

Remote Sensing and GIS Techniques for Evaluation of Groundwater Quality In Smart City Bhubaneswar, Odisha, India

Susanta Kumar Choudhury ¹, Prof. (Dr). G. Sunpriya Achary ² and Prof. (Dr). V. Madhava Rao ³

¹Research scholar, Department of Civil Engineering, School of Science & Technology, GIET University, Gunupur, Odisha, India

²Associate Professor (Chemistry), Department of Basic Science, Gandhi Institute For Technology (Autonomous), Bhubaneswar, Odisha, India

³Research Professor, Department of Civil Engineering, GIET University. Gunupur, Odisha, India

ABSTRACT:

Groundwater quality in Bhubaneswar has special significance and needs great attention of all concerned because it is the major alternate source of domestic, industrial and drinking water supply. The present study monitors the ground water quality. Physico-chemical analysis data of the groundwater samples collected at predetermined locations forms the attribute database for the study, based on which, spatial distribution maps of major water quality parameters are prepared using Arc-GIS software. Thematic maps for the study are prepared by visual interpretation of SOI toposheets on 1:50,000 scale using Arc-GIS software (Ver.10.3). Water Quality Index (WQI) was then calculated to find the suitability of water for drinking purpose. The study revealed that the groundwater is suitable for drinking purpose. Hill-Piper diagram that the groundwater in the region of study does meet the "Indian Standard (IS)-10500:2012" for potable water.

Keywords: Remote Sensing & Geographical Information System (GIS), Groundwater Quality, Water Quality Index (WQI), Spatial Distribution, Correlation, Hill-Piper Diagram

1. INTRODUCTION:

Fresh water is one of the basic requirements for sustenance of life. The human race through ages has strived to locate and develop it. Water, a vital source of life in its natural state is free from pollution but when man tampers the water bodies it loses its natural conditions. Groundwater has become an essential resource over the past few decades due to the increase in its usage for drinking, irrigation and industrial uses etc. the quality of ground water is equally important as that of quantity. The urban environment quality is deteriorating day by day with the large cities reaching saturation points and unable to cope with the increasing pressure on their infrastructure. Bhubaneswar, the capital city of Odisha is facing a rapid change

in the environmental quality. Rapid urbanization brings with it many problems as it places huge demand on land, water, housing, transport, health, education, etc. [1]. Environmental pollution has reached alarming levels in the last 5-6 years mainly due to industries and automobiles. This rising population density will continue to have an impact on the quality and quantity of local water resources.

Remote sensing and GIS are effective tools for water quality mapping, modeling and environmental change detection [2]. GIS can be a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale [3] keeping this in view,

we have integrated Remote Sensing, GIS and field studies for the evaluation of ground water quality of the Bhubaneswar city. There is an urgent need to have a firsthand assessment of the prospective ground water quality in Bhubaneswar.

2. GEOLOGY AND HYDROLOGY OF THE STUDY AREA:

The city of Bhubaneswar, Odisha, may be found in the Bhubaneswar Block in the district of Khurda. It is between 20°12'N and 20°25'N, and 85°44'E and 85°55'E in geographic coordinates. Location on toposheets 73 H/15 and 73 H/16 from the Survey of India (1:50,000 Scale) (As per Central Ground Water Board, South Eastern Region, Bhubaneswar, Odisha). According to the results of the 2011 Census conducted by the Government of India, Bhubaneswar is classified as a Class I Urban Agglomeration and a City. Bhubaneswar, the city, is part of the Bhubaneswar Urban Region and is managed by the Municipal Corporation. Bhubaneswar is home to 886,397 people. There are 468,577 males and 417,820 females in total. (Source: Census, Government of India, 2011).

Although Bhubaneswar Municipal Corporation's (BMC) municipal territory is just 186 sq. km., the city master plan area extends up to 233 sq. km. [Source: Bhubaneswar Municipal Corporation(BMC)]. The 68 wards that make up the city are the basic administrative units. As a whole, the city rises 45 meters above mean sea level. The city lies 435 kilometers south of Kolkata, on the South Eastern Railway line between Howrah and Chennai. The major cities of Kolkatta, Chennai, Hyderabad, and Visakhapatnam can all be reached quickly and easily from Bhubaneswar because of the city's convenient access to highways, railways, and an airport. The city is crossed by NH-16 and NH-203. A map showing where exactly Smart City Region Bhubaneswar (BMC) may be found (Fig-01).

Climate in the study area is humid subtropical.

After the raining season of June through September, when the South-West Monsoon produces an average of 1604.26 mm of precipitation (1981 to 2020), comes the dry seasons of early November through May. Monthly averages are consistently warm, ranging from 21.1% to 26.4% Celsius. The highest mean temperature reaches 37.3 °C just before the rainy season begins, while the lowest mean temperature drops to 15.52 °C. The area has eastern coastal plains, along the axis of the Eastern Ghats mountains topography with its elevation generally between 15 meters and 60 meters above the mean sea level (CGWB, Bhubaneswar-2010).

Western and central Bhubaneswar are characterized by undulating uplands, whereas the eastern half of the city has a relatively level topography with a gentle inclination towards the east or south east. (Fig- 02). The East Coast Railway line serves as a rough dividing line between the aforementioned physical configurations. "Lateritic cover is found in the highland areas, whereas alluvial cover is predominating in the gently sloping slopes, with a thin lateritic cover in certain places. Hilltop outcrops composed of the Athgarh Formation, an Upper Gondwanan shale-and-sandstone series, dot the western highland regions. The city of Bhubaneswar is supported by rocks that are both Upper Tertiary and Quaternary in age. The Athgarh Formation of the Upper Gondwana Group is a shale-sandstone series that is part of the Upper Tertiary rocks. Laterites and alluvial deposits are two examples of the Quaternary deposits.

In much of the city, the Athgarh Formation is thicker than 200 metres. Laterites and alluvial deposits are the primary components of the Quaternary igneous and sedimentary formations. Mainly found in the central and western areas, the laterite and lateritic gravels provide a capstone over the country rocks. Laterites have an average thickness of 4–5 m and a maximum thickness of 12–13 m in isolated areas.

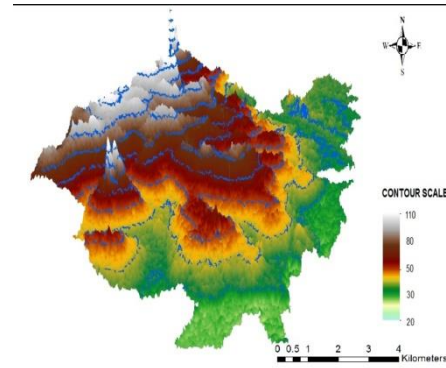
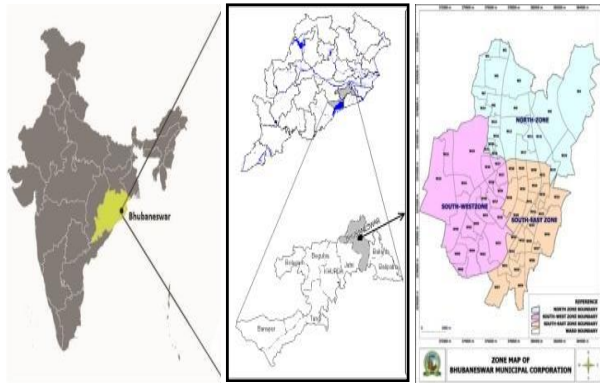


Fig-01: Map of Smart City Region Bhubaneswar (BMC), Odisha. Bhubaneswar.) Fig-02. Relief Map of Bhubaneswar

Athgarh formation aquifer systems are mostly composed of sandstones, both at shallow and deep depths. Shale mostly forms phreatic aquifers, which are only marginally effective. The lateralized layer begins at an average depth of 5 to 6 meters and continues to a depth of 12 to 15 metres in the weathered zone. In the western and west-central parts of the city, only phreatic/shallow unconfined (dug well zone) laterite aquifers and, on rare times, seasonal (perched aquifers) laterite aquifers form, each of which stores water until January or February. The typical depth of the aquifers formed by laterite in the west is 10–14 metres, and they keep water virtually continuously flowing through them. Phreatic aquifers have an average depth to water level of around 4.77 mbgl, with a range from 1.22 mbgl to a high of 11.30 mbgl in 2009. Phreatic aquifers are typically found at a depth of 4.38 metres below ground level, with a post-monsoon depth to water level ranging from 1.08 metres below ground level to a maximum of 9.02 metres below ground level (2009).

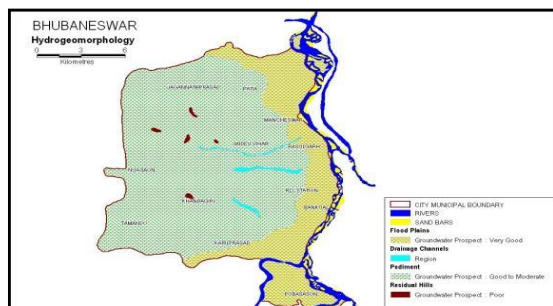


Fig-03 : Hydrogeomorphological Map of Study Area.

3. MATERIALS AND METHODOLOGY

• SAMPLE COLLECTION AND LABORATORY ANALYSIS

The research was carried out at nine (9) different locations all around the Bhubaneswar smart city (BMC). Between May 2020 and November 2020, we collected 18 samples for cation and anion analysis from two sets of one-liter HDPE bottles. (Pre- Monsoon & Post-Monsoon).

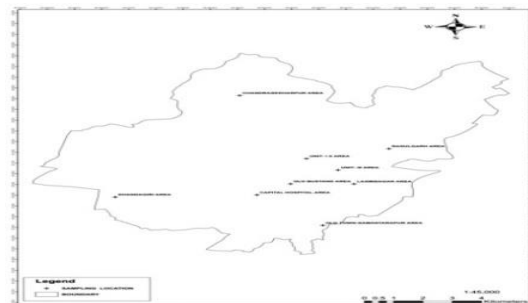


Fig-04: Map of the Sampling Locations in the Study Area Smart City Region Bhubaneswar (BMC), Odisha.

The samples were obtained after the bottles

were washed and rinsed with the water that would be collected in them. The boreholes were left to run for about three (03) minutes before to the collection. Cation level samples were obtained and immediately stabilised with diluted hydrochloric acid. All samples were kept

cool and tested as soon as possible after collection. Major water quality indicators were measured in accordance with APHA standards, including pH, EC, TDS, TH, Ca²⁺, Mg²⁺, Na⁺, K⁺, CO₃²⁻, HCO₃⁻, Fe, Cl⁻, SO₄²⁻, and NO₃²⁻, F.

Location	Longitude	Latitude	Symbol
Khandagiri Area	85°46'45.1 2"	20°15'24.8 4"	L1
Old Town-Samantarapur Area	85°50'34.4 4"	20°14'05.6 4"	L2
Laxmisagar Area	85°51'08.6 4"	20°16'01.2 0"	L3
Chandrasekharpur Area	85°49'02.2 8"	20°20'01.0 2"	L4
Capital Hospital Area	85°49'35.7 6"	20°15'30.6 0"	L5
Old Bus stand Area	85°49'58.8 0"	20°16'01.5 6"	L6
Unit- I X Area	85°50'16.4 4"	20°17'12.4 8"	L7
Unit- Iii Area	85°50'51.0 0"	20°16'40.4 4"	L8
Rasulgarh Area	85°51'47.5 2"	20°17'40.2 0"	L9

Table-01: GPS details of the Sampling Locations of the Study Area Smart City Region of Bhubaneswar (BMC).

The cations and anions were analyzed using a spectrometric method. Physical characteristics such as pH and Conductivity were measured directly in the Field using pH meters and Conductivity meters, respectively.

• **GROUND WATER QUALITY MAPING**

A Geographic Information System (GIS) analysis of the water quality in the region of research is carried out. During the pre- and post-monsoon seasons, we calculated the regional distribution of key indicators of water quality. The research calls for many sets of information, including the 1:50000 scale 73 H/15 and 73H/16 topo sheet from the Survey of India, as well as the fused data of IRS-IDPAN and LISS-111 satellite imagery of route 100 and row 60 from ORSAC,

Bhubaneswar.

IRS-IDPAN and LISS-111 satellite images are geo referenced in EASI/PACE v6.3 using ground control points and SOI toposheets as a reference, and then fused to provide a high resolution (5.8m of PAN) and color (R,G,B band of LISS-11) output. The combined data is then separated into sections using latitude and longitude in a printed output. This data is then artistically interpreted to create themed maps. These thematic maps (Raster data) are scanned with an A₀ -Flatbed Deskjet scanner and then vectorized in AUTOCAD 2000. These maps are edited with ARC/INFO v3.5.1, and then produced with ARC view v3.1, a geographic information system tool.

• **WATER QUALITY INDEXES (WQI) ANALYSIS**

One of the best methods for assessing water quality and disseminating that assessment to interested parties and decision-makers is the water quality index. Thus, it became a critical component in the evaluation and administration of ground water. The Water Quality Index is a tool for estimating water quality using the values of several different water quality indicators (WQI). The score is based on several indicators of overall water quality. Human consumption potential of ground water is considered in developing the WQI. The Weighted Arithmetic Index Method was utilised in the creation of the Water Quality Index (WQI). Using the formula for each parameter q_i , we developed a quality rating system.

$$q_i = (C_i / S_i)$$

Each parameter's quality rating scale may be calculated by dividing the parameter's concentration in the sample water (C_i) by the applicable quality standards (S_i). Weights (w_i) were given to various parameters, and from those, standardized or relative weights (ω_i) were derived.

$$\omega_i = [W_i / \sum W_i]$$

There is a sliding scale from one (1) to five (5) for the weights, depending on how crucial they are for determining the quality of the water. Since total dissolved solids, electrical conductivity, fluoride, and nitrate concentrations are so crucial to determining the quality of a water supply as a whole, they each get a maximum weight of five (5), while potassium receives a minimum weight of one (1) due to the little danger it presents to consumers' health. The significance of many additional chemical criteria in establishing water quality is rated on a scale from one to five. pH is given a value of 3 to show alkalinity and its impact on hardness; sodium, chloride, and sulphate are all given a value of 3; and sulphate is given a value of 3

because it indicates salinity and its effects on taste. Since different minerals, such as calcium, magnesium, carbonates, and bicarbonate, contribute to hardness in different ways, we give each mineral equal weight (2).

The water quality index (WQI) was obtained by adding the quality rating scale (q_i) and relative weights (ω_i).

$$WQI = \sum_{i=1}^n q_i \omega_i$$

WQI = Water quality index Score; q_i = Quality rating scale; ω_i = relative weights of the i^{th} parameter.

The Water Quality Index (WQI) was frequently cited when discussing water quality in relation to a certain use. In this analysis, we take into account the Water Quality Index (WQI) for consumption, with a maximum WQI of 100.

$$WQI = [\sum q_i \omega_i] \times 100$$

4. RESULTS AND DISCUSSION:

The following tables provide an abstract of the ground water chemistry data for the research area. The tested data of eighteen (18) locations for each of the parameters have been converted into spatial variation using Arc GIS- 10.3 (Fig: 05 to Fig: 34).

• **Groundwater Quality Variation:**

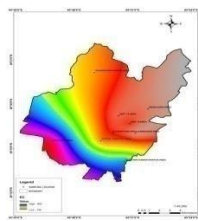
Samples of water taken from the site where the study was conducted showed a pH range of 5.3% to 7.7%. Except for three (03) areas, almost everything was within the secure area (BIS 10500: 2012). The only place I could find water with a higher TDS was in the Khandagiri region. Pre- and post-monsoon samples were identical in terms of the absence of EC and TH. Chloride levels are generally well under allowable limits, with the exception of the Khandagiri region, where they reach 261.85 mg/lit. All of the water samples were below the maximum possible concentrations for sodium, carbonate, bicarbonate, sulphate, nitrate, and fluoride.

Potassium levels were discovered to be significantly higher than allowed in both Khandagiri and Old Town samples.

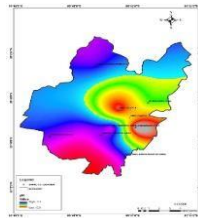
A higher concentration of Iron was found in the samples almost at all the locations except location - 01 (L1). The World Health Organization (WHO) threshold of 0.3 mg/lit was significantly exceeded by this concentration (value) at all monitoring locations. The dispersion of FeCO_3 or the reaction of oxidised iron minerals with organic matter may contribute to a higher concentration of iron in the groundwater. Precipitation of $\text{Fe}(\text{OH})_3$, a prevalent issue in certain sections of the research region, turns the pure water become a hazy brown color rather quickly after it is

removed. Dissolved oxygen removal by organic materials within sediments leaching to decreased conditions may also contribute to increased concentrations of this element in groundwater. Because of this, the groundwater is enriched with dissolved iron due to the increased suitability of iron carrying minerals. Higher concentrations of the element are found in the groundwater because of the presence of clay layers above the aquifers in the research region, which foster the formation of a reducing environment. The biological cycle and the subsequent leaching of iron (Fe) from the top soil into the groundwater is shown by the presence of Fe enrichment throughout the year.

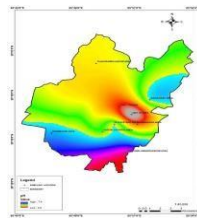
• **SPATIAL VARIATIONS OF DIFFERENT PARAMETERS**



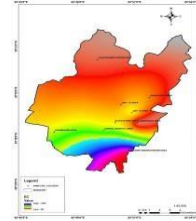
Pre-monsoon pH



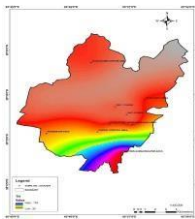
Post-monsoon pH



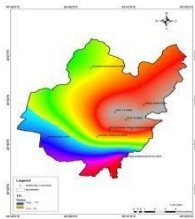
Pre-monsoon EC



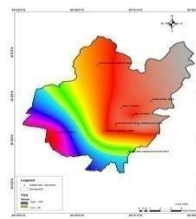
Post-monsoon EC



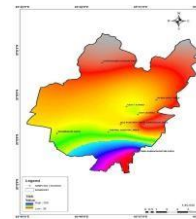
Pre-monsoon TDS



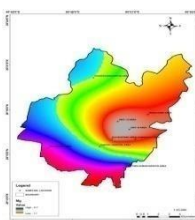
Post-monsoon TDS



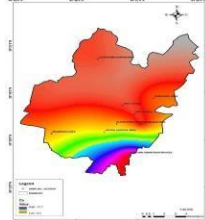
Pre-monsoon TH



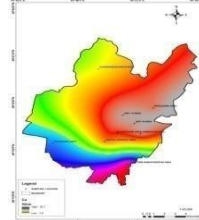
Post-monsoon TH



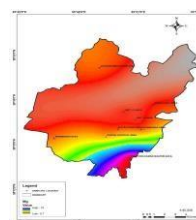
Pre-monsoon (Ca^{2+})



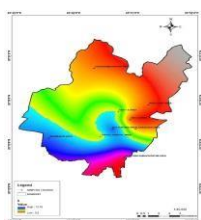
Post-monsoon (Ca^{2+})



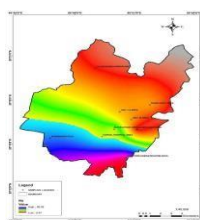
Pre-monsoon (Mg^{2+})



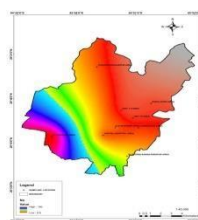
Post-monsoon (Mg^{2+})



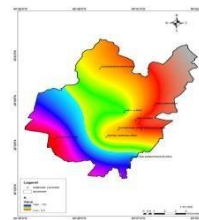
Pre-monsoon (Na⁺)



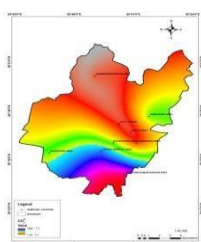
Post-monsoon (Na⁺)



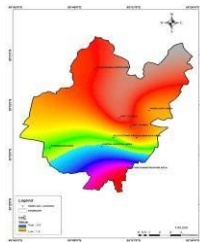
Pre-monsoon (K⁺)



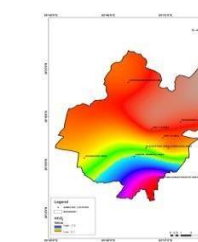
Post-monsoon (K⁺)



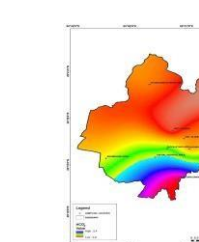
Pre-monsoon (CO⁻²)



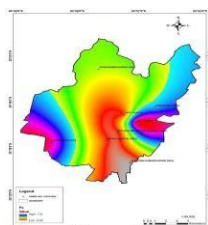
Post-monsoon (CO⁻²)



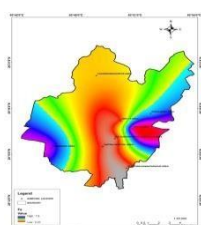
Pre-monsoon (HCO⁻²)



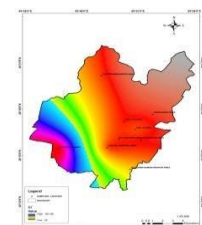
Post-monsoon (HCO⁻²)



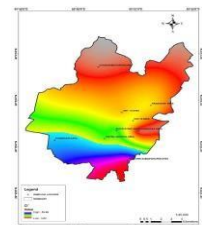
Pre-monsoon (Fe)



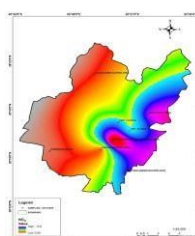
Post-monsoon (Fe)



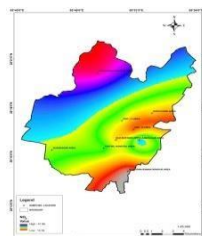
Pre-monsoon (Cl⁻)



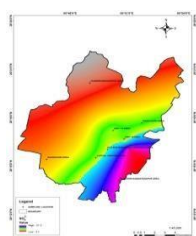
Post-monsoon (Cl⁻)



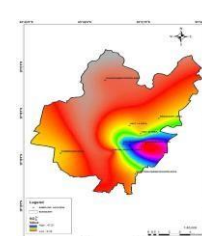
Pre-monsoon (SO₄²⁻):



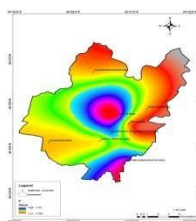
Post-monsoon (SO₄²⁻):



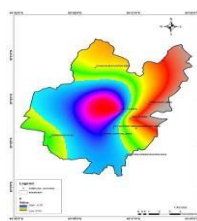
Pre-monsoon (NO₃⁻):



Post-monsoon (NO₃⁻)



Pre-monsoon (F)



Post-monsoon (F)

• **WATER QUALITY INDEX (WQI):**

According to the conventional water quality classification method based on WQI value, the determined total WQI value for the study area is 79.97%, placing it in the "Good Quality" category. (Table: 0 4).

A greater concentration of Iron, Total Dissolved Solids, Chloride, EC, and Potassium accounts for the higher WQI value found in the Khandagiri region (L1). Samples indicated that 44.45% were of "Excellent" quality for human consumption, 22.225% were of "Good" quality, and 33.335% were of "Poor" quality. No samples were deemed to be in the "Very Poor" or "Unsuitable for drinking purpose" categories. Over all, Bhubaneswar (BMC) smart city area water is deemed to be safe for human consumption.

• **CORRELATION FACTOR ANALYSIS:**

In order to comprehend how the groundwater samples fit together in a multidimensional space defined by the investigated characteristics,

factor analysis (FA) was performed on the groundwater samples together with the water quality index (WQI). This has developed into a useful tool to examine the relationships between various variables in a dataset. According to the findings, TDS and TH were significantly and positively related to EC. Both EC and TDS were shown to be highly associated with chloride. The results indicated that iron and fluoride were negatively associated. High EC in Khandagiri site (L1) samples was attributed to high TDS, TH, and Chlorides contents in the groundwater of the study area.s

• **WATER QUALITY ANALYSIS BY HILL - PIPER DIAGRAM:**

By combining (K^+ with Na^+) and (CO_3^{2-} with HCO_3^-), we are able to chart with only 6 parameters rather than the usual 8, and the Piper trilinear diagram may be used to display the concentration of any of the 8 main ions (Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Cl^- , CO_3^{2-} , HCO_3^{2-} , and SO_4^{2-}). Using the cation and anion concentrations shown in the bottom triangles of the piper diagram, we can determine the total ion concentration.

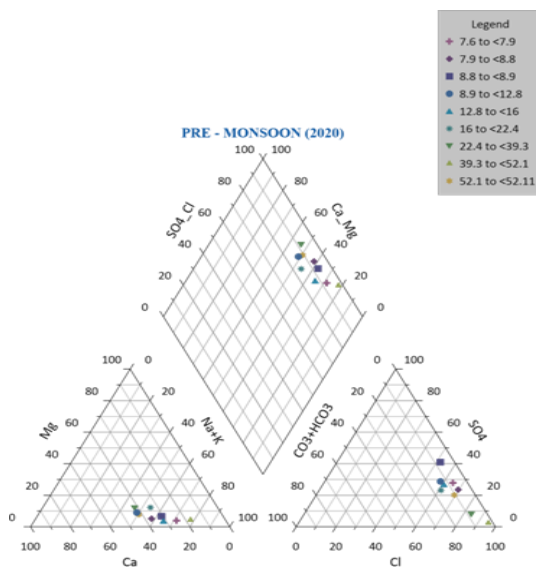


Fig-35: Hill - Piper Diagram (Pre - Monsoon: 2020)

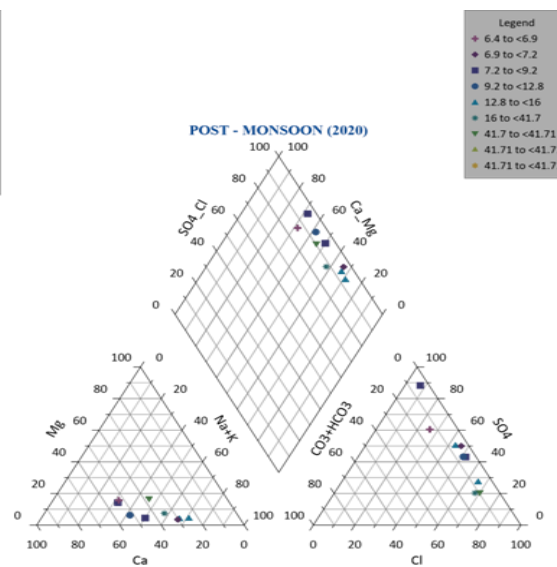


Fig-36: Hill - Piper Diagram (Post - Monsoon: 2020)

Ca 2+	Na ⁺ + K ⁺	Mg ²⁺	Cl ⁻	2- SO ₄	- HCO ₃ ⁻ + CO ₃	L-ID
39.3	175	9.7	261.86	6.7	6.1	L1
52.1	63	9.7	70.96	20.6	10.8	L2
8.8	17.8	1.9	26.98	21.3	3.7	L3
22.4	24.8	6.3	32.98	3.1	3.2	L4
16	25.7	5.8	31.98	12.1	8.2	L5
12.8	26.4	1.5	29.8	13.2	6.1	L6
7.6	21.9	1.2	28.1	12.1	3.2	L7
7.9	12.5	1.1	34.3	11.6	3.4	L8
8.9	10.3	1.9	22	10.9	5	L9

Ca ²⁺	Na ⁺ + K ⁺	Mg ²⁺	Cl ⁻	2- SO ₄	- HCO ₃ ⁻ + CO ₃	L-ID
12.8	37.25	2.4	39.9	16.79	4.1	L1
41.7	50.8	18.0	59.98	17.28	8.3	L2
7.2	4.3	1.9	3.99	47.51	2.3	L3
6.4	3.86	1.9	3.62	8.45	1.9	L4
16	26.65	3.4	29.98	8.95	5.3	L5
12.8	29.3	1.9	29.6	34.7	4.2	L6
6.9	15.1	0.8	17.2	18.6	1.4	L7
7.2	7.9	0.7	21.6	17.9	2.1	L8
9.2	7.4	1.1	19.1	16.3	2.3	L9

Table-02: Hill - Piper Diagram (Pre - Monsoon: 2020) **Table-03: Hill - Piper Diagram (Post - Monsoon: 2020)**

	W _i	ΣW _i	$\omega_i = \frac{w_i}{\sum w_i}$	Min ^m (C _i)	Max ^m (C _i)	Std. Dev (σ)	Mean (C _i)	(S _i)	(q _i) = (C _i /S _i)	[ω _i q _i]	WQI
pH	3	46	0.06521	5.3	7.7	0.710	6.739	7.5	0.899	0.05860	79.97 % (GO OD)
EC	5	46	0.10869	65	904	211.703	269.833	1000	0.270	0.02932	
TDS	5	46	0.10869	38	592	129.55	163.111	500	0.326	0.03545	
TH	3	46	0.06521	20	178	49.981	56.611	200	0.283	0.01846	
Ca ²⁺	2	46	0.04347	6.4	52.1	13.311	16.444	75	0.219	0.00953	
Mg ²⁺	2	46	0.04347	0.7	18	4.387	3.956	50	0.079	0.00344	
Na ⁺	3	46	0.06521	2.37	150	32.349	24.763	200	0.124	0.00807	
K ⁺	1	46	0.02173	0.2	25	6.515	6.346	12	0.529	0.01149	
CO ₂₋₃	2	46	0.04347	1.2	7.2	1.693	3.222	200	0.016	0.00070	
2- HCO ₃	2	46	0.04347	0.2	3.6	0.828	1.278	120	0.011	0.00046	
Fe	2	46	0.04347	0.23	7.9	2.938	3.585	0.3	11.950	0.51956	
Cl ²⁻	3	46	0.06521	3.62	261.86	55.519	42.441	250	0.170	0.01107	
SO ₄ ²⁻	3	46	0.06521	3.1	47.51	10.116	16.56	250	0.066	0.00432	
2-	5	46	0.10869	0.59	41.88	11.292	16.354	45	0.363	0.03950	

NO3										
F	5	46	0.10869	0.03	0.45	0.114	0.181	1	0.181	0.01967
	46		1.0						$[\sum \omega_i q_i]$	0.76968

Table-04 : Summary statistics of physico-chemical parameters concentration with BIS- 10500: 2012 Standard Concentrations (S_i), Unit Weights (W_i), and Normalized / Relative Weight (ω_i), and overall WQI in groundwater of Study Area

LOCATIONS	PERIOD YEAR - 2020	WQI SCORE IN %	QUALITY
L1	PRE-MONSOON	159.447	Poor
	POST-MONSOON	127.140	Poor
L2	PRE-MONSOON	48.9730	Excellent
	POST-MONSOON	42.7390	Excellent
L3	PRE-MONSOON	122.299	Poor
	POST-MONSOON	109.874	Poor
L4	PRE-MONSOON	61.2100	Good
	POST-MONSOON	55.8360	Good
L5	PRE-MONSOON	34.9310	Excellent
	POST-MONSOON	38.9440	Excellent
L6	PRE-MONSOON	29.1420	Excellent
	POST-MONSOON	35.3540	Excellent
L7	PRE-MONSOON	39.1620	Excellent
	POST-MONSOON	36.1300	Excellent
L8	PRE-MONSOON	128.870	Poor
	POST-MONSOON	129.423	Poor
L9	PRE-MONSOON	94.5820	Good
	POST-MONSOON	91.2990	Good

Table-05: WQI Scores and the Quality of Samples of selected locations of the Study Area.

Quality of Water	WQI Score (%)	Numbers of Samples	Total Numbers of Samples	%age of Samples
Excellent	< 50	8	18 Nos.	44.45 %
Good	50 - 100	4		22.22 %
Poor	100 - 200	6		33.33 %
Very Poor	200 - 300	0		0 %
Unsuitable for Drinking	> 300	0		0 %

Table-6 : Standard water quality classification scheme based on WQI value

Correlation between Groundwater Quality Parameters:

	pH	EC	TDS	TH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Fe	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	F
		µs/cm ²	mg/lit												
pH	1														
EC	0.548	1													
TDS	0.485	0.987	1												
TH	0.623	0.907	0.833	1											
Ca ²⁺	0.599	0.896	0.817	0.995	1										
Mg ²⁺	0.663	0.891	0.831	0.963	0.933	1									
Na ⁺	0.421	0.916	0.963	0.678	0.655	0.710	1								
K ⁺	0.421	0.942	0.937	0.824	0.822	0.799	0.874	1							
CO ₃ ²⁻	0.611	0.544	0.444	0.683	0.690	0.635	0.307	0.481	1						
HCO ₃ ⁻	0.571	0.509	0.380	0.722	0.743	0.637	0.202	0.448	0.895	1					
Fe	-0.467	0.043	0.151	-0.199	-0.220	-0.180	0.260	-0.098	-0.449	-0.516	1				
Cl ⁻	0.368	0.897	0.954	0.638	0.613	0.671	0.995	0.859	0.251	0.140	0.321	1			
SO ₄ ²⁻	-0.384	-0.120	-0.190	0.018	0.077	-0.132	-0.258	-0.095	0.351	0.465	-0.048	-0.289	1		
NO ₃ ⁻	0.040	-0.097	-0.054	-0.109	-0.168	0.091	0.071	-0.121	-0.497	-0.462	0.085	0.060	-0.533	1	
F	0.029	0.102	0.041	0.189	0.257	0.030	-0.065	0.351	0.262	0.345	-0.684	-0.092	0.280	-0.425	1

Table- 7 : Correlation Between Different Parameters Of Ground Water At Bhubaneswar Smart City Region Pre- Monsoon (2020).

	pH	EC	TDS	TH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Fe	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	F
		µs/cm ²	mg/lit												
pH	1														
EC	0.646	1													
TDS	0.585	0.985	1												
TH	0.697	0.919	0.899	1											
Ca ²⁺	0.743	0.952	0.922	0.986	1										
Mg ²⁺	0.669	0.897	0.874	0.997	0.978	1									
Na ⁺	0.787	0.899	0.855	0.784	0.850	0.750	1								
K ⁺	0.695	0.773	0.753	0.694	0.754	0.672	0.915	1							
CO ₃ ²⁻	0.809	0.912	0.844	0.879	0.939	0.863	0.928	0.807	1						
HCO ₃ ⁻	0.718	0.905	0.827	0.886	0.940	0.885	0.867	0.761	0.973	1					
Fe	-0.416	-0.419	-0.429	-0.443	-0.497	-0.465	-0.389	-0.551	-0.467	-0.493	1				
Cl ⁻	0.732	0.950	0.929	0.810	0.868	0.769	0.971	0.843	0.900	0.842	-0.332	1			
SO ₄ ²⁻	-0.142	-0.241	-0.256	-0.138	-0.147	-0.119	-0.199	0.007	-0.153	-0.080	0.191	-0.237	1		
NO ₃ ⁻	0.051	0.073	0.124	0.105	0.114	0.108	-0.075	0.060	-0.015	0.059	-0.190	0.021	0.651	1	
F	0.161	0.160	0.216	0.152	0.191	0.156	0.275	0.558	0.212	0.152	-0.733	0.175	-0.036	-0.015	1

Table- 8: Correlation between Different Parameters of Ground Water at Bhubaneswar Smart City Region Post- Monsoon (2020).

5. CONCLUSION:

With the exception of iron (Fe), pre- and post-monsoon water quality testing in the Bhubaneswar Smart City Region in 2020 show that the water does meet the standards for

human consumption set by the World Health Organization and the Bureau of Indian Standards.

A small proportion of tests revealed acidic water levels. Nearly all parameters were found to be

well within their respective acceptable limits across the research region, with the exception of EC, TDS, Potassium, and Chloride in the Khandagiri area (L1) (Except Iron). Even while iron is essential for human health, drinking water with a high fiber content may have an unpleasant odour, colour, or sediment. [3, 9].

The WQI of the study area is found to be 79.97, which indicates the overall groundwater quality of Bhubaneswar City is good for drinking purpose. Higher values of WQI in some locations are resulting from the higher concentration of Iron, TDS, Chlorides, EC, and Potassium. From what can be seen in the Hill-piper diagram, most pre-monsoon samples seem to be of the Na⁺-K⁺-Cl⁻-SO₄²⁻ type. For post-monsoon almost 50% of samples are Ca²⁺ - Mg²⁺ - Cl⁻ - SO₄²⁻ type and rest of samples fall under Na⁺ - K⁺ - Cl⁻ - SO₄²⁻ type.

From the analysis it was also found that, TDS, TH, Chlorides, and EC were highly & positively correlated with each other. Total dissolved solids (TDS), total hydrogen (TH), and chloride concentrations in groundwater all contribute to the water's high EC value. The correlation between Fluoride and Iron was shown to be negative. Groundwater in the smart city of Bhubaneswar has been rated as "Good" for human consumption. Results from this study show that Geospatial and Geostastical Techniques (WQI, FA) may be useful in researching groundwater quality.

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