Assessment of water quality in the piped water supply system in Bhubaneswar city

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Abstract

Drinking water of right quantity and approved quality is the basic need for the development of any civilization. As per SDG 6 it is essential to provide equitable water in terms of quality and quantity to every citizen. Due to the huge growth of population along with the increase of infrastructure, educational institutions, industrial growth in the city of Bhubaneswar there is threat to the quality of the supply water. In this context the water sample has been collected from 67 wards of Bhubaneswar from the focused areas near to industry, market complex, educational institutions and near to the construction site in a particular ward. Nearly 15 water quality parameters have been tested and analysed using weighted arithmetic water quality index method. The study found that around 10.46% deviation in pH, 22.69% in hardness, 10.36% in conductivity, 19.16% in DO from the standard limit as per the guidelines of WHO. Also, it was concluded that no more threat to the heavy metal contamination like Lead copper and zinc in any of the samples. After discussion with Public Health Engineering Department, it was found that the deviation of the parameters is due to the ageing of the pipeline system which is under the consideration of their work. It shows that system needs to be monitored frequently for water quality related issues.

1. Introduction

Global water consumption has expanded and this value would continue to increase in the next 50 years. To ensure sustainable management, availability of water and sanitation for all by Goal 6 of the SDGs the provision of safe and affordable drinking water has to be achieved by 2030. It has been observed that cities like Bhubaneswar with large population depend more on surface water as opposed to ground water. Water quality can deteriorate during distribution due to a number of variables, including interactions within the bulk water or between the distributed water and pipe material (Kirmeyer et al. 2001). Furthermore, the breakdown of a disinfectant, like chlorine can deteriorate a distribution system's microbiological conditions, putting customer’s health at risk (Clark and Haught 2005).

Due to the rapid urbanization, people’s concern for health issues and higher aspiration level of the consumers in cities like Bhubaneswar, government has brought more focus on the water supply for human consumption (Odisha state water policy 2013). The domestic water demand is growing dramatically in Bhubaneswar because of the twin phenomena of population growth and rural-urban migration, the Industrialization, market segmentation, construction etc. are growing very rapidly. Now a days due to population growth an increased distance between population and water sources is observed, leading to fast expansions of various water networks. Potable piped water supplies to all people with 24/7 access to high-quality water at a cost that is reasonable, equitable, sustainable, and environmentally acceptable is the need of the hour. Improving quality and for preventing diseases are essential features of a good quality life.

Though the piped water supply has been implemented in Bhubaneswar a mid-sized city and state capital of Odisha, India, but question arises here that whether the equity in real sense has been achieved or not.

Since the public are from a variety of professional backgrounds, it is pertinent to create awareness about the calibre of supply water (Nasirian et al. 2007). In this sense, the water quality index (WQI), which was initially developed by Horton in 1965, has been broadly used by many researchers now a days. The WQI is an all-inclusive instrument that combines several supply water chemical constituents into a comprehensible format. This is accomplished by using an aggregation function and selectively weighing water quality factors (Abtahi et al. 2015). Moreover, the Water Quality Index (WQI) has demonstrated efficacy in disseminating water quality data to decision-makers, as evidenced by its extensive implementation in numerous research on water quality assessment (Batabyal; Chen et al. 2019).

The Water Quality Index (WQI), frequently employed by researchers in developing nations, utilizes the Weighted Arithmetic Water Quality Index Method (WAWQIM). This strategy is especially common in areas with inadequate infrastructure for comprehensive data collection (Yogendra & Puttaiah 2008). In this study, the Water Quality Index (WQI) was employed as a tool to examine the condition of the water and the variations in water quality.

As very few research has been done on quality of piped water supply system with an assumption that it is always very safe and good quality. In order to get the answer to this question we have measured some of the important quality parameters across 335 locations which are getting piped water supply. The Water quality parameters those have been studied includes hardness, pH, chloride, Dissolved Oxygen (DO), alkalinity, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), nitrate, sulphate, lead, copper and zinc.

1.1 Study Area

Bhubaneswar city is situated in 20° 12'N to 20° 25' N latitude and 85° 44'E to 85°55'E longitude across the main axis of eastern Ghats in Khordha district of Odisha on the western flange (Fig. 1). Bhubaneswar is the capital city of eastern state, Odisha. A rich heritage associated with the city, the spread of religious spots (Bhubaneswar is referred to as Temple City), contemporary acknowledgement as education and IT hub have contributed significantly to growth and publicity of the city.

The City of Bhubaneswar has been divided as per BMC (Bhubaneswar Municipality Corporation) in to three zones North zone with 21 wards, South-west zone with 21 wards and south-east zone with 25 wards. The Total population in all these wards are 8,43,402; of which, correspondingly, are 446,204 males and 397,198 females. (2011 census, BMC data). Estimated population in BBSR 9,39,818(2019), approximately 10,000 increase/Year. The population density is approximately 2131 persons per square kilometer with the Average male literacy rate of the city was 94.66%, while for female it is 88.73% during Census 2011. As announced by the Honorable Minister of Urban Development, Bhubaneswar topped the ranking of top 20 smart cities from among the 98 nominated cities. Bhubaneswar has been selected under smart city development plan by Government of India. As smart city, the primary mission is to fulfil desired aspirations of the citizens in smart and sustainable way. It is thus worthwhile to determine the extent of water quality detrimental across the wards of Bhubaneswar and intervene in a suitable way to ensure that SDGs are met.

Few research on quality measurement of supply water has been reported with the assumption that supply water quality may not get deteriorated, but present research has hypothesized that infrastructure aging, type of pipe material and combination of wastewater and drinking water may impact the quality of supply water and disturb the objective of desired quality stated by WHO and IS 10500 (2012). At sometimes these factors may lead to loss of potability of piped water supply. It was studied that most of the leak points are detected which are the damages and cracks due to the laxity of contractors during installation and pipe fittings. Also, most of the leak points were detected at connection points of couplings, elbows, valves and saddle clamps. Backfilling and bedding sand containing large and sharp stones cause the scratching and puncturing of the pipes and fittings (Turki Al Qahtan et al. 2020). Furthermore, it was also verified that the Water quality is impacted when synthetic materials are used in water pipes, particularly when trace organics are leached out by the flowing water. After testing, the presence of carbon tetra chloride (CTC), Toluene, chloroform, styrene, O-xylene were also detected in the water pipeline system (Shaikh et al. 2019). The variation of DO (Dissolved Oxygen) is directly related to the corrosion rates through redox couple reaction in the pipe line system. DO consumption relates to the pipe line materials like copper, steel and Iron (Vargas et al. 2010).

Applications of biochemical oxygen demand are used to calculate the total amount of oxygen consumed over an extended period of time by bacteria and other microorganisms involved in stabilising decomposable organic matter. The BOD test is widely used to assess the effects of effluents from sources such as pulp mills, municipal wastewater treatment facilities, feedlots, and vegetation used in food processing, which can include large amounts of biodegradable organics. According to Dey et al. 2021 an increased oxygen demand indicates the possibility of a rise in dissolved oxygen as the organic content in the sewage is oxidised by the macrobiotics. The extremely low oxygen demand indicates the presence of toxic or non-biodegradable contaminants in pure water. As the BOD content of drinking water ranges from 1 to 2 ppm hence the water is considered reasonably clean when its BOD content falls between 3 to 5 ppm, it is considered moderately clean. The BOD value of contaminated water is between 6 and 9 ppm. A high level of pollution is indicated by a BOD value of more than 10 ppm in water (Koda et al. 2017).

Corrosion and water quality degradation in water distribution systems are significantly influenced by the type of pipe used. Pipe system combination of unlined cast iron pipes and galvanised pipes were used to study characteristics of deposited scale and water quality in water distribution system. Bench testing conducted to assess water quality parameters such as pH, Dissolved Oxygen (DO), oxidation and reduction potential, alkalinity, conductivity, turbidity, colour, Fe^{2+} and Zn^{2+}. It was found that significant effect of pipe material over corrosion scale characteristics which leads to water quality variation. Iron mainly released as ferric particulate from pipe lines affect the pH and alkalinity level (Li et al. 2016). Learbuch et al. 2021 observed the impact of pipe material over the microbial population and development of biofilm under semi stagnant condition. It is deduced that pipe material plays an important role in the growth of biomass concentration, increase of specific microorganisms and the bacterial community composition in distribution system with unchlorinated drinking water.

2. Methodology

The study has been concentrated on piped supply water of north zone, south west zone and south east zone of Bhubaneswar which comprises of 67 wards as per Bhubaneswar Municipal Corporation (BMC). The supply water sample collection areas were emphasized keeping the following vulnerable areas in mind like industrial area, market complex, high density population, construction site and academic institutions.

The water quality parameters for Bhubaneswar city were tested zone wise in the laboratory as per guidelines stated in Bureau of Indian Standard IS 10500 (2012). Water samples were collected randomly from those areas mentioned from 67 wards which have been presented here as zone wise data. In Each ward 5 locations were selected keeping the view of the areas with the presence of more population, new ongoing constructions, academic or industry and also presence of market hub. The areas were selected keeping in view that more chance of contamination in comparison to other areas due to the multiusers in one place and also the chance of more wear and tear, corrosion, leakage etc. of the water pipe line system. The parameters were selected keeping the review of past authors in connection with the quality for potable water.

Water samples of supply water were collected with a sample size almost 335 and were kept around 5° C in glass bottles of 1 L for analysis. From each area 2 water samples were collected in a clean new 1 litre screw tight bottle and tested as per testing procedure in APHA (American Public Health Association) book. Some parameters like sulphate, nitrate, lead, copper and zinc have been tested from NABL accredited Laboratories of Bhubaneswar.

The physico chemical parameters like pH, DO, conductivity, alkalinity, hardness, chloride, TDS, BOD, sulphate, nitrate, lead, copper, zinc have been tested using the standard methods in APHA. Since lead, copper, zinc tested values are found in the range of below detectable limit so those values have not been included in the calculation and the values are presented in Appendix. The weighted arithmetic index approach was used to calculate the water quality index considering the average values for each parameter. (Brown et al. 1970).

2.1 Analysis of water quality parameters

2.1.1 Calculation of Water Quality Index

The WQI was determined using drinking water quality criteria recognized by the Bureau of Indian standard (BIS) and the World Health Organization (WHO). According to Oni and Fasakin (2016), the WQI approach is a useful tool for educating the public and policymakers about the quality of the water. It is a unambiguous tool that makes it possible to integrate water metrics that are crucial for the water quality. Given these conditions, the weighted arithmetic index approach (Brown et al. 1970) is utilized in this work to compute the WQI, which is the most appropriate technique to assess the impact of pollution on supply water.

The Water Quality Index (WQI) (Inayathulla & Paul 2013) is given as:

$$WQI = \frac{\sum_{i-1}^{n} q_i w_i}{\sum_{i-1}^{n} w_i},$$

Where,

qi = quality rating of i_{th} water quality parameter

wi = unit weight of i_{th} water quality parameter $\simeq$ 1; and qi relates the value of the parameter in polluted water to the standard permissible value i,e.

$$q_i = 100\left(\frac{v_i - v_{i0}}{s_i - v_{i0}}\right) k = \frac{1}{\sum_{i-1}^{n} 1/s_i}$$

Where, Vi = estimated value of the i_{th} parameter,

v_{io}= ideal value of the i_{th} parameter

s_i= standard permissible value of the i^{th} parameter as per IS 10500

In most of the cases, v_{io}=0 except for pH and DO

For pH, v_{io}=7 and for DO, v_{io}=14.6 mg/l.

The unit weight (w_i), which is inversely proportional to the values of the recommended standards is obtained

$$\text{as}: wi = \frac{k}{si}, \text{Where} k = \frac{1}{\sum_{i=1}^{n} 1/si}$$

The rating of the water quality using the above method is shown in Table.1

Table 1
Standard of Water Quality Index (Sinha, Kumar & Singh 2014)

Water Quality Index Level	Water Quality Status
0–25	Excellent Water Quality
26–50	Good Water Quality
51–75	Poor Water Quality
76–100	Very Poor Water Quality
> 100	Unsuitable for Drinking

2.1.2 Use of ArcGIS Software for identification of contaminated areas

ArcGIS software has been used to identify the vulnerable areas in different wards of Bhubaneswar. ArcGIS is a map data that provides foundation for mapping and analysis. It helps users understand the patterns, relationships, and geographic contexts of an area.

Table 2
Summary statistics of water quality parameters and comparison with IS 10500 (2012) standards

Water quality parameters	Zones	Min	Max	Avg	Standard Deviation	IS 10500 Guidelines	No. of samples exceeded the permissible limit	Percentage of samples exceeded the permissible limit
pH	N	5.56	8.61	7.66	0.70	6.5–8.5	12	11.65%
	S-W	5.56	8.61	7.73	0.69		14	13.33%
	S-E	6.23	8.59	7.56	0.48		8	6.40%
DO	N	5.91	8.38	7.50	0.52	6.5-8 mg/l	21	20.38%
	S-W	5.91	8.95	7.54	0.54		23	21.90%
	S-E	5.91	8.20	7.43	0.49		19	15.20%
Electrical Conductivity (EC)	N	58.25	480.30	255.42	90.63	300 mg/l	9	8.73%
	S-W	67.70	519.90	251.01	85.78		5	4.76%
	S-E	173.16	581.47	342.97	73.69		22	17.60%
Alkalinity	N	16.00	128.00	58.83	21.85	200 mg/l	-	-
	S-W	16.00	128.00	59.64	21.97		-	-
	S-E	22.00	78.00	46.05	13.75		-	-
Total Hardness (TH)	N	13.12	262.40	118.45	60.24	200 mg/l	15	14.56%
	S-W	13.12	229.60	116.96	57.98		10	9.52%
	S-E	98.40	268.96	186.09	40.78		55	44%
Chloride	N	18.46	87.03	33.86	11.65	250 mg/l	-	-
	S-W	18.46	87.03	34.29	10.76		-	-
	S-E	21.30	64.61	38.84	7.61		-	-
Total Dissolved Solids (TDS)	N	37.86	312.20	166.02	58.91	500 mg/l	-	-
	S-W	44.01	337.94	163.16	55.75		-	-
	S-E	112.56	377.96	222.93	47.90		-	-
Biochemical Oxygen Demand (BOD)	N	0.58	4.98	2.54	1.32	< 5.0 mg/l	-	-
	S-W	0.58	4.98	2.75	1.26		-	-
	S-E	0.55	4.60	2.39	1.00		-	-
Sulphate	N	3	30	15.57282	8.307334	200 mg/l	-	-
	S-W	3	30	17.14286	8.105588		-	-
	S-E	3	30	16.88	8.048843		-	-

Water quality parameters	Zones	Min	Max	Avg	Standard Deviation	IS 10500 Guidelines	No. of samples exceeded the permissible limit	Percentage of samples exceeded the permissible limit
Nitrate	N	0.2	24.9	11.80777	7.346517	45 mg/l	-	-
	S-W	3	30	16.41905	7.595268		-	-
	S-E	3	30	16.88	8.062858		-	-

3. Results and Discussion

The statistical summary of water quality parameters and their comparison with their permissible limits with percentage of samples deviated from permissible limit as per IS 10500 (2012) has been shown in Table 2. The water quality parameters in Table 2. have been plotted for three different zones using Box-whisker plot are illustrated in Figs. 2(a), (b), (c), (d), (e), (f), (g), (h), (i), and (j).

From the Table (2) and Fig. 2(a) it has been found that the Bhubaneswar piped supply water has a pH that ranges from 5.56 to 8.61 in both north zone and south- west zone while it is 6.23 to 8.59 in south-east zone. The average values of all the three zones are 7.66, 7.73 and 7.56 respectively, which indicates that the supply water is slightly alkaline. According to Sajil Kumar et al. (2013), hydroxides, carbonates, and bicarbonates primarily regulate the alkalinity of groundwater. It has been marked that the piped supply water samples exceeding beyond the permissible limit are 11.65% in north zone, 13.33% in south west zone and 6.4% in south east zone respectively. The standard deviation is 0.48 to 0.70 which indicates the value clustered tightly to the mean. Figure 3 represents the areas which are more affected in pH are Damana Area of ward No8 and Indradhanu market area of ward no 27 whose pH values are 8.61. Also, the areas which are acidic water has been detected in areas like Sriram Nagar of ward no 59, Swadhin Nagar of ward no 34 and Pancha Sakha Nagar of ward no 64 whose pH values are 5.56 ,5.74 and 5.56 respectively. It shows that the areas which are affected by this variation of pH are expected due to the factors like old age of supply pipes more than 40 years and also due to lack of maintenance.

One significant indicator of water quality and organic pollution in bodies of water is dissolved oxygen (DO). Dissolved Oxygen has the average value 7.5, 7.54 and 7.43 in north, south west and south east zone respectively. There is a deviation of DO values of 20.38%, 21.9% and 15.2% samples from the permissible range in the zones of North, South-west and South-east respectively as shown in Table.2. Also, it is found that there are some areas having DO values less than 6 mg/l, such as Sikharchandi Nagar of Word no 2, Shakti Vihar of ward no 20, Shree Vihar of ward no 22, Dumduma Phase 3 of ward no 64, Jharapada high school area of ward no 42 as presented in Fig. 4. Ordinarily, polyphosphates are coated inside municipal water supply pipes to shield the metal from oxygen exposure and thus results in high DO concentrations.

We understand that the electrical conductivity of water decides the minerals and salts that are dissolved in the water. Electrical Conductivity (EC) is from 58.25 μs/cm to 480 μs/cm in north zone, 67.7 μs/cm to 519.9 μs/cm in south west zone and 173 μs/cm to 581.47 μs/cm in south east zone of Bhubaneswar respectively. As per Fig. 5 it is observed that in north zone 8.73% samples, 4.76% in south west zone and 17.6% in south east zone are beyond the permissible limit. There are some areas having conductivity higher than 500 μs/cm are Sir Pu Bhoi Sahi of ward no 51, Nico Park Lake area of ward no 28, Bhoi Sahi of Ward no 28, Gridco Colony of ward no 29, Sarala Nagar and

Santoshi Nagar of Ward no 31 shown in Fig. 5. Runoff water, septic systems, animal wastes and sewage leaking into the ruptured old pipeline system are the probable causes of unusual level of electrical conductivity.

As per Fig. 2. (d), the data have been presented in graphical form with the help of box and whisker plot graph. The median of the lower half of the data set is known as the first quartile (Q1). The midway number of a data collection that splits it into two equal sections is called the median which is represented as Q2 and the median of the upper half of the data is known as the third quartile (Q3). In north zone the first quartile (Q1) is 43.2, the median is 58.96, and the third (Q3) is 68.7. For south west zone Q1 is 53.4, Q2 is 59.64 and Q3 is 64.3. For south east zone Q1 is 43.05, Q2 is 45.7 and Q3 is 47.85. From the graph it can be concluded that north zone has a large variation i.e. 25–75% areas deviated with high alkalinity values as compared to south west zone and south east zone. As per Fig. 6, it has been found that no areas are affected by alkalinity.

Chloride is non-reactive by nature; it typically enters supply water systems through soil erosion caused by potash fertilisers and animal and human waste (Yousuf et al. Citation 2012). As per Fig. 2(f) in North zone the mean is 33.86 mg/l, 34.29 mg/l in south west zone and 38.84 mg/l in south east zone. The standard deviation of Chloride is 11.65 for north zone, 10.76 for south west zone and 7.61 for south east zone. As per Fig. 8, there is no sign of deviation from the permissible limit.

As per Fig. 2 (h), the mean value in the three zones varies from 2.39 to 2.75. This indicates a relatively consistent range of values across the zones. Additionally, according to Fig. 10, all of the BOD (Biochemical Oxygen Demand) values fall within the allowed range. This suggests that the water quality in the measured zones meets the specified standards or regulatory requirements, affirming the overall environmental health in those areas."

As per IS-10500-2012, the range for Sulphate is 200 mg/l. Beyond 400 mg/l the water is harmful and cause disease if used for consumption. The dissolution of minerals, atmospheric deposition, and various human sources (fertiliser, mining, etc.) are the sources of sulphate. The high sulphate levels found in many global aquifers are largely due to gypsum. The average value ranges between 15.57 mg/l to 17.14 mg/l in the three zones of Bhubaneswar. Figure 11 represents that no sulphate content is present in Bhubaneswar.

According to IS10500-2012, the nitrate range is 45 mg/l, which is the desired level, and all the samples are with in the limit. Maximum value observed is 30 mg/l in both south east zone and south west zone which is presented in the Fig. 2 (j). The high rates of precipitation that promote fertilizer infiltration are responsible for the high NO_3^- values in the source of supply water (Wagh et al. 2017b, 2018b). High concentration in nitrate causes blue baby syndrome. Figure 12 indicates that Bhubaneswar supply water is safe from Nitrate contamination.

3.1 Water Quality Index and its Analysis

Table 3
Water quality Index status of supply water in different zones of Bhubaneswar

Water Quality Status	North zone	South-west zone	South-east zone
Excellent Water Quality	23.81%	9.53%	28.58%
Good Water Quality	76.19%	90.47%	71.42%
Poor Water Quality	-	-	-
Very Poor Water Quality	-	-	-
Unsuitable for Drinking	-	-	-

From Table 3. it can be observed that water quality is of excellent and good condition has been found in the supply water of north, south-west and south-east zone of Bhubaneswar. Highest percentage of excellent water quality has found in south-east zone of Bhubaneswar i.e. 28.58%, while lowest percentage has found in south-west zone i.e. 9.53%. Highest percentage of good water quality i.e. 90.47% has found in south west zone of Bhubaneswar. While north zone and south east zone shows 70–80% of good water quality index. No sign of poor, very poor and unsuitable water quality index has found in all the three zones of Bhubaneswar.

It is evident from Fig. 13 that certain regions of Bhubaneswar have good drinking behaviour scores in terms of water quality index. One outlier is formed with a value of 11 belongs to ward no. 17 of north zone of Bhubaneswar which is highly deviated from the normal values. North zone shows median 30.4, south-west zone shows median 33.2 and south west zone shows median value 28.5 which indicates that on an average south west zone has better water quality as comparison with other two zones.

4. Conclusion

The above study area which has been focused here as per the piped supply water of BMC in total 67 wards of north zone, south west zone and south east zone of Bhubaneswar is safe for human consumption at present condition. The deviation which has been identified in some parameters such as pH, Dissolved Oxygen, Electrical Conductivity and Total Hardness is due to the old age pipeline system, effects of corrosion and also lack of proper maintenance. As per the view of PHED (Public Health Engineering Department) of Bhubaneswar the pipelines are getting replaced phase wise seeing the feasibility of the areas. The quality deterioration of drinking water in supply pipe lines of Bhubaneswar needs a periodical survey to check the further deterioration and fulfill the demand of SDG6.

Declarations

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Author Contribution

All authors contributed to the study conception and design. Material preparation, data collection done by Mr. Ashok Kumar Tarai, research scholar and analysis were performed by Dr. Kshyana Prava Samal. The manuscript was prepared by Dr. Kshyana Prava Samal. All authors read and approved the final manuscript.

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Data Availability

The data that support the findings of this study are available from the corresponding author, Kshyana Prava Samal, upon reasonable request. The data are not publicly available due to privacy concerns. Access to these data may be granted after completion of a data access agreement and approval by the Institutional Review Board. The data are stored in the repository maintained by the School of Civil Engineering at KIIT Deemed to be University, Bhubaneswar, Odisha. For inquiries regarding access to the data, please contact Kshyana Prava Samal at kshyanaprava.samalfce@kiit.ac.in or via mobile at +91-7326996764.

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Figures

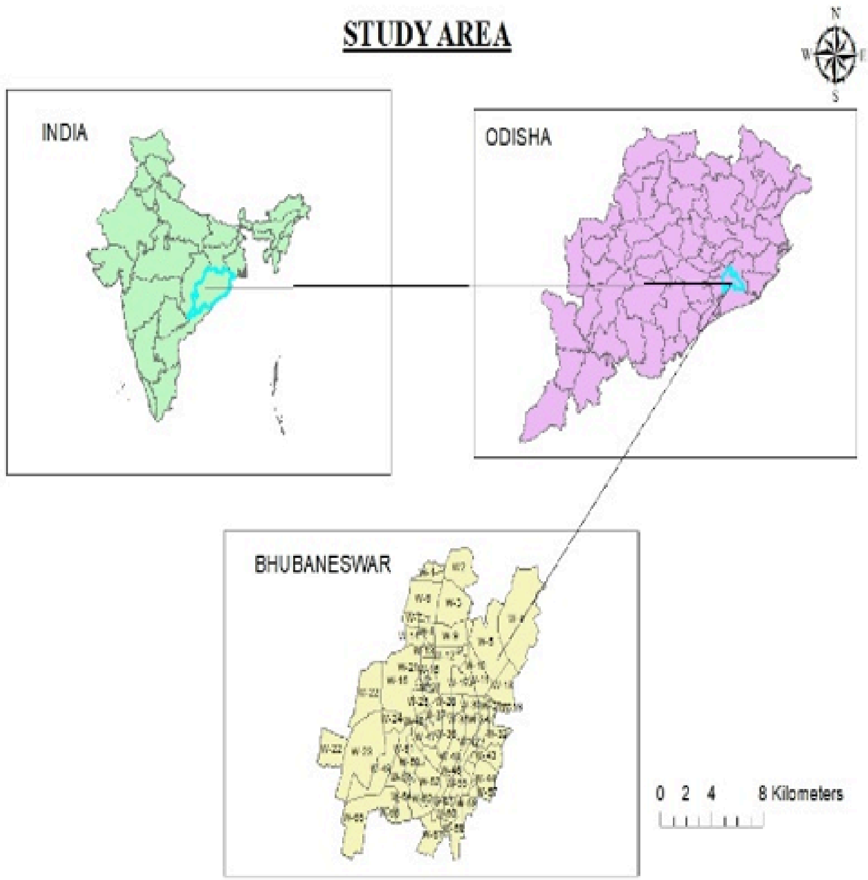

Figure 1

Bhubaneswar Index map

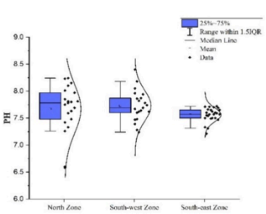

Figure 2 (a). Box-whisker plot represents comparison pH

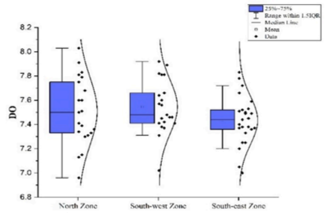

Figure 2 (b). Box-whisker plot represents comparison DO

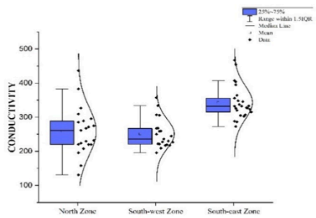

Figure 2 (c). Box-whisker plot represents comparison electrical conductivity

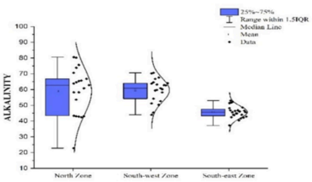

Figure 2 (d). Box-whisker plot represents comparison alkalinity

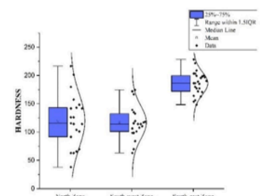

Figure 2 (e). Box-whisker plot represents comparison hardness

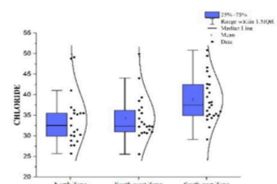

Figure 2 (f). Box-whisker plot represents comparison chloride

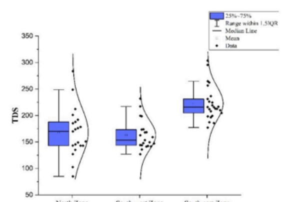

Figure 2 (g). Box-whisker plot represents comparison TDS

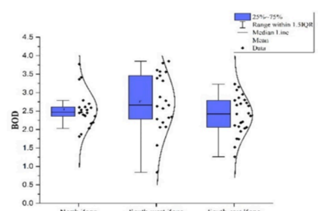

Figure 2 (h). Box-whisker plot represents comparison BOD

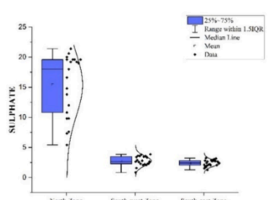

Figure 2 (i). Box-whisker plot represents comparison sulphate

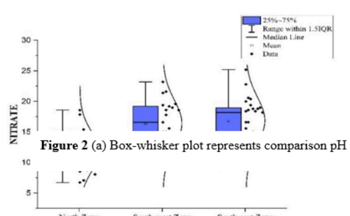

Figure 2 (j). Box-whisker plot represents comparison nitrate

Figure 2

See image above for figure legend

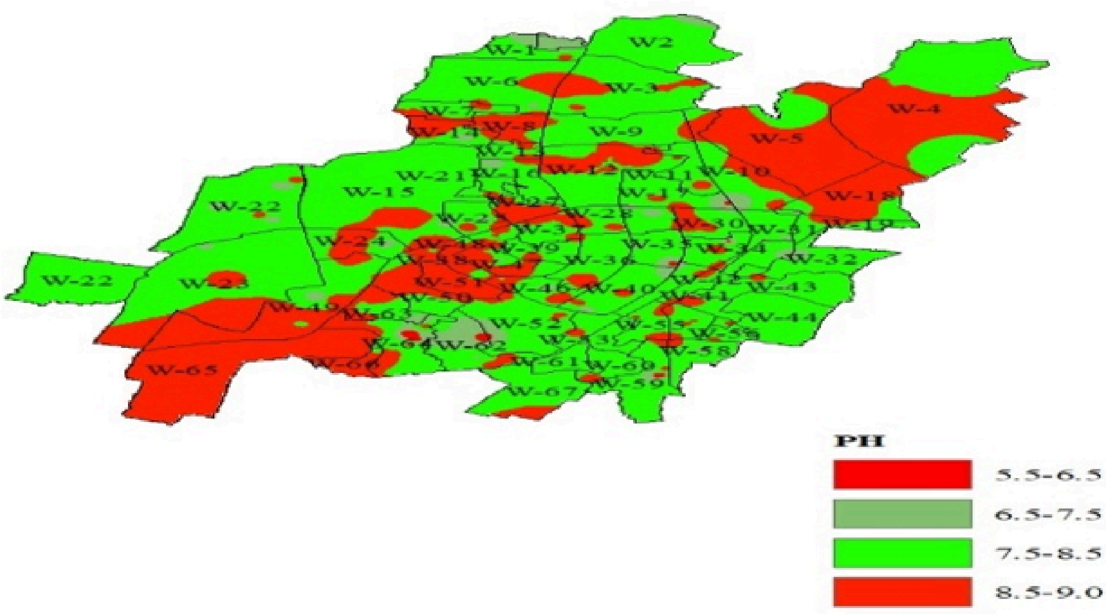

Figure 3

Ward wise pH in supply water of Bhubaneswar

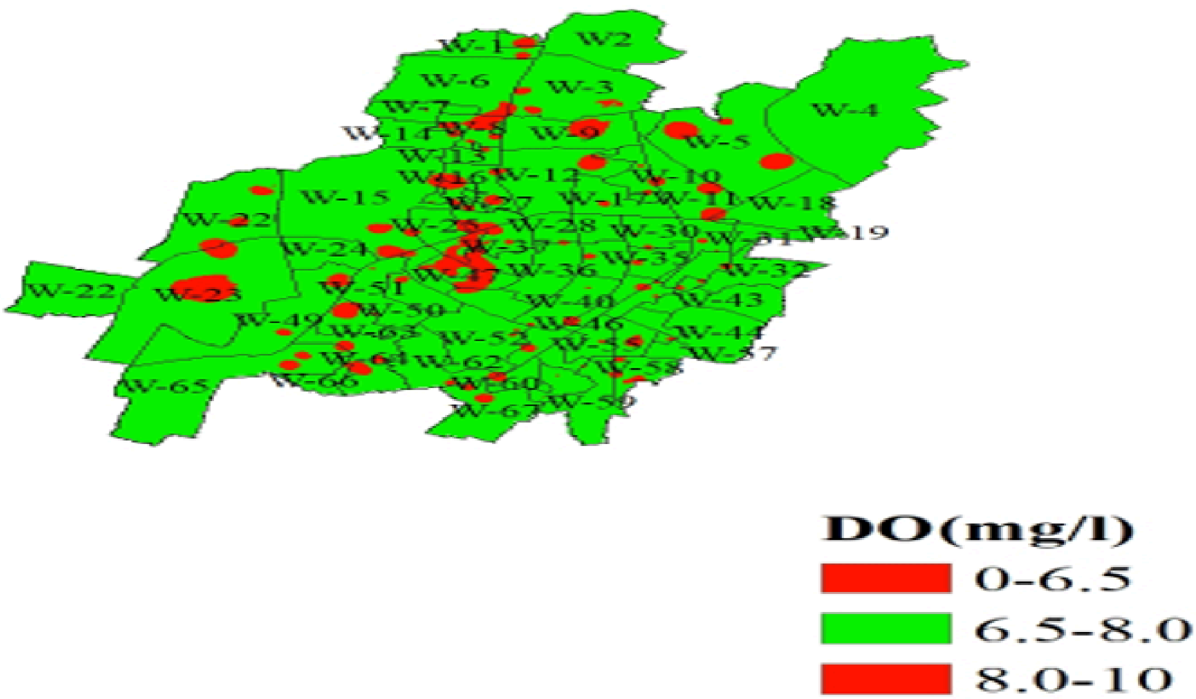

Figure 4

Ward wise Dissolved Oxygen in supply water of Bhubaneswar

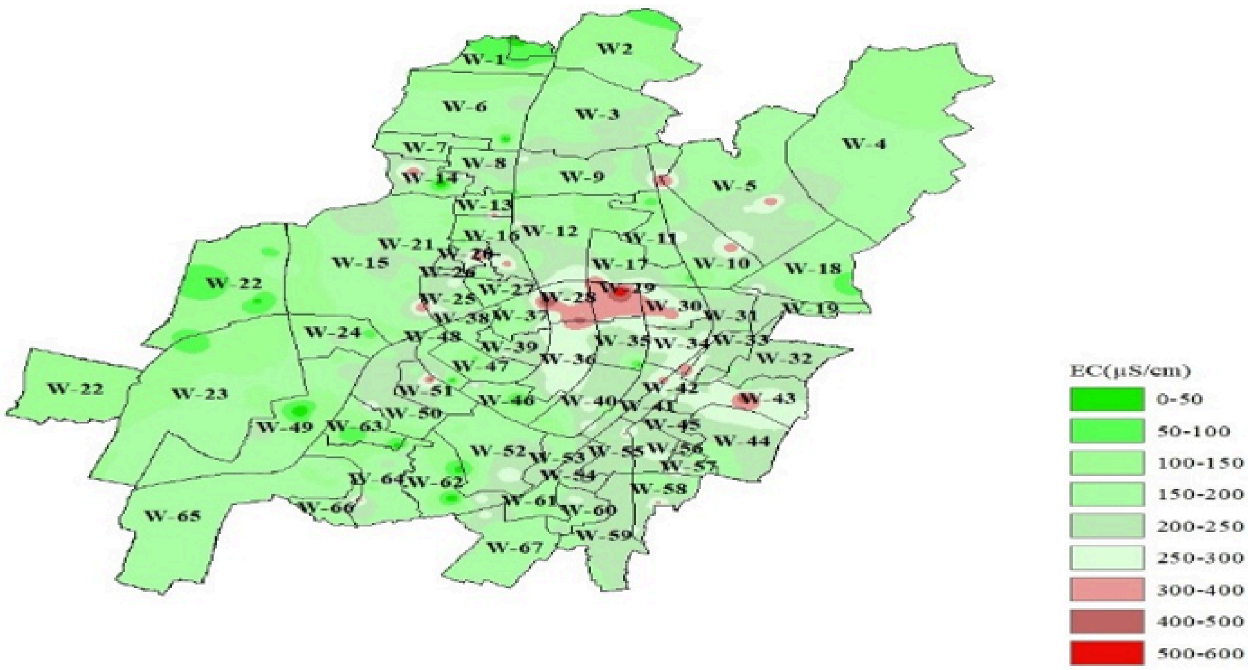

Figure 5

Ward wise EC in supply water of Bhubaneswar

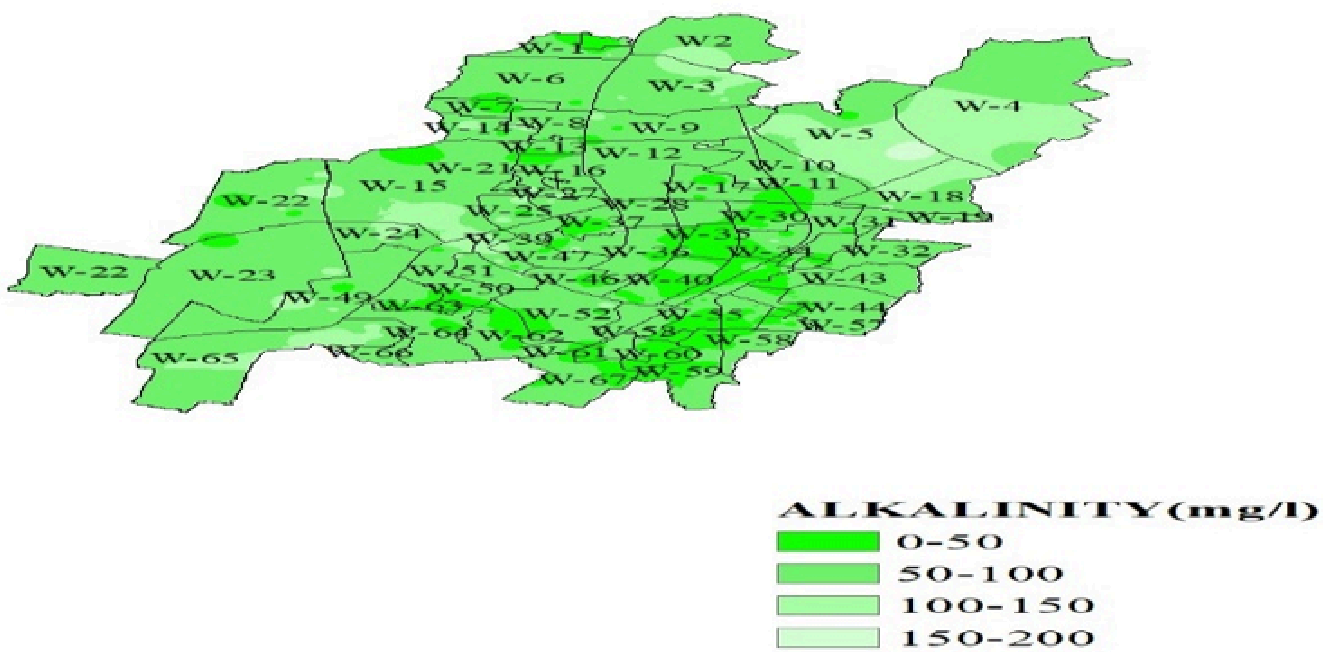

Figure 6

Ward wise alkalinity in supply water of Bhubaneswar

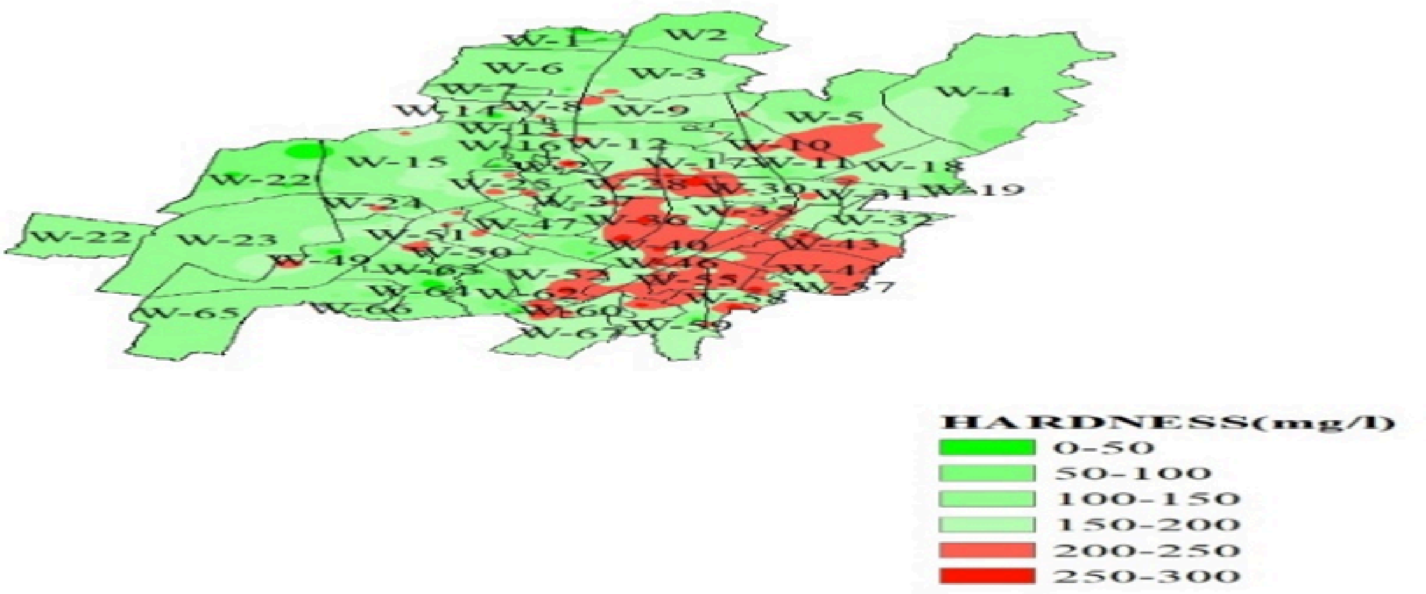

Figure 7

Ward wise Total Hardness in supply water of Bhubaneswar

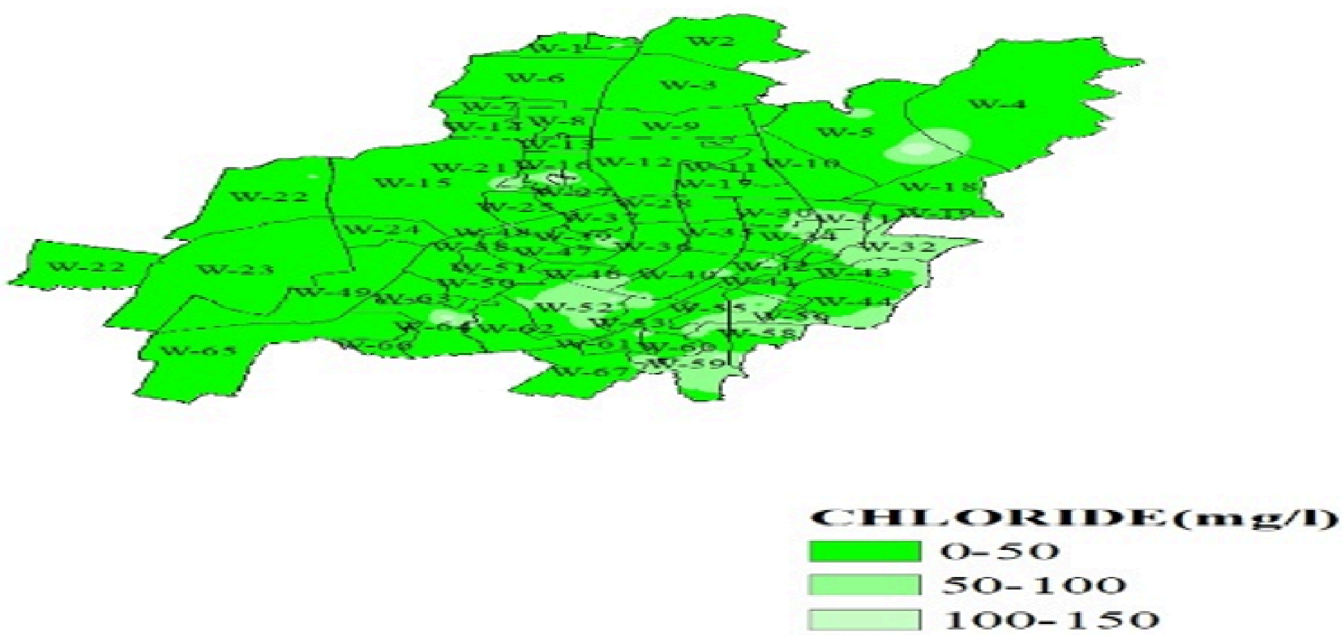

Figure 8

Ward wise chloride in supply water of Bhubaneswar

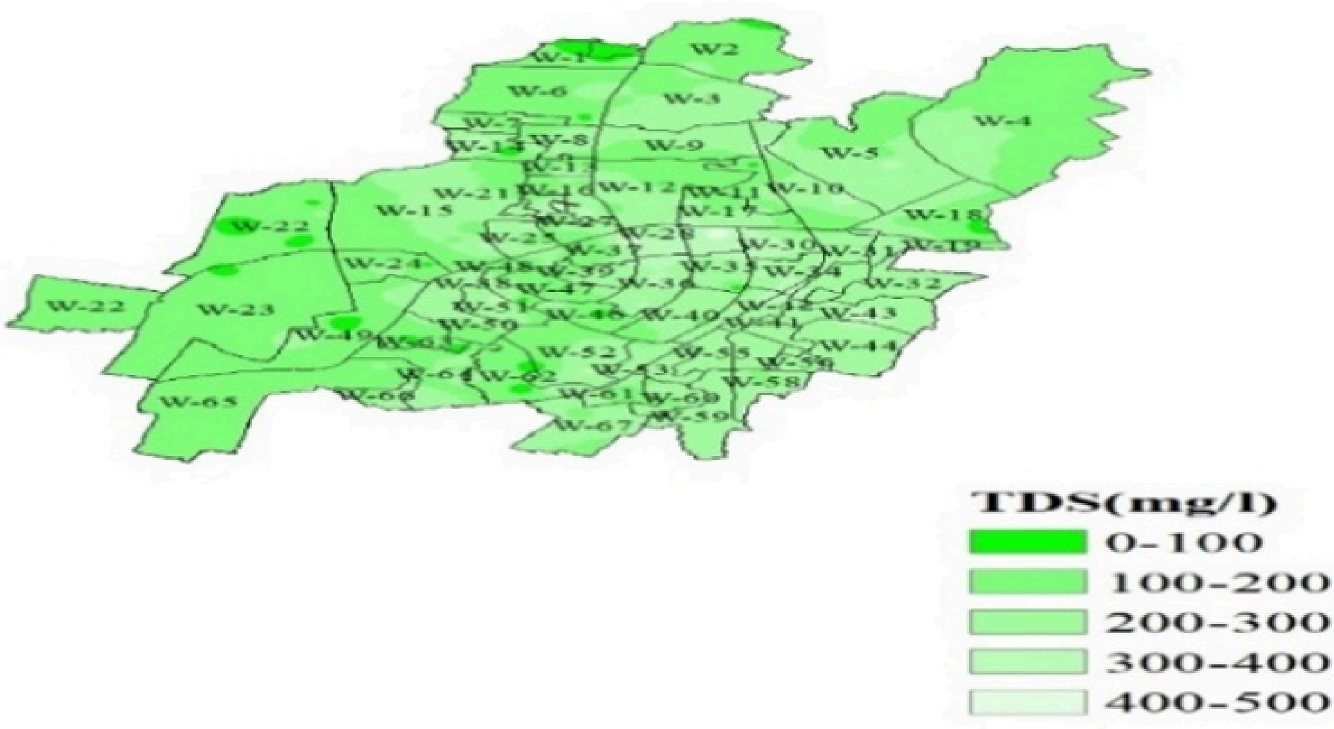

Figure 9

Ward wise Total Dissolved Solids in supply water of Bhubaneswar

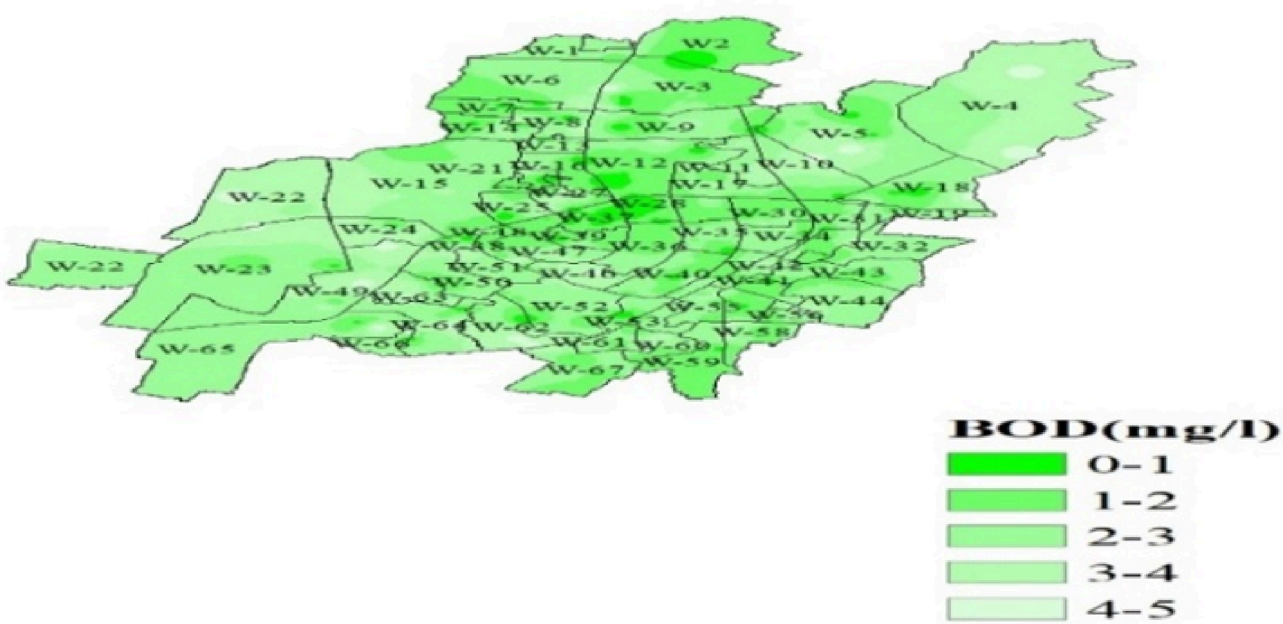

Figure 10

Ward wise Biochemical Oxygen Demand in supply water of Bhubaneswar

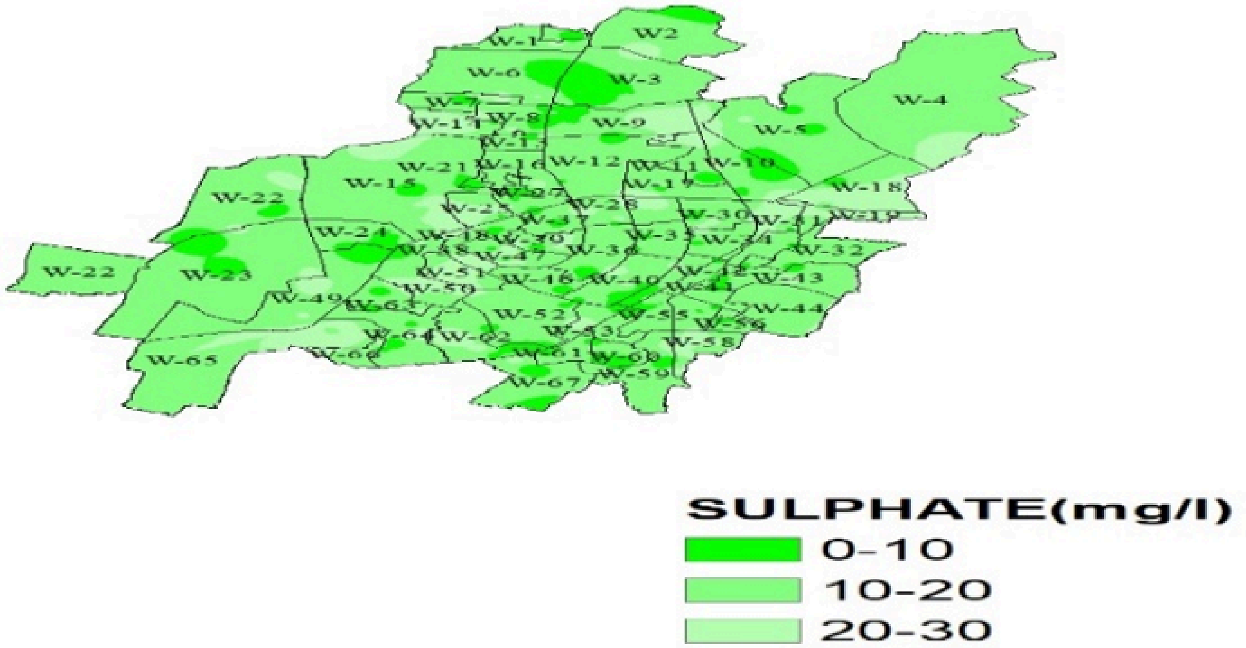

Figure 11

Ward wise sulphate in supply water of Bhubaneswar

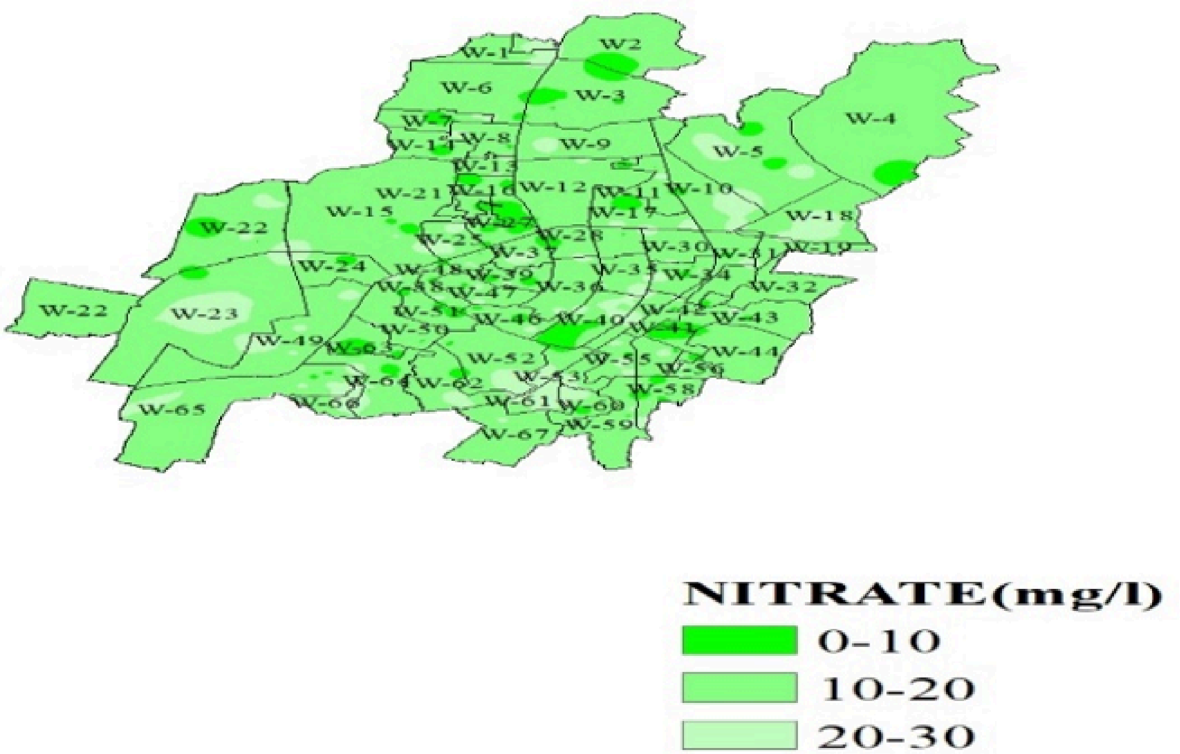

Figure 12

Ward wise nitrate in supply water of Bhubaneswar

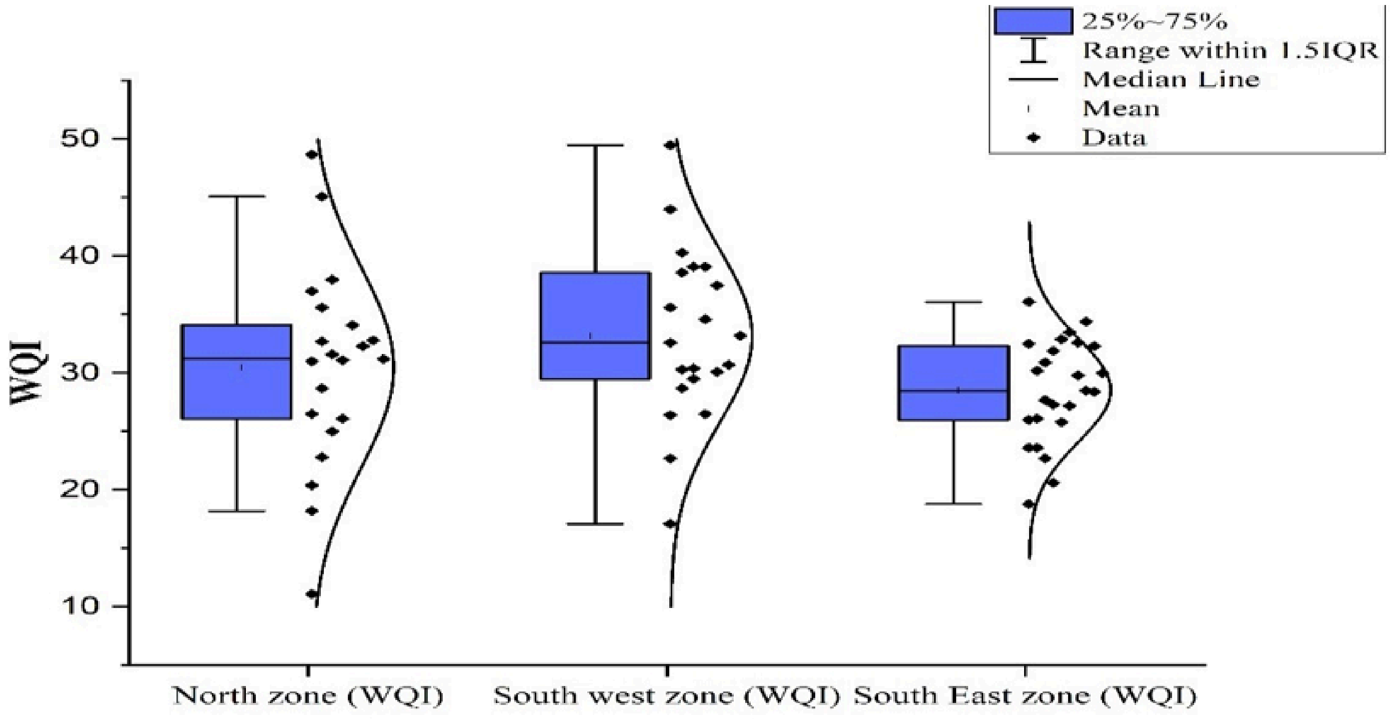

Figure 13

Box and whisker plot for Water Quality Index of supply water between north zone, south west zone and south east zone of Bhubaneswar

Supplementary Files

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- APPENDIX.docx