water quality of these resources is declining with time due to various natural and anthropogenic sources of pollution. As surface water is major source of drinking water, made essential to monitor its quality regularly. In the present study an attempt was made to check suitability of surface water for drinking purposes and coupling of water quality index with GIS tools for better visual representation of the data. The generated WQI map can be used as a monitoring tool for surface water quality of Bhokardan area of Jalna district, Maharashtra state, India. The surface water quality is estimated by analyzing the various physico-chemical parameters, such as pH, alkalinity, electrical conductivity, fluoride, chloride, nitrate, sulphate, potassium, total hardness, *E. coli,* turbidity, total dissolved solids, dissolved oxygen and biochemical oxygen demand measured at 32 different selected locations in the study area for pre-monsoon and post-monsoon seasons. The overall results revealed that almost all the surface water sources from the Bhokardan area, Jalna district, India were found unsuitable for drinking purposes. The application of coupling WQI with GIS techniques to evaluate sequential and spatial variations in surface water quality was, therefore, found suitable and effective for monitoring and managing surface water resources.

KEYWORDS

Surface water, Water quality index, Spatial distribution, Bhokardan area

1. INTRODUCTION

Surface and groundwater resources are extremely sensitive aquatic systems to pollutants due to their exposure to the various point and non-point sources of pollutions [1]. Exhaustive monitoring of surface waters are essential and vital to assure the accessibility of quality water for its various uses [2,3]. Water security is emerging as a progressively significant and vital issue for India. Surface water is used for drinking, agricultural and industrial purposes. In India, monsoon is the main source of surface water. The annual utilizable surface water resources of India are estimated to be 690 km^3. The accessibility and quality of freshwater resources are the most persistent of the various environmental challenges on the national prospect in India. The pressure on water resources are from various sources and impacts can take diverse forms. Exponential population growth resulted in rapid urbanization, industrialization and agricultural development give rise to high adverse impacts on the quality and quantity of water in India [4]. The consequence of landuse patterns on river water quality was examined in three, different river basins located in Epirus, northwestern Greece by Kotti and found that inorganic nutrient load was mostly due to sites that drain agricultural areas [5]. Similar investigation was carried out on water quality of the Songhua river in northeast China by Yu and results showed that the main pollutants were nitrogenous pollutants released from non-point sources [6]. Nitrate appeared as a major problem of safe drinking water in the central region of India and observed 411 mg/L of nitrate [7]. The main sources of variation in surface water quality are due to both seasonal factors and anthropogenic activities [8].

The water quality index (WQI) provides a single number which expresses the overall state of a particular water body at a particular period after assessing several water parameters for that particular water body [9]. Water quality index is a competent technique for evaluating the fitness of water quality for different uses. The evaluation of surface water quality can be a complex process undertaking various parameters capable of creating numerous pressures on overall water quality. It is also a very applied and tool for relaying the information on overall quality of water to the layman and concerned government, non-government organizations local governing bodies [10]. The use of WQI simplifies the presentation of results of investigation

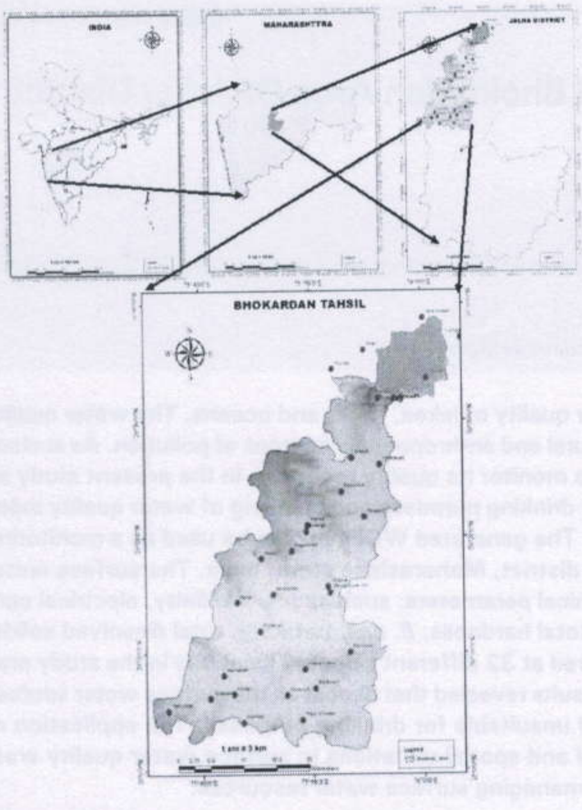

Figure 1. *Location map of the study area*

associated to a water body, as it summarizes in a single unitless value, the collective effect of several water quality parameters analyzed. The use of water quality index in estimating the quality of surface water bodies, such as rivers and lakes have increased tremendously since the initial WQI established by Horton and upgraded version by Brown [11,12].

In the rural communities of the Jalna district, agriculture is the main livelihood activity and the backbone of the societies. Climate change is expected to impact agriculture by increasing water demand, limiting crop productivity and resulting in reducing water availability in areas where irrigation is needed [13]. In the present investigation, an attempt has been made to examine the suitability of surface water samples collected along rivers and dams, using the 'weighted arithmetic index method' specified by Brown [12]. The reason for selecting the WAWQI method since it has advantage over other methods as in this method multiple water quality parameters are combined into a mathematical equation that rates fitness of water body through a number called water quality index as well as defines the suitability of surface as well as groundwater sources for human consumption.

1.1 Study area

Bhokardan is one of the taluka located in the Jalna district. Geographically it is located at 20.250508 °N 75.774236 °E. It has an average elevation of 587 m and having area of 1273 km^2 in the year 2014-15. The location map of the study area is presented in figure 1. The ancient city lies on minor peaks on the south bank of Kelana river. Keeping in view the present demand and source and sustainable management of water, Central Ground Water Board has categorized Bhokardan taluka as critical and semi-critical taluka under the National Aquifer Mapping Programme in India, during XII five-year plan [14]. The Jalna district is a central district in the region of Marathwada in the state of Maharashtra in western India. The average annual rainfall in the Jalna district is about 606 mm for last seventy years [15]. The district frequently experiences scarcity of water, whenever received rainfall is as low as 400-450 mm. The rural societies are mainly depending on agricultural and allied activities. The dominant cultivation of cash drop is cotton in combination with a mix of maize, pearl millet (bajra), pulses (tur, mug, uadid) and soybean in the kharif season and sorghum (jowar) and to some degree wheat in the rabi (winter) season [13]. The main surface water used in the study area is for drinking and agricultural purposes including livestock. Government public open wells are main source of drinking water in the study area.

2. MATERIAL AND METHOD

2.1 Sample collection and analysis

The sampling locations mostly consist of rural areas in this region. Yearly samples were collected at 32 locations preferably of drinking water sources of government owned or private wells for two years. Total 32 integrated surface water samples were collected during pre and post-monsoon period for the year 2014-2015 and analysed for various quality parameters, like pH, alkalinity, total hardness, turbidity, electrical conductivity (EC), chloride, total dissolved solids (TDS), fluoride, phosphate, nitrate, sulphates, dissolved oxygen (DO) and biochemical oxygen demand (BOD) using standard methods [16,17]. Samples were collected in 2 L capacity plastic cans which is acid washed and pre-rinsed with reagent grade distilled water followed by washing with water to be sampled. The methodologies implemented for the determination of water quality parameters of the collected samples are given in table 1.

2.2 Calculation of water quality index

Based on the significant role of the parameters and

Table 1. *Water quality parameters and their associated units and analytical method used*

Variables	Analytical methods
Temperature (°C)	Digital thermometer
pH	Electrometric method
Alkalinity (mg/L)	Titration method
Electrical conductivity (µS/cm)	Electrometric method
Turbidity (NTU)	Nepheloturbidity method
Total dissolved solids (mg/L)	Electrometric method
Total hardness (mg/L)	EDTA method
Dissolved oxygen (mg/L)	Winkler method
Potassium (mg/L)	Flame photometer
Chloride (mg/L)	Titrimetric method
Sulphate (mg/L)	Spectrophotometry
Fluoride (mg/L)	Spectrophotometry
Phosphate (mg/L)	Spectrophotometry
Nitrate (mg/L)	Spectrophotometry
BOD (mg/L)	Dichromate method
E. coli (MPN/100)	Multiple tube method

Table 2. *Weight assigned and relative weight calculated for selected parameters*

Parameter	Standards as per BIS and CPCB	Wi (weight)	Wi (relative weight)
pH	6.5 - 8.5	3	0.063
Total alkalinity (mg/L)	200	2	0.042
Turbidity (NTU)	1	5	0.104
Total hardness (mg/L) as $CaCO_3$	200	2	0.042
Conductivity (µS/cm)	2000	3	0.063
TDS (mg/L)	500	4	0.083
Sulphate (mg/L)	200	4	0.083
Fluoride (mg/L)	1	5	0.104
Chloride (mg/L)	250	3	0.063
Nitrate (mg/L)	45	5	0.104
Potassium (mg/L)	10	2	0.042
BOD (mg/L)	2	5	0.104
E. coli (MPN/100 mL)	1	5	0.104
		Σwi = 48	ΣWi = 1.000

their relative importance in the overall quality of water for drinking purposes each parameter has been assigned specific weightage [18]. In the first step, selected 13 water quality parameters which play significant role in

Table 3. *Surface water classification based on water quality index*

WQI value	Water quality
<50	Excellent
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Water unsuitable for drinking

assessment of drinking water quality has been allocated a weight (wi) presented in table 2. The maximum weight of 5 has been allocated to the parameter nitrate, turbidity and *E. coli* due to its significant role in water quality. Total hardness and potassium are given the minimum weight of 2 since they may not be harmful to human health. The maximum weight assigned is 5 and minimum is 1. In the next step, the relative weight (Wi) is calculated by using the following formula

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \quad ...(1)$$

Where Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters. Calculated relative weight (Wi) values of each parameter are also given in table 2. In the third step, a quality rating scale (qi) for each parameter is calculated by dividing its concentration in each water sample by its corresponding standard according to the guidelines laid down in the BIS and the result multiplied by 100.

$$qi = Ci/Si \times 100 \quad ...(2)$$

Where qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample (mg/L) and Si is the Indian drinking water standard for each chemical parameter (mg/L) according to the guidelines of the BIS [19]. For computing the WQI, the SIi is first determined for each chemical parameter by multiplying quality rating with relative weight, finally the summation of sub-index is used to determine WQI as per the following formula :

$$SIi = Wi * qi \quad ...(3)$$

$$WQI = \Sigma SIi \quad ...(4)$$

Where SIi is the sub-index of ith parameter; qi is the rating depending on concentration of ith parameter and n is the number of parameters. The excellent water to water unsuitable for drinking' as per table 3.

2.3 Spatial modelling and surface interpolation through inverse distance weighted

Spatial modelling (an extended module of ArcGIS 10.2)

Table 4. *Descriptive statistics of the concentrations of the water quality parameters in pre and post-monsoon season*

Water quality parameter	BIS drinking water standards	Minimum		Maximum		Mean		Standard deviation	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
pH	6.5-8.5	6.4	5.9	8.2	7.9	7.77	7.46	0.33	0.38
Alkalinity (mg/L)	200	98	98	324	287	216.59	193.53	50.98	54.92
Turbidity (NTU)	1	5	2	60	59	21.91	9.56	10.85	10.31
TH (mg/L)	200	45	33	121	98	69.16	54.50	15.79	14.19
EC (μS/cm)	2000	491.1	237.3	1254.8	1792.3	847.81	765.21	183.07	277.87
TDS (mg/L)	500	300	253	955	1091	541.59	496.16	154.64	154.61
Sulphate (mg/L)	200	75.41	54.56	313.5	205.66	100.49	85.63	42.87	25.03
Fluoride (mg/L)	1	0	0	1.1	1.04	0.38	0.38	0.33	0.33
Chloride (mg/L)	250	56.2	56.1	480.5	431.8	171.20	145.37	93.18	89.72
Nitrate (mg/L)	45	23.5	32.2	178.1	89.3	67.88	52.37	40.19	14.25
Phosphate (mg/L)	—	0.13	0.12	8.5	8.46	0.54	0.57	1.45	1.45
Potassium (mg/L)	—	3.8	1.5	20.3	29	8.23	8.05	3.62	6.08
BOD (mg/L)	—	4.2	3	184.1	213.8	24.00	15.29	36.00	36.81
DO (mg/L)	—	0	0	7.5	7.7	5.21	6.33	1.87	1.72
E. coli (MPN/100 mL)	0	2	2	46	45	11.31	8.13	9.87	8.51
WQI	—	180	135	2803	3078	647.63	392.28	548.62	527.42

was used to interpolate the spatial distribution of the surface water quality parameters. Inverse distance weighted (IDW) interpolation method was used to create different spatial distribution maps of GWQI. IDW is an algorithm used to interpolate data spatially or evaluation of observations between measurements. Each observation was projected in an IDW interpolation is a weighted average of the neighbouring sample points. Weights are computed by taking the inverse of the distance from an observation point location to location of the point being assessed [20,21]. The interpolation technique used by several investigators in their study was inverse distance weighted (IDW) method [22,23,24].

3. RESULT AND DISCUSSION

Surface water is storage of water on the ground or in a stream, river, lake, wetland and ocean. Surface water is naturally refilled by rainfall and naturally vanished through discharge to evaporation, transpiration and sub-surface seepage into the groundwater [25]. The accessibility of surface water in a watershed depends upon the rainfall within the watershed, storing capacity of the particular watershed, porousness of the soil, runoff features of the land, timing and duration of precipitation and the local evaporation rates, etc., [26]. Surface water quality is a significant factor that decides its usage for drinking and irrigation purposes [27]. Surface water quality monitoring and evaluation have become a critical problem because it affects human and aquatic life [28]. As per water quality status reviewed by Dandge the overall surface water quality of the Jalna district was poor, which could be due to high total dissolved solids, fluoride, sulphate, nitrate and *E. coli* concentrations exceeding the permissible limit [29]. In present study following outcomes were observed related to various surface water quality parameters. The physico-chemical characteristics of surface water samples in Bhokardan area were statistically analyzed and the results, such as maximum, minimum, mean and standard deviation parameters are depicted in table 4. The physical and chemical parameters of the analytical results of groundwater were compared with the standard guideline values recommended by the Bureau of Indian Standards for drinking and public health standards [19].

3.1 pH

The pH is the negative $\log_{10}$ of the hydrogen ion concentration stated in mol/L. Sørensen introduced the term pH in 1909. The letter, p, is used to represent the negative logarithm to the base_{10}. The pH scale from

0 to 14 covers all the hydrogen ion concentrations found in diluted aqueous solutions and biological systems [30,31]. Measurements of pH have been extensively used as a fast, exact level of the acidity of all the liquids [31,32]. A water having a pH of more than 8.5 could specify that the given water is hard. Hard water does not pose a health risk but can cause aesthetic problems and decrease consumption of water [34]. The pH value of samples from various sampling sites was in the range of 6.4-8.2 with an average of 7.8 during pre-monsoon. During post-monsoon season the pH was observed in the range of 5.9-7.9 with a mean of 7.5 which is slightly lower than pre-monsoon season. The results revealed that most of the water source is alkaline in nature. As per BIS the permissible limit of pH is 6.5–8.5 [19]. Almost all observed values for pH were well within permissible limit except for one site. The lower pH was observed near Shipora village, this may be attributed due to the seepage from molasses oxidation pond, anthropogenic activities like untreated sewage discharge in the study area.

3.2 Total alkalinity

Alkalinity of water mainly includes the sum of the carbonates, bicarbonates and hydroxides of magnesium, calcium, sodium and potassium [35,36]. The sources of alkalinity in freshwater watercourses is generally resulting from several sources, such as weathering of rocks and soil, salts, biological uptake and reduction of strong acid anions, evaporation and precipitation of minerals, atmospheric deposition of dust and industrial wastewater discharge [16]. In the present study, the alkalinity value was found in the range of 98-324 mg/L with an average of 216 mg/L during pre-monsoon while during post-monsoon season it was observed in the range of 98-286 with an average of 193.5 which is lower than pre-monsoon season. As per the permissible limit ofalkalinity is 200 mg/L as $CaCO_3$ [19]. Out of total samples, 66 and 50% of water samples showed beyond permissible limit for drinking during pre-monsoon and post-monsoon, respectively.

3.3 Hardness

Water hardness is the traditional measure of the ability of water to react with soap, hard water needs much more soap to produce a lather. Hardness levels above 500 mg/L are normally considered as aesthetically undesirable. There does not appear to be any considerable evidence that water hardness causes adverse health effects in humans [37,38]. In the present study area, total hardness values were observed in range of 45-121 mg/L with an average concentration of 69.2 mg/L as $CaCO_3$. The minimum value was observed at both Kumbahri and Hasnabad while maximum near Shipora village, during pre-monsoon period. Total hardness values were observed in the range of 33-98 mg/L with an average of 54.5 mg/L. Minimum value was observed at Padmavati dam while highest was observed at near Shipora village during post-monsoon period. Total hardness values were observed in all samples are well below the permissible limit of 300 mg/L as per drinking water standards [19].

3.4 Turbidity

Turbidity is typically expressed as nephelometric turbidity units (NTU). Turbidity can be defined as haziness or milkiness, or cloudiness and is caused by suspended particles, chemical precipitates, organic particles and organisms scattering light at more or less 90 degrees to the direction from which the light enters the sample [39,40]. The turbidity was analysed using turbidity meter and recorded in nephelometric turbidity units. The recorded turbidity in study area ranges from 5-60 NTU and 2-59 NTU in pre and post-monsoon season, respectively. Alllocations showed higher values of turbidity than permissible limit of 1 NTU prescribed by BIS during both pre and post-monsoon seasons [19]. The highest turbidity of 60 and 59 NTU was recorded near Shipora in pre and post-monsoon season, respectively. Turbidity values were highest in pre-monsoon as compared to post-monsoon season in the study area. Analogues trend was also observed by many researchers [41,42,43,44,45]. As turbidity affect rate of photosynthesis in aquatic plants, therefore, it is a significant factor affecting concentration of dissolved oxygen in the stream [46].

3.5 Chloride

Chloride is a significant anion in surface water and municipal wastewater. The salty taste developed due to chloride concentrations is in constant and depends on the chemical composition of the water. Most of the rivers and lakes have chloride concentrations of less than 50 mg/L and any noticeable increase may be indicated that water is contaminated with sewage [35,47]. In the present study, the maximum value of 480.5 mg/L of chlorides was recorded near Shipora village, while minimum value of 56.2 mg/L was observed at village Padamavati during pre-monsoon period. The maximum value of 431.8 mg/L was observed at Bhokardan while minimum value of 56.1 mg/L was observed at village Padmavati in post-monsoon period. The permissible limit of chloride in drinking water is 250 mg/L [19]. As per drinking water standards about 17% and 13% of samples were found above permissible limit in pre-monsoon and post-monsoon seasons, respectively.

Chloride is found in nearly all waters and is derived from a number of sources, increases the chloride concentration in freshwater is mainly due to urban runoff and sewage effluent. It also derives from various activities carried out in agricultural field as well as from many industrial activities [48,49,50,51]. Similarly, Mullaney reported chloride concentrations greater than the USEPA recommended aquatic criteria concentration for chloride of 230 at some sites is dominated by forested and urban land cover and agricultural landuse [52].

3.6 Fluoride

Fluorine is a common element that does not present in the elemental state in nature due to its highly reactive properties. The climate of the region and the chemical composition of rock minerals through which water circulates is responsible for the concentration of fluoride. It shares about 0.3 g/kg of the Earth's crust and occurs in the form of fluorides in several minerals principally the most common are fluorspar, cryolite, pyroxene, hornblende, biotite and fluorapatite [50,53,54]. The maximum natural level of fluoride reported is 2800 mg/L. Fluorides may also enter inland surface water because of industrial discharges [55]. The concentration of fluoride in surface water range from 0.01-1.1 mg/L with an average of 0.4 mg/L and 0.01-1 mg/L with average of 0.4 mg/L for pre and post-monsoon periods, respectively. The results revealed upto 6% and 3% of sampling locations showing high fluoride concentrations for pre and post-monsoon periods, respectively which is beyond the permissible limits of 1.0 mg/L set by BIS [19].

3.7 *Escherichia coli*

Escherichia coli (E. coli) is a sort of bacteria that act as significant water quality indicator. Presence of *E. coli* in surface waters indicate there has been contamination of faecal matter and existence of other disease-causing micro-organisms. When these pathogens are in a stream, they can infect humans through ingestion and causes various diseases, like diarrhoea, giardia, hepatitis and cholera [56,57]. In the study area, the observed range of *E. coli* was 2-46 MPN/100 mL and 2-45 MPN/100 mL in pre and post-monsoon season, respectively. The highest *E. coli* (46 MPN/100 mL and 45 MPN/100 mL) was observed in pre and post-monsoon season, respectively at Bhokardan. The *E. coli* were detected in all samples during both pre and post-monsoon seasons, which may be attributed to surface runoff and discharge of untreated sewage into the rivers and lakes, signifying that the *E. coli* contaminated water in the present study area was unsafe and required treatment before drinking.

3.8 Dissolved oxygen

Dissolved oxygen (DO) is one of the most vital parameters of concern with any type of aquaculture operation so, it is very significant to know variations of dissolved oxygen concentrations in surface water [58]. The presence of dissolved oxygen in aquatic systems is essential for the existence and growth of many aquatic organisms. Dissolved oxygen acts as an indicator of the health and geochemical value of surface water and groundwater systems [59]. Though the percentage of O_2 in the atmosphere is approximately 20%, it has very low solubility in water and its solubility declines with increasing temperature and salinity. A tropical freshwater fish pond at sea level with a temperature of 35°C will be at 100% oxygen saturation, with a DO level of 6.949 mg/L. Even if oxygen will diffuse into surface waters from the atmosphere at rates of 1-5 mg/L daily, the primary source of oxygen in most natural water bodies is photosynthesis process carried out by phytoplankton and aquatic macrophytes, which ranges from 5-20 mg/L daily [58,60].

The DO of the surface water samples was ranged from 0-7.5 mg/L with an average value of 5.2 mg/L and 0-7.7 mg/L with an average value of 6.3 mg/L in pre and post-monsoon season, respectively. The almost nil DO was recorded near Shipora village during both pre and post-monsoon seasons, which may be due to high BOD value at particular station. Dissolved oxygen was found highest in almost all the sites except near Shipora village, during post-monsoon season as cold water can hold more dissolved oxygen than pre-monsoon having high temperature. The dissolved oxygen values also depend on various factors, like temperature, inhabitants of zooplankton and phytoplankton, pressure and time of sampling [61].

3.9 Biochemical oxygen demand

The biochemical oxygen demand (BOD) is an amount of the biochemically oxidizable material present in the water sample expressed in terms of the oxygen required to decompose it [62,63,64]. Sources of biochemical oxygen demand include leaves, woody debris, dead plants and animals, animal manure, effluents from various industries, wastewater treatment plants, sewage treatment plants, feedlots and urban surface runoff [65]. Amongst the water quality parameters, BOD is one of the most significant and normally used parameters for assessing the level of water pollution [66,67]. The BOD of the surface water samples ranged from 4.2-184.1 mg/L and 3.0-213.8 mg/L in pre and post-monsoon season, respectively. The highest biochemical oxygen demand (213.8 mg/L) was recorded near Shipora village, during both pre and post-monsoon seasons, which may be due to surface runoff from molasses storage tanks as sampling site is near to sugar factory adjacent to village and discharge of untreated sewage into the stream, indicating there would be much organic matter present in the surface water. As a concern of other sites depicted high values of BOD is may be due to occurrence of high nitrate and phosphates. Nitrates and phosphates in the streams can contribute to high BOD levels. Nitrate and phosphates are plant nutrients and can cause plant life and algae to grow rapidly.

3.10 Electrical conductivity

Unpolluted water is not a good conductor of electric current. Increase in ions concentration increases the electrical conductivity of water. Normally, the concentration of dissolved solids in water is directly proportional to the electrical conductivity. Electrical conductivity measures the ionic process of a solution that allows it to transmit current [68]. In the present investigation values were observed for conductivity during pre-monsoon period ranging from 469.1-1254.8 μS/cm at 36 °C, the minimum conductivity value was observed at village Padmavati while maximum near Shipora village with 726.3-740.3 μS/cm, respectively. The average value of electrical conductivity was 847.8-765.2 μS/cm observed in pre and post-monsoon season, respectively. According to drinking water guideline of WHO, electrical conductivity value should not exceed 400 μS/cm. The current investigation indicated that all the sites depicted conductivity beyond drinking water guideline value. These results clearly indicate that water in the study area was considerably ionized and has higher level of ionic concentration activity due to higher concentration of dissolved solids.

3.11 Total dissolved solids

In rivers and lake water, TDS include calcium, chlorides, phosphorus, iron, nitrate, sulphur and constituent that will pass through a sieve with pore size of around two microns. The higher amount of TDS affects the water balance in the cells of aquatic organisms [65,69]. The concentration of TDS during pre-monsoon season was in the range of 300-955 mg/L with an average of 541.6 mg/L, while during post-monsoon season, the range was 253-1091 mg/L with an average of 496 mg/L. As per BIS the permissible limit of TDS is 500 mg/L [19]. The current investigation indicated that 50 and 41% of sites depicted TDS beyond drinking water standard value in pre and post-monsoon season, respectively. The occurrence of high total dissolved solids is due to the influence of anthropogenic sources, such as domestic sewage, septic tanks and agricultural activities. The increase in TDS in Marathwada region of Maharashtra may be due to high rate of evapotranspiration in the area, as it falls under the rain scarcity zone [70].

3.12 Nitrate

Nitrate is the most common nitrogen pollutant in raw water domestic supplies. In rural area farming and allied activities that include predominantly the application of huge amounts of fertilizers and animal manures are chief sources of nitrate pollution [71]. The nitrate level in surface water is usually low varies between 0-18 mg/L but can reach maximum levels because of agricultural runoff, refuse dumping site runoff, contamination with human and animal wastes. The concentration often varies with the season and may increase when the river is fed by nitrate rich aquifers [72]. A study was carried out by a group of researcher Xue to identify preliminary sources of nitrate in semi-arid river basins and they concluded that domestic sewage and agricultural activities are the main sources of nitrate in the surface water after analyses of hydrochemistry and isotopic compositions [73]. Similar investigation was carried out in Kenya on the impact of nitrogen fertilizer applications on surface water nitrate levels by Maghanga and arrived at an analogous conclusion [74].

The concentration of nitrate during pre-monsoon season was in the range of 23.5-178.1 mg/L with an average of 67.9 mg/L, while during post-monsoon season, the range was 32.2-89.3 mg/L with an average of 52.4 mg/L. As per BIS the permissible limit of nitrate is 45 mg/L [19]. The present investigation indicated that 75 and 72% of sites showed nitrate concentration beyond drinking water standard value in pre and post-monsoon season, respectively. It is significantly noted that the status report on water quality of water bodies and groundwater in Maharashtra for the year 2004-2005, maximum value of nitrate observed is 239 mg/L at Muthad village, taluka Bhokardan from Jalna district which is 9 times more than the BIS permissible limit [19]. It is also observed that 319 well waters have exceeded the BIS permissible limit in Maharashtra state [70]. Similar results were reported in CGWB and a group of researchers reported nitrate levels in rural as well as urban areas of Nagpur and Bhandara districts of Maharashtra, India by Taneja [75,76].

3.13 Phosphate

Phosphate is a limiting nutrient for primary producers in freshwater streams. Its abundance promotes cyanobacterial growth [77,78]. Phosphates in surface waters principally originate from sewage effluents containing phosphate based synthetic detergents, from industrial effluents or from urban and agricultural runoff where intensive application of inorganic fertilizers. In sewage, typically upto 40% of the phosphate comes from cleaners and about 50% from human excretion [35,79]. Phosphate concentration of surface water samples varied from 0.1-8.5 mg/L with an average value of 0.5 mg/L and 0.1-8.5 mg/L with an average value of 0.6 mg/L during pre and post-monsoon season, respectively. The maximum values of phosphate are principally due to storm water, urban runoff, runoff from agriculture field; washing activities might be contributed to the inorganic phosphate in surface water. Similar results were reported by Patel, Sahoo, Upadhyay [80,81,82]. Kharat observed high phosphate level of 192.2 mg/L in Godavari river from the Nashik district, Maharashtra state, India [83].

3.14 Sulphate

Sulphates occur naturally in several minerals, including barite, epsomite and gypsum. Sulphates and their products are generally used in the manufacturing of fertilizers, chemicals, paper, soaps, textiles, fungicides, pesticides, dyes, glass and astringents [84,85]. Sulphate concentration of surface water samples varied from 75.4-313.5 mg/L with an average value of 100.5 mg/L and 54.6-205.7 mg/L with an average value of 85.6 mg/L during pre and post-monsoon season, respectively. In the present study area, sulphate concentration in 97% of samples in both seasons is well below permissible limit of 200 mg/L prescribed by BIS [19]. The maximum sulphate of 313.5 and 205.7 mg/L was observed near Shipora village in pre and post-monsoon, respectively. Satone observed sulphate level of 150 mg/L in Wardha city, Maharashtra, India [86]. Studies by Caraco suggested that anthropogenically persuaded increases in sulphate concentrations of waters may have a double effect on phosphate cycling in lakes [87]. It was concluded that presence of sulphate in drinking water can also result in a noticeable taste; the lowest taste threshold concentration for sulphate is approximately 250 mg/L as the sodium salt. Sulphate may also contribute to the corrosion of water supply systems content of freshwater averages at 20 mg/L, ranging from 0-630 mg/L in rivers, lakes range from 2-250 mg/L and groundwater from 0-30 mg/L [85].

3.15 Potassium

Potassium is one of significant nutrients amongst the mineral cations required by plant in soil. The earth crust contains 2.4% potassium. It is mainly present in complex silicate components; some potassium is associated with organic material and clay portion of soil [88]. In natural water, potassium is added from rock, fertilizer, salt and soil through dissolution process. Potassium is a vital element in humans and is rarely, but always, found in drinking water at concentration that could be a concern for healthy humans. It is found extensively in the environment, including all natural waters. Adverse health effects due to potassium intake from drinking water are improbable to occur in healthy individuals [89]. Potassium occurs generally in all natural waters and other spheres of the environment, including. It is not considered necessary to establish a health-based guideline value for potassium in drinking water [40]. Potassium concentration of surface water samples varied from 3.8-20.3 mg/L with an average value of 8.2 mg/L and 1.5-29.0 mg/L with an average value of 8.1 mg/L during pre and post-monsoon season, respectively. The maximum potassium of 20.3 and 29.3 mg/L was observed near Shipora village in pre and post-monsoon, respectively. It may be due to surface runoff or seepage of molasses from molasses storing ponds and mixing of sewage to surface water from nearby villages. Analogues outcome observed in groundwater samples of Nanded city in Maharashtra, India [90].

3.16 Water quality index

It was observed that the WQI was very suitable for the categorization of the surface and groundwaters monitored [3]. The study carried by showed, the efficiency of water quality index to investigate and understand a dataset for effective evaluation of surface waters [91]. Tyagi studied of different types water quality indices, interpreted that the aim of WQI is to recommend a single value to water quality of a source [92]. Besides, interpretation of all important water quality parameters, WQI can reduce many parameters into a simple expression resulting in easy interpretation of water quality monitoring data for better understanding to layman. The WQI results showed that majority of the water sample fall under very poor and unsuitable drinking water category. The WQI assessment data significantly depicted that 97% of the water samples fall within the 'water not suitable for drinking purpose' and only 3% sample fall under 'very poor water' categories, none of the samples exhibited good and excellent quality in the study area during pre-monsoon period while 31%, 34% and 35% of the water samples exhibited 'water not suitable for drinking', 'very poor water' and 'poor water' class, respectively. None of the samples exhibited good and excellent quality in the study area during post-monsoon, like pre-monsoon pe-

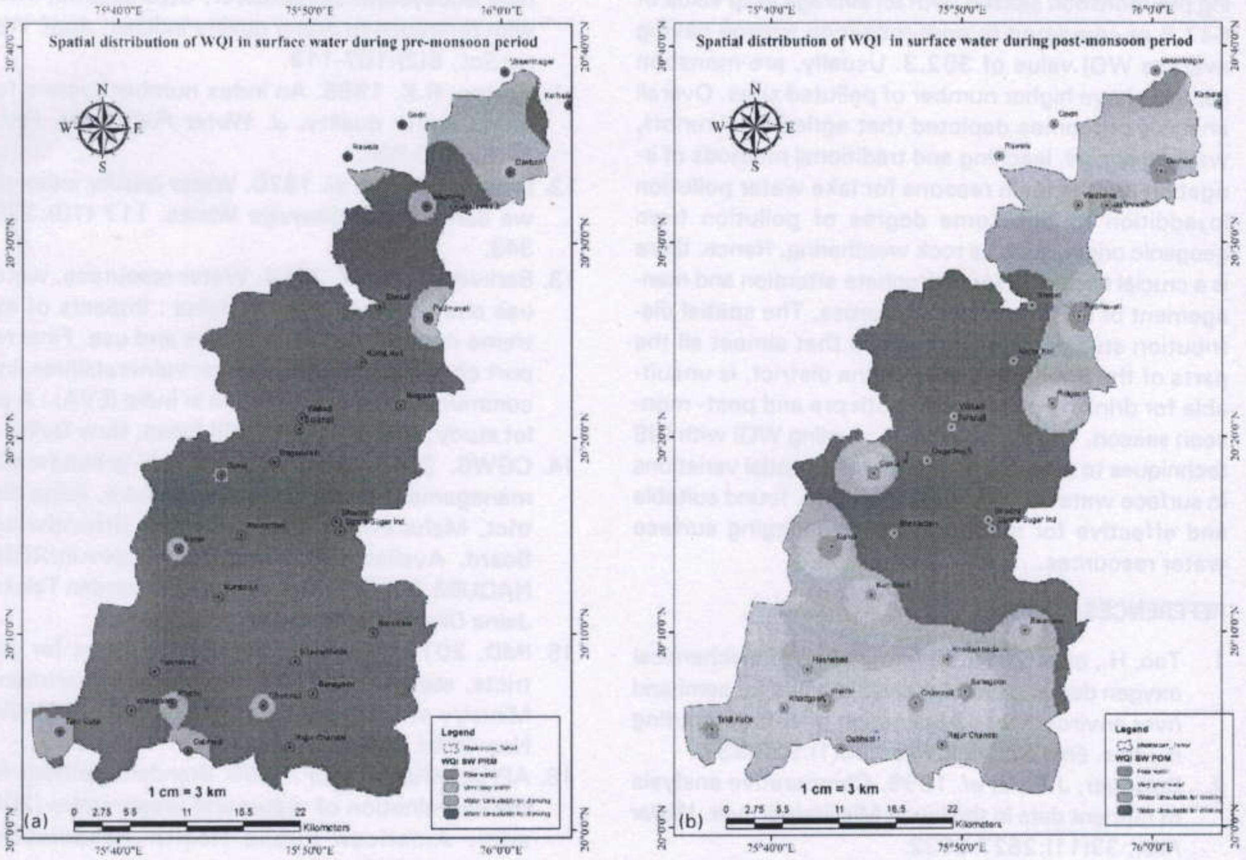

Figure 2. *Spatial distribution of water quality index in surface water during (a) pre-monson season and (b) post-monsoon season*

riod. Highest WQI values were recorded (2803 and 3078) near Shipora village during pre and post-monsoon period, respectively, whereas minimum WQI values were recorded as 180 at Padamvati village and 132 at Vasantnagar village during pre and post-monsoon period, respectively. The surface water quality was observed most worsened during pre-monsoon season as compared to post-monsoon season. Analogues trends were observed by various investigators and their co-investigators in different parts of India [93,94, 95,96]. The studies carried out by Bora also revealed similar seasonal trends in surface water quality as of present investigation [97].

The spatial distribution map of SWQI during pre and post-monsoon season presented in figure 2. The spatial map depicted that all part of the study area falls under the category of 'water unsuitable for drinking purpose' except Padmavati at northern part of the area which falls under the category of 'very poor water' during pre-monsoon, whereas most of sites from northern and southern part of the region shifted their category from very poor water to poor water and water unsuitable to very poor water during post-monsoon season. None of the sites falls under the good and excellent category.

4. CONCLUSION

Surface water quality and its suitability for drinking purposes in Bhokardan area have been evaluated. The water quality index data of the present study revealed that ajority of the water sample fall under very poor and unsuitable drinking water category. WQI assessment data showed that 97% of the water samples fall within the category of 'water unsuitable for drinking purpose', only 3% sample fall under 'very poor water' categories and none of the samples exhibited good and excellent quality in the study area during pre-monsoon season while 31%, 34% and 35% of the water samples fall within the 'water unsuitable for drinking purpose', very poor water and poor water category, respectively. Similarly as of pre-monsoon status of water quality none of the sample meet good and excellent quality in the study area during post-monsoon season. The water quality was found most worsened during pre-monsoon season with an average WQI value of 647.6 as compared to post-monsoon season having average WQI value of 392.3. Usually, pre-monsoon samples have higher number of polluted sites. Overall analysis outcomes depicted that agricultural runoff, waste disposal, leaching and traditional methods of irrigation are the main reasons for lake water pollution in addition to this some degree of pollution from geogenic origin, such as rock weathering. Hence, there is a crucial necessity for appropriate attention and management of surface water resources. The spatial distribution studies of WQI revealed that almost all the parts of the Bhokardan area, Jalna district, is unsuitable for drinking purposes in both pre and post- monsoon season. The application of coupling WQI with GIS techniques to evaluate sequential and spatial variations in surface water quality was, therefore, found suitable and effective for monitoring and managing surface water resources.

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