

# Study of Groundwater Quality in Shallow Tubewells of Bhubaneswar City Using WQI Method

Kshyana Prava Samal <sup>1,\*</sup>, Priyanka Mishra <sup>2</sup>, Ashok Tarai <sup>3</sup>, Asish Kumar Pradhan <sup>4</sup>

## Abstract

Shallow groundwater is extremely vulnerable owing to overexploitation, anthropogenic activities, and environmental effects. Declining quality of groundwater poses an enormous risk for human health and entire ecosystem. Nearly 50 per cent urban water supply is contributed by groundwater in Indian cities. Since Bhubaneswar shares a similar scenario where 34 out of 67 wards are partially covered with municipal water supply and the residents of these areas are largely dependent on groundwater, evaluation of groundwater quality has become inevitable. In this context this study has been done for existing shallow tube wells of 50m-100m deep from 20 wards of Bhubaneswar, which are mostly used for drinking water purposes by the people of low-income group. Around 94 samples were collected to check the physico-chemical parameters like pH, Alkalinity, Total Hardness (TH), Electrical Conductivity (EC), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), and Chloride, as per Indian standards (IS 10500). The groundwater quality was evaluated for human consumption using the Weighted Arithmetic Water Quality Index method. Water Quality Index results showed that 12.8% of groundwater samples are in very poor while 18% samples are in poor category. Quality of groundwater from all tube wells were found to be grim in ward 29 and very poor to poor in wards 12, 16, 27 and 28. The scenario revealed nearly 32% groundwater is under risk of contamination by both natural and anthropogenic activities. These findings would help to formulate an efficient monitoring and management system for sustainability of groundwater resources.

**Keywords:** Groundwater quality, water quality index, weighted arithmetic mean method, tube well, contamination

### \*Author for Correspondence

Kshyana Prava Samal

<sup>1</sup> Associate Professor, Department of Civil Engineering, School of Civil Engineering, KIIT Deemed to be University, Bhubaneswar, Odisha, India.

<sup>2</sup> Assistant Professor, Department of Architecture & Planning, School of Architecture & Planning, KIIT Deemed to be University, Bhubaneswar, Odisha, India

<sup>3</sup> Research Scholar, Department of Civil Engineering, School of Civil Engineering KIIT Deemed to be University, Bhubaneswar, Odisha, India.

<sup>4</sup> Research Assistant, Department of Civil Engineering, School of Civil Engineering, KIIT Deemed to be University, Bhubaneswar, Odisha, India

Received Date: April 23, 2024

Accepted Date: August 20, 2024

Published Date: October 16, 2024

**Citation:** Kshyana Prava Samal, Priyanka Mishra, Ashok Tarai, Asish Kumar Pradhan. Study of Groundwater Quality in Shallow Tubewells of Bhubaneswar City Using WQI Method. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S559-S574p.

## INTRODUCTION

Rapid urbanization accompanied by socio-economic and demographic changes, technological and infrastructure development, and new dimensions in urban transformation in any nation brings in opportunities and potential to improve the well-being of societies. On the other hand, this brings in a lot of challenges and threats such as intensified and unplanned spatial transformations, inducing stress on existing services, exploitation of environmental resources [1]. lack of infrastructure including water supply and sanitation and other services. Inadequate affordable housing leading to people occupying the agricultural land which is converted to unplanned urban fringe settlements or form slums and informal settlements [2,3]. These transformations are accountable for the destabilization, degradation, and contamination of water bodies. This gives rise to conflict in the quality and availability of groundwater,

predominantly shallow groundwater, creating a critical environmental concern. As per the UN world water development report 2022 (United Nations 2022) [4], groundwater dependence would be intensifying in the coming decades to cater to the needs of around 50% of the global urban population. Also, the world bank [5] and the central ground water board (CGWB) [6] statistics indicate that in Indian cities nearly 50 percent of urban water supply is contributed by groundwater. The groundwater contamination combined with the effects of climate change would put additional stress on groundwater resources. Thus, groundwater quality becomes an important issue to be distinguishably tackled.

Natural geological factors may alter the pH, alkalinity, fluoride, phosphorus, sulphate, and iron concentrations of groundwater [7]. The direct recharge and discharge relationships with surface water and local precipitation substantially affect the quality of shallow groundwater by anthropogenic factors [8], which include domestic and industrial effluents, wastelands, disposal of untreated biological wastes from hospitals, stormwater runoff, leachate from landfills, etc. [9,10]. Topography, demographics, and socio-economic activities further add to the variations in the quality of groundwater [11,12]. This induces a great risk for the residents of those areas that depend mostly on shallow tube wells.

Water Quality Index (x WQI) is a mathematical tool which integrates various water quality parameters into a single numerical score, representing a cumulatively derived numerical expression for describing the overall status of quality of water [13,14]. WQI, developed in the 1970s, is an effective means to monitor changes in quality of water in a specific source of water or to compare the quality of one source of water with other sources in a region or around the world [5]. Since the index is based on a variety of parameters, it provides a clear picture of water quality and straightforward results in different environmental conditions for water quality analysis [16,17]. Moreover, it reduces various parameters into a simple expression, which simplifies the analysis of water quality monitoring data. Dash & Kalamdhad (2021), mapped the research in the domain of water quality indexing till 2020 and found that the developing countries are more active in the research involving WQI. Primary focus of India and Iran is on groundwater and its suitability for drinking, whereas, Malaysia focused largely on aquaculture and rejuvenation of river water. Table 1 shows the studies on the quality of groundwater using WQI in Indian cities during past few years.

**Table 1.** Recent Studies on the Quality of Groundwater Using WQI in India.

Study Area	Parameters analysed	Findings	Reasons	Reference
Faridabad and Gurgaon	pH, EC, TH, HCO <sub>3</sub> <sup>-</sup> , CO <sub>3</sub> <sup>2-</sup> , Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , SiO <sub>2</sub> , NO <sub>3</sub> <sup>-</sup> , F <sup>-</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup> , K <sup>+</sup>	10 out of the 28 sites unsuitable for drinking purposes	Deteriorated water quality primarily due to demographic changes, industrial growth, and rapid urbanization.	[19]
Bundelkhand	pH, TH, alkalinity, EC, TDS, Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup> , K <sup>+</sup> , HCO <sub>3</sub> <sup>-</sup> , Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , NO <sub>3</sub> <sup>-</sup> , F <sup>-</sup> , Mn, Cu, Ag, Zn, Fe and Ni	WQI in the study area ranges from 4.75 to 115.93.	Deterioration due to both anthropogenic and geogenic activities. NO <sub>3</sub> concentration triggered due to unplanned sewerage system and unlined septic tanks; higher concentration of TDS, F and HCO <sub>3</sub> in North due to poor fluxing of groundwater	[20]
Suburban areas of Visakhapatnam	pH, TDS, TH, EC, Na <sup>+</sup> , K <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , NO <sub>3</sub> <sup>-</sup> , HCO <sub>3</sub> <sup>-</sup> , Cl <sup>-</sup> , and SO <sub>4</sub> <sup>2-</sup>	27% of the groundwater samples are poor for drinking and 20% are poor for industrial purposes.	Impacts of pollution, hardness and alkalinity.	[21]
Allahabad	pH, electrical conductivity, TDS, F, Fe, total alkalinity, TH, Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , Na <sup>+</sup> ,	4.23% area is under category of good, 74.82% moderate, whereas 12.12% under poor and 0.66% very poor category	Over exploitation of groundwater, urbanization, and anthropogenic activities.	[22]

	K <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , HCO <sub>3</sub> <sup>-</sup> , and NO <sub>3</sub> <sup>-</sup>			
Industrial Clusters, Tripura	Temperature, pH, TDS, HCO <sub>3</sub> <sup>-</sup> , Cl <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , TH, Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup> , K <sup>+</sup> , PO <sub>4</sub> <sup>3-</sup> , NO <sub>3</sub> <sup>-</sup> , Pb, Cd, F <sup>-</sup> , Fe, Mn, As, Cu, Zn, and Cr	Most of the samples have poor to unfit groundwater quality for drinking purposes.	Presence of heavy metals in the industrial areas.	[23]
Shamirpet urban region, Hyderabad	pH, EC TDS, DO, CO <sub>3</sub> <sup>2-</sup> , HCO <sub>3</sub> <sup>-</sup> , Na <sup>+</sup> , K <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , F <sup>-</sup> , Cl <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup>	Very poor quality (27%) water in area dominated by industrial activities; Poor water quality (60%) in water-scarce zones 53% unsuitable for human consumption; Higher concentration of F <sup>-</sup> (13%) and NO <sub>3</sub> <sup>-</sup> (47%).	Deterioration due to both natural reasons, industrial activities, and over-exploitation of groundwater for irrigation.	[24]
Ranchi	pH, TDS, TH, Cl <sup>-</sup> , EC, Total alkalinity, SO <sub>4</sub> <sup>2-</sup> , F <sup>-</sup> , Na <sup>+</sup> and Se, As, Mn, Ni, Se, Fe, Cu, Cr, Cd, Co, and Pb	Out of the 44 sampling locations, 9% show good water quality, 80% poor, 7% very poor water quality, 4% are unfit for drinking.	Impact of urban areas, industrial and commercial zones	[25]

Baloch et al. (2021) observed that groundwater quality in Sindh province is deteriorating and used WQI with other tools to find the suitability of water for adults and children. Şener et al. (2017), while studying the groundwater quality in the Egirdir lake basin, suggested that integrating WQI with other advanced tools such as the Geographic Information System (GIS), further assists in determining the spatial and temporal variability of groundwater along with the pattern of distribution of water quality parameters.

The capital city of Odisha, Bhubaneswar, is under rapid urbanization, with infrastructural expansion, industrialization, and commercialization, and is coming up as an institutional and educational hub. The intensification of groundwater consumption and reduced areas of recharge are increasing the vulnerability of underground aquifers [28]. Srivastava et al. (2014), has found that overflow of untreated sewage from oxidation ponds into valleys and nallahs in the city is increasing the levels of contaminants in the groundwater of Bhubaneswar. As per Mishra et al. (2021), the quality of groundwater of Bhubaneswar is declining, which may be alarming in the next few decades.

Achary et al. (2013) and Majumdar (2019) observed while investigating the physico-chemical parameters of the rivers Kuakhai and Daya, which flow through the city, that the water quality of the river is deteriorating gradually due to domestic waste and wastewater being discharged into the river. Achary et al. (2013) also analyzed the quality of groundwater using WQI and found that groundwater is slightly acidic in nature with higher concentration of iron, though it was in the safe limit as prescribed by WHO. Groundwater collected from dug wells from densely inhabited areas like Raghunathpur, Patia, Laxmipur slum area, and Chakeishiani, was found to contain large quantity of NO<sub>3</sub>, Fe, Mn, and K. Solid and liquid wastes discharged in open spaces and drains are likely to augment the flow of contaminants through laterite soil, which is predominant in the city's geological profile ions [28,29].

The capital city of Odisha, Bhubaneswar is under a fast track of growth with high rate of urbanisation in the state. This is leading to uncontrolled changes in land use and landcover, blind extraction of groundwater with reduction in recharge zones, rising standards of infrastructure yet poor sewage and drainage systems throughout the city. The rising challenges in coping with the ever-increasing pressure on groundwater resource, keeping in view both quantity and quality, has become a key factor while planning for the sustainable development. Also, majority of population being dependent on

groundwater, monitoring groundwater quality becomes crucial to safeguard the aquifers. An array of research has been conducted for groundwater quality in the city showing that it is under a challenging scenario where the quality is at stake due to both natural and anthropogenic factors. Time stands still for no one, it would be wise to protect the precious resource to avoid the arising grim situation as seen in many of the other cities in the country. The key focus of this research attributes to the protection of water resources under SDG 6 by means of water quality analysis in shallow tube wells in Bhubaneswar, which have become highly vulnerable. This study would contribute to formulate and implement suitable management practices and holistic urban development to ensure the sustainable use of the groundwater resources.

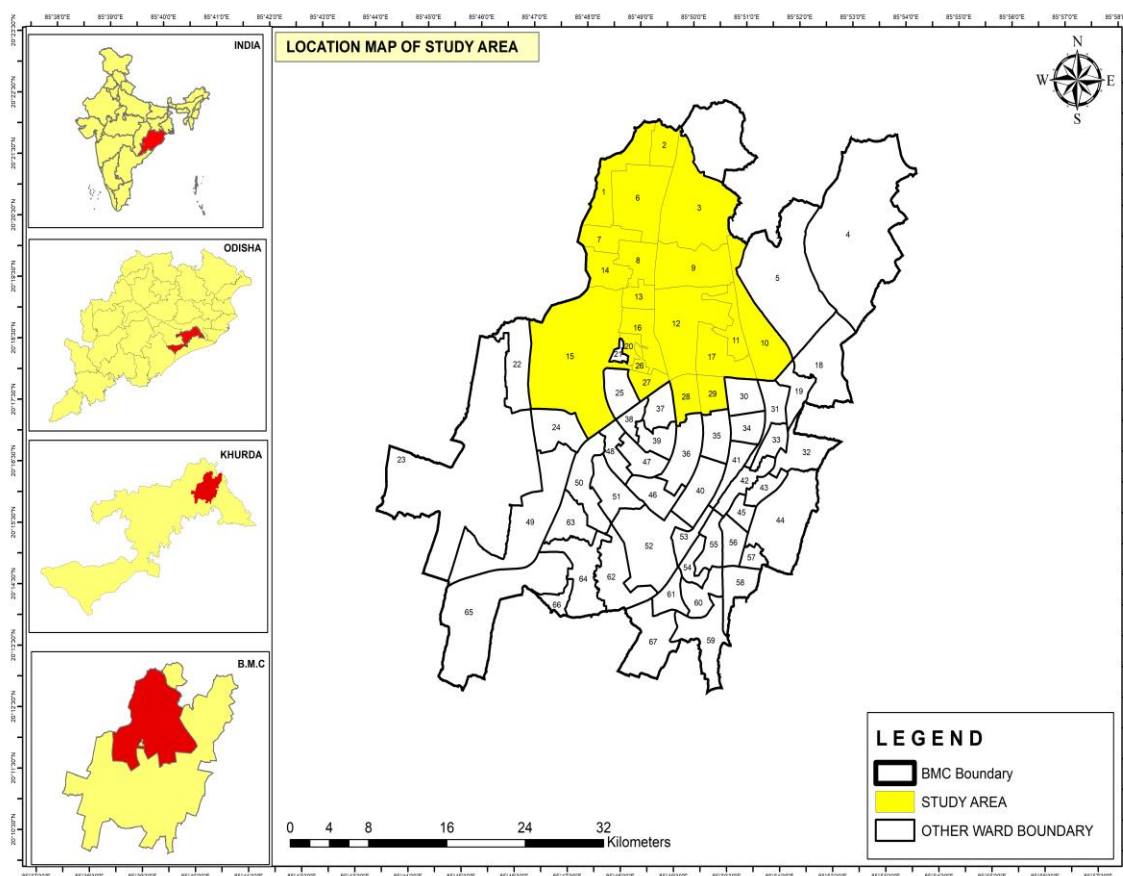
## MATERIALS AND METHODS

### Description of the Study Area

Bhubaneswar, the capital city of Odisha in the eastern coast of India, lies between 20°12'N and 20°25'N latitude and 85°04'E to 85°05'E longitude (Figure 1). The city is divided into 67 wards and 46 revenue villages in an area of 186 sq. km. The population has seen a huge escalation from 16,512 in 1951 to 1,131,000 in 2019. Bhubaneswar experiences hot & humid summers usually from the end of March to mid-June when the temperature reaches up to 46°C and more and becomes dry & cool in winter. The average annual rainfall of the city is 1540 mm.

### Hydrogeomorphology

Geologically, the upland areas in Bhubaneswar have lateritic cover, with dispersed hillocks in the west which are made up of Upper Gondwana shale-sandstone sequences, one of the oldest and most stable land masses in the world. The gently sloping areas in the east and south-east are covered in alluvial material, topped by a thin lateritic layer.

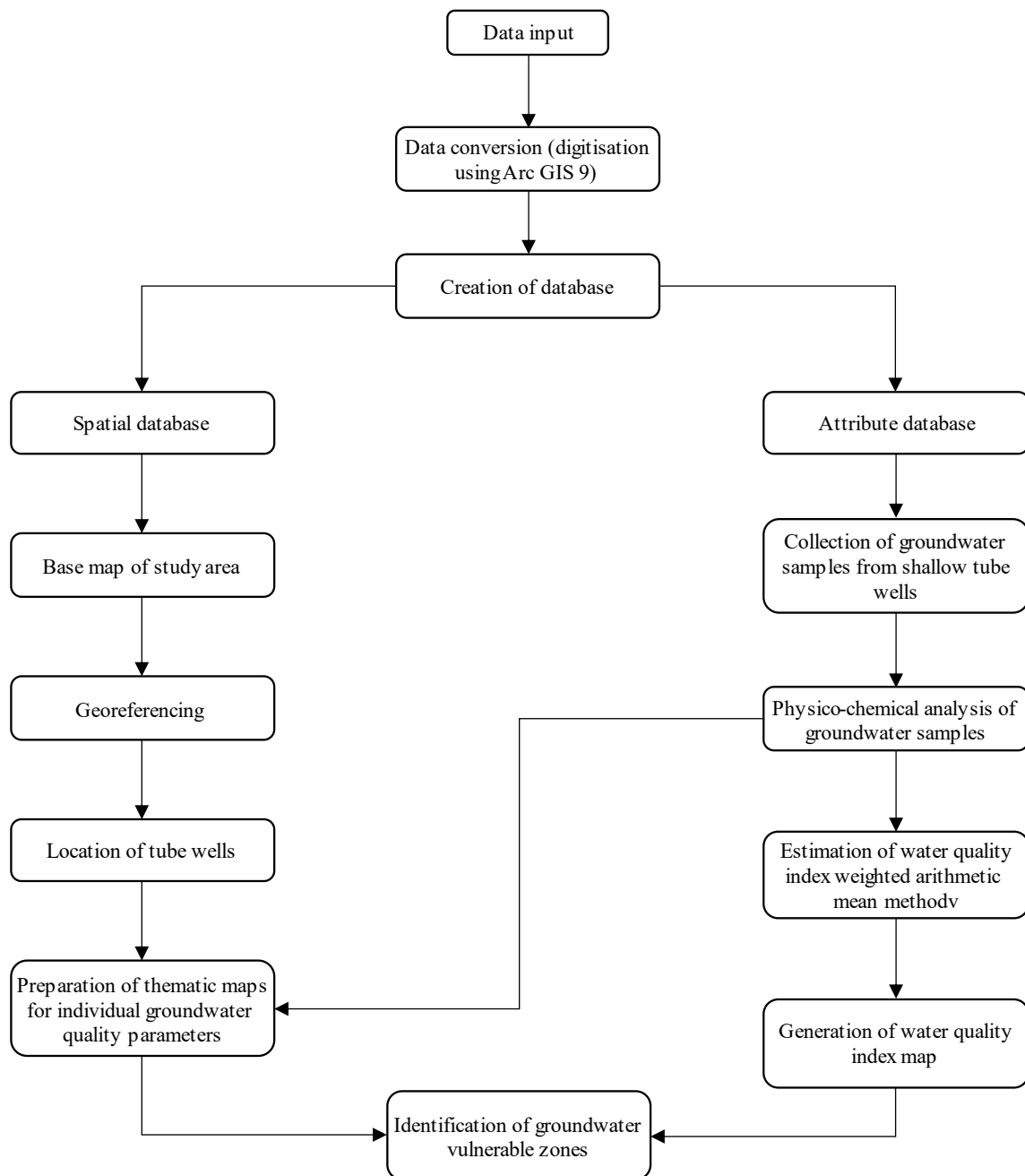


**Figure 1.** Location of study area.

### Collection and Analyses of Water Samples

20 wards in North and Central Bhubaneswar were selected from a total of 67 wards, where the tube wells were in functional condition. 94 samples were taken directly from different tube wells at different locations in one-liter new plastic bottles which were filled up to the brim. 4 to 6 samples were collected from each ward. 3 liters of water was collected for testing purpose from each tube well. During sample collection, data quality and consistency was ensured. The samples were immediately sealed and were all labeled systematically. The labeled samples were tested and analyzed in the laboratory for the selected physico-chemical parameters within 24 hours of collection of the samples.

The flowchart for the methodology for the study is represented in Figure 2. The experiments for all the water quality parameters were conducted in Environmental Engineering Laboratory at the KIIT School of Civil Engineering, Bhubaneswar.



**Figure 2.** Methodology for groundwater quality analysis

**Quality Analysis of Samples**

Water quality parameters such as pH and EC of the groundwater samples were measured using Eu Tech multiparameter analysis meter. pH measures acidity or alkalinity in a solution, while EC assesses its electrical conductivity based on the concentration of dissolved ions, both crucial parameters in understanding water quality and environmental conditions. Total alkalinity of the samples was measured by acid-base titration. Titrimetric method using standard EDTA, HCl and AgNO<sub>3</sub> as titration solution was used for evaluating TH and chloride. Total alkalinity signifies water's ability to counteract acids and stabilize pH, reflecting the presence of bicarbonates, carbonates, and hydroxides that enhance alkalinity, while BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) are essential indicators for assessing water quality, including groundwater, by revealing organic and chemical pollution levels [34].

**Weighted Arithmetic Water Quality Index Method (WAWQIM)**

The Weighted Arithmetic Water Quality Index Method was used to calculate WQI to assess the quality of water for drinking purposes. This method classifies the water quality according to the degree of purity by using the water quality parameters like acidity, hardness, pH, sulphate, chloride, DO, BOD, COD, alkalinity, Fe, and NO<sub>3</sub>-[15]. Here we have taken, pH, DO, Conductivity, Alkalinity, hardness, Chloride, TDS and BOD. All the Tests have been conducted in the Environmental laboratory of School of Civil Engineering, KIIT University as per IS 10500(2012). Then Weighted Arithmetic Water quality index method is used to calculate the Water Quality Index which identifies the Quality of water [35].

**Method for Calculation of Weighted Arithmetic Water Quality Index Method**

$$WQI = \frac{\sum_{i=1}^n qiwi}{\sum_{i=1}^n wi}$$

Where,

qi=quality rating of water quality parameters.wi= unit weight of water quality parameters;

$$\sum_{i=1}^n wi=1$$

qi relates the value of the parameter in polluted water to the standard permissible value and is obtained as follows:

$$qi = 100 \left( \frac{vi - v_{i0}}{si - v_{i0}} \right)$$

Where,

vi=estimated value of the parameters

vio= ideal value of the parameters

si=standard permissible value of the parameters

In most cases, vio=0 except for pH and DO

For pH,vio=7; For DO, vio=14.6mg/l.

The unit weight (wi)is inversely proportional to the values of the recommended standards and is obtained as:

$$Wi=k/si$$

Where,

$$k = \left( \frac{1}{\sum_{i=1}^n 1/si} \right)$$

**Table 2.** Classification Of WQI Range and Water Quality Status Rating [35].

WQI level	Water quality status	WQI level	Water quality status
0-25	Excellent	76-100	Very Poor
26-50	Good	Above 100	Unsuitable for Drinking
51-75	Poor		

Table 2 presents the classification scheme comprising five classes of water quality ranging from excellent, good, poor, very poor to unsuitable for drinking purposes, with lower index scores indicating better water quality [35].

## RESULTS AND DISCUSSION

### Physico-Chemical Characterization Of Groundwater

Table 3 shows the results of the eight physico-chemical parameters of the 94 groundwater samples collected from the 20 wards.

**Table 3.** Results of Physico-Chemical Parameters of the Groundwater Samples in Study Area.

Ward no	Place	pH	DO	Conductivity (mg/L)	Alkalinity (mg/L)	Hardness (mg/L)	Chloride (mg/L)	TDS (mg/L)	BOD (mg/L)
	Permissible limit	6.5-8.5	6.5-8.5 mg/L	200-800µs/cm	20-200mg/L	upto 200mg/L	upto 250mg/l	upto 500	<5mg/l
1	Infocity PS Area	6.39	7.63	122.2	52	209	36.92	79.43	0.93
1	Western Apartment	6.73	6.57	82.8	64	301	42.6	53.82	1
1	Chirkhal Toli Slum	6.06	7.45	290	56	170	73.84	188.5	0.95
1	Silicon College Area	6.76	7.42	260	58	169	71.84	169	0.92
1	Future Bhubaneswar School Area	6.53	7.28	180	59	172	63.28	117	0.99
2	Prasanti Vihar	6.23	6.79	203	36	223	85.2	131.95	0.49
2	Munda sahi	6.2	7.29	210	44	223	68.16	136.5	0.43
2	KIIT Campus	6.02	7.12	209	48	212	70.23	135.85	0.46
2	Sikharchandi Slum Area	6.08	7.36	212	35	196	53.96	137.8	0.46
3	Shree Vihar	7.12	7.68	201.2	56	144	36.92	130.78	1
3	Damana Village	6.95	7.85	227	28	183.68	56.8	147.55	0.37
3	Kanana Vihar Ph2	6.57	7.8	221	28	144	42.6	143.65	0.3
3	Patia Village	6.17	7.73	213	20	91.84	68.16	138.45	0.33
6	Nilapadia	6.9	7.23	165.6	36	209.92	73.84	107.64	0.78
6	Pragati Vihar	7.5	6.79	160.6	36	196.8	76.68	104.39	0.78
6	Club Town	7.2	7.77	156.2	40	223.04	56.8	101.53	0.7
6	Sishu Vihar	7.3	7.64	152.6	32	78.72	99.4	99.19	0.76
6	Metro Home	7.3	7.27	149.9	36	118.08	59.64	97.435	0.73
7	Sailashree Vihar	7.1	8.3	243	25	120.2	58.23	157.95	0.98
7	Sailashree Vihar VIM Area	7.21	7.26	230	45	288.2	55	149.5	0.75
7	Kanyashram Area	6.69	7.85	213	39	309	53.7	138.45	0.23
7	Vivekananda Sikhya Kendra Area	7.31	7.83	219	36	310	48	142.35	0.21

8	Niladri Vihar Sector2	7.46	7.42	141	28	118.08	28.4	91.65	0.71
8	Prachi Enclave	7.28	7.29	139	26	120.09	40.63	90.35	0.68
8	Damana Hat	6.2	6.22	142	35	123.03	35.2	92.3	0.52
8	District Centre	7.03	6.69	133	38	110.53	33.48	86.45	0.99
9	OMFED Square	6.79	7.48	203.9	72	189	46.23	152.925	1
9	Kalyan Mandap Area	7.28	7.42	182.2	68	170.23	48.7	136.65	0.43
9	Aditya Care Area	6.29	7.37	188.7	63	172.53	53.93	141.525	0.32
9	Gadakana Village	7.82	7.53	210.3	75	180.4	59.68	157.725	0.35
9	Rangamatia Village	6.69	7.21	206.5	63	173.2	52.5	154.875	0.36
10	Mancheswar Industrial Estate	6.59	7.42	235	48	144.23	73.8	176.25	0.33
10	Bhotapada Village	6.26	7.23	225	72	152.56	78.23	168.75	0.43
10	IDCO Colony	7.2	7.33	220	68	122.33	89.63	165	0.48
11	VSS Nagar	6.23	7.58	220	53	142.26	68.23	165	0.39
11	Housing Board Area	6.53	6.89	235	49	153.23	56.23	176.25	0.32
11	Dhirikuti Sahi Slum	7.62	7.43	226	46	159.23	57.3	169.5	0.41
11	Patra Sahi Slum	7.98	7.89	270	58	147.33	49.33	202.5	0.38
11	Hotel Management Area	7.22	7.66	233	43	143.22	62.83	174.75	0.35
12	Xavier Square	7.6	8.94	235	20	130.6	61.88	152.75	0.79
12	Gandhi Park Area	8.5	7.76	238	53	298.33	43.29	154.7	0.68
12	Regional Area	8	7.69	240	40.9	308.93	53.89	156	2
12	Swosti Premium	8.1	7.82	220	43.3	311.99	49.86	143	0.23
12	Railway Colony	8.2	7.8	210	39.8	311.5	48.18	136.5	0.85
13	NABARD Office Quater	8.26	7.2	349	36	258	46.38	226.85	0.77
13	BDA Colony Ph2	7.29	7.29	198	50	250.2	33.76	128.7	0.78
13	Nilamadhab Slum	7.36	7.66	225	27	243	52.3	146.25	0.77
13	Staff Quater	6.59	7.89	171	49	236	62.29	111.15	0.79
13	Rail Vihar	6.26	7.82	98	26	239	35.36	63.7	0.7
14	Niladri Vihar Sector 3	6.95	7.25	202	79	192.28	68.45	131.3	0.42

14	Buddha Park Area	6.23	7.25	210	85	170.34	58.3	136.5	0.48
14	Lumbini Vihar	7.12	7.38	178	72	165.26	62.23	115.7	0.46
14	Niladri Vihar Slum	6.69	7.68	235	82	180.58	60.76	152.75	0.33
15	CRPF	6.93	7.42	203	57	144.05	52.5	152.25	0.22
15	Horticulture	6.99	7.23	201.1	48	142.56	57.43	150.825	0.3
15	VIP Area	6.96	7.36	210	46	145.23	49.73	157.5	0.21
15	Rental Colony	6.98	7.25	220	50	150	50.2	165	0.25
15	Ekamra Villa	6.8	7.83	213	50	153.23	56.23	159.75	0.23
16	Tarini Nagar	8.28	7.83	235	72	236.16	51.12	152.75	0.63
16	Bajpayi Nagar	8.25	7.57	230	40	240	59.64	149.5	0.53
16	Nalco Area near Suryansh Hotel	7.69	7.57	220	12	104.96	31.24	143	0.61
16	Nalco Area	7.63	7.23	223	40	262.4	35.58	144.95	0.62
16	RCM College Area	8.23	7.21	230	48	144.32	33.67	149.5	0.53
16	Maitri Vihar	8.21	6.99	240	12	144.32	40.28	156	0.56
17	Utkal University Area	6.83	7.5	202	48	169.23	58.43	151.5	0.58
17	Patharabandh Slum	7.26	7.39	210	50	170.58	60.59	157.5	0.53
17	Dr. Shyam Prasad Mukherjee Park	7.23	7.73	208	46	189.68	65.63	156	0.6
17	Tarini Slum	6.99	7.55	198	53	180.98	68.29	148.5	1
17	Postal Colony	7.13	7.38	203	52	179.33	70.53	152.25	0.48
20	Sriram Nagar	6.83	7.53	323	52	190.23	43.68	242.25	0.69
20	Santosh Nagar	6.58	7.43	210	53	188.64	50.23	157.5	0.6
20	Mangala Slum	6.23	7.23	198	48	187.23	52.33	148.5	0.65
20	Ekamra Vihar	6.59	7.85	207	49	189.33	48.26	155.25	0.63
20	Mahabir Nagar	6.26	7.68	199	58	191.26	49.23	149.25	0.62
26	Saranapalli	6.29	7.82	319	43	183	71	207.35	0.32
26	Tarini Nagar	6.89	7.39	312	48	177	68.23	202.8	1
26	Dasarathi Apartment	6.58	7.25	303	56	176.5	57.6	196.95	0.43
26	Bishnupriya Apartment	6.42	7.22	298	52	165.26	72.33	193.7	0.43
26	Nilachakra Nagar	6.38	7.21	308	51	196.3	73.23	200.2	0.58

27	Jaydev vihar	8.01	7.83	191.2	35	197	48.43	124.28	0.97
27	Nayapalli ID Market	6.93	7.16	201	48	171	59.28	130.65	0.96
27	Nayapalli PS Area	8.5	7.83	209	51	173.5	75.38	135.85	0.98
27	IRC Village	7.08	7.23	199	46	198.4	60.29	129.35	1.1
27	NABARD Office	6.9	7.29	196	40	185.7	58.97	127.4	1
28	New AG Colony	6.24	3.72	331	40	144.32	59.64	215.15	0.53
28	Acharya Vihar N.H Near bridge	6.99	7.93	203	48	196.8	31.24	131.95	0.49
28	Reserve Police	5.69	7.63	200	52	190.7	35.58	130	0.43
28	Science Park Slum	6.71	7.62	210	52	170.6	33.67	136.5	0.46
28	Acharya Vihar	6.21	7.66	220	20	165.82	40.28	143	0.48
29	DCP Office Area	8.79	8.17	201.3	104	275.52	31.24	130.845	1
29	Irrigation Colony Area	8.02	8.11	185.7	64	262.4	36.92	120.705	0.6
29	RD College Area	8.21	8.11	186.9	128	262.4	42.6	121.485	0.64
29	Ananda Bazaar	8.21	8.08	204.7	52	380.48	34.08	133.055	0.44
29	Radha krushna Temple	8.62	8.1	210.2	72	131.2	42.6	136.63	0.48

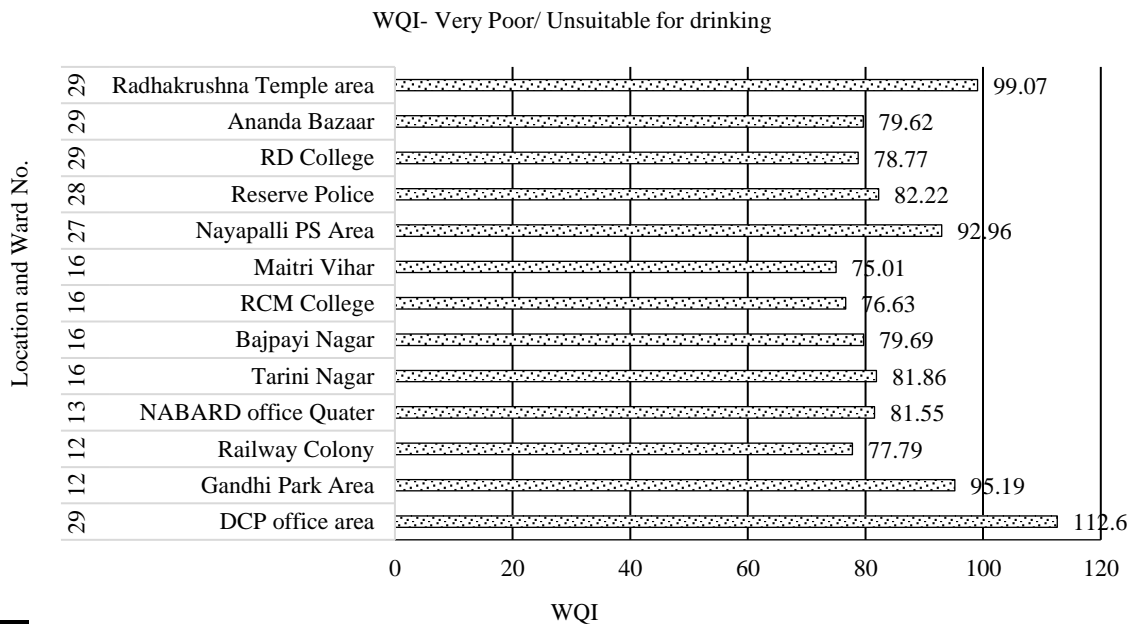
Water quality index is an effective mathematical tool to analyse the quality of groundwater computing all the individual physico-chemical parameters into a single index. WQI was calculated to evaluate the quality of groundwater of the 20 wards in Bhubaneswar in pre-monsoon period in May 2021. The results were compared with drinking water limit values determined by the Central Pollution Control Board (CPCB) of India standards criteria [6]. and Indian Standards (IS) 10500 [36]. Calculated WQI was classified into five classes as given in Table 2, ranging from excellent to unsuitable for drinking purpose.

**Table 4.** Sample calculation of WQI for Ward no.1

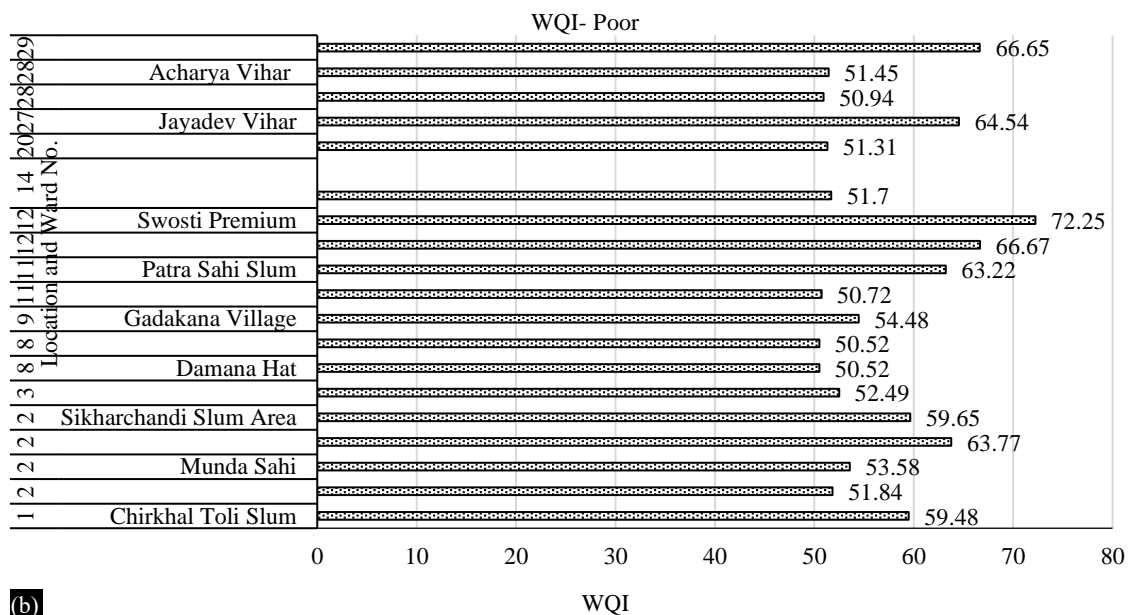
S/N	1	2	3	4	5	6		
<b>Parameter</b>	pH	Conductivity	Alkalinity	Chloride	Hardness	TDS		
<b>si</b>	8.5	300	200	250	200	500		K=
<b>1/si</b>	0.117647	0.003333	0.005	0.004	0.005	0.002	0.13698	7.300315
<b>Unit Weight (wi=k/si)</b>	0.858861	0.024334	0.036502	0.029201	0.036502	0.014601	1	
<b>STW1 (qi)</b>	40	40.73333	26	14.768	104.5	15.886		
<b>STW2 (qi)</b>	20	27.6	32	17.04	150.5	10.764		
<b>STW3 (qi)</b>	60	96.66667	28	29.536	85	37.7		
<b>STW4 (qi)</b>	13.33333	86.66667	29	28.736	84.5	33.8		
<b>STW5 (qi)</b>	0	60	29.5	25.312	86	23.4	WQI=	
<b>Infocity PS Area (qiwi)</b>	34.35	0.99	0.95	0.43	3.81	0.23	40.77	
<b>Western Apartment (qiwi)</b>	17.18	0.67	1.17	0.5	5.49	0.16	25.17	

<b>Chirkhal Toli Slum (qiwi)</b>	51.53	2.35	1.02	0.86	3.1	0.55	59.42	
<b>Silicon College Area (qiwi)</b>	11.45	2.11	1.06	0.84	3.08	0.49	19.04	
<b>Future Bhubaneswar School Area (qiwi)</b>	0	1.46	1.08	0.74	3.14	0.34	6.76	
<b>Quality of Water in WQI</b>							25	

The computed WQI values of groundwater samples were found to be in range of 6.76 to 112.3 The WQI values obtained for the groundwater samples are given below in Table 4 and Fig. 3 (a-d).



(a) Samples with Very Poor/ Unsuitable for drinking WQI.



(b) Samples with Poor WQI



Groundwater is found to be hard in all the locations in ward 12 and some samples in wards 6, 7, 13, 16, and 29. Groundwater quality is excellent to good in all the samples in Ward 6, 7, 10, 15, 17, and 26. On the other hand, groundwater quality is found to be poor in Chirkoli Toli Slum, KIIT Campus, Patia Village, and Damana Haat in Wards 1, 2,3 and 8 respectively. Out of the four samples from ward 3, the tube well of Patia village shows water quality deterioration. Similarly, Gadakana Village in Ward 9 and Patra Sahi Slum in Ward 1, NABARD office qtrs. in Ward 13, Buddha Park in Ward 14, Nayapalli Police Area in Ward 28, Reserve Police in Ward 29 are found to have poor groundwater quality. 80% samples in Ward 12 and 66.67% samples in Ward 16 fall in poor to very poor-quality range for drinking purpose. The poor quality indicates a high impact of local conditions, which include land use and associated anthropogenic activities. The highest WQI value was found to be 112.3 for the samples collected from the DCP Office Area, which makes it unfit for drinking. The analysis of the groundwater samples reveals around 22% samples are acidic in nature whereas high pH is found in Radhakrushna Temple and the DCP office area. The values for WQI for different Wards reveal that WQI is 112.3 in DCP Office Area in Ward 29, that makes it unsuitable for drinking (IS10500, 2012).

The interpolation values of WQI has been shown in Figure 4 using ArcGIS technique as shown in Fig. 4. It is observed that overall, 68% of samples are in excellent and good range, 30.8% are in poor to very poor range and one sample is found to be unfit for drinking. Most of the locations showing poor and very poor groundwater quality are around slum areas or highly populated areas with high density. The anthropogenic activities with increasing population and burden on existing infrastructure are a threat to the quality of groundwater, which may create health hazards and other quality issues in next few decades.

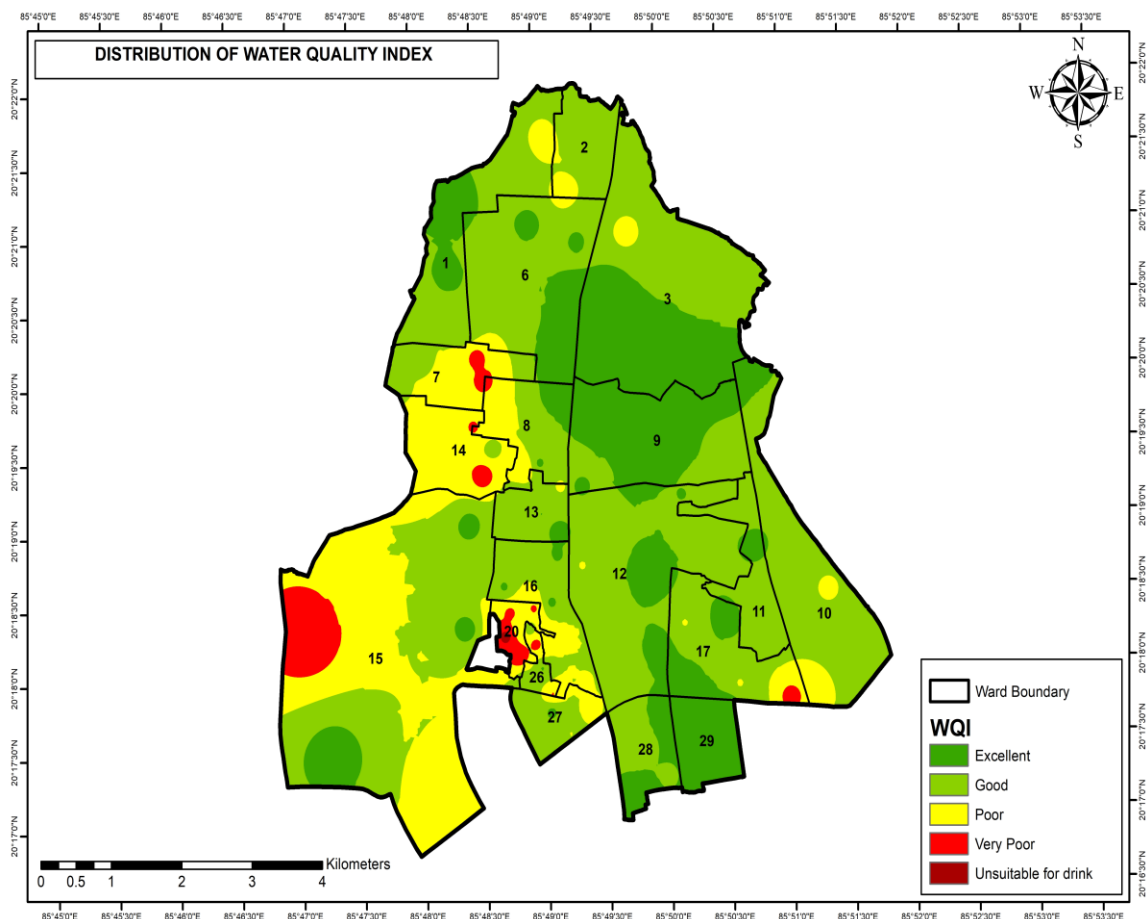


Figure 4. Interpolation of WQI.

## CONCLUSIONS AND RECOMMENDATIONS

Finally, the WQI values indicate nearly 70% of shallow tube wells are under safe condition and 30% of the tube wells have got contaminated due to the lack of maintenance. Deteriorated groundwater quality is observed in the samples taken from the shallow tube wells near slums and high-density areas. The poor quality of groundwater may be attributed to low pH value, disposal of untreated waste, siting of tubewells close to the toilets, leakage or spilling of overused septic tanks, unplanned drainage leading to direct disposal of wastewater in the open drains. This study highlights the immediate need for regular monitoring of the vulnerable resources which is the key element for sustainable development.

Although, WQI with Weighted Arithmetic Mean Method is commonly used to assess the quality of water, it is important to select the parameters carefully and limit the number of parameters used, else the results may be insignificant. In addition, other methods of calculation for the water quality index can be used for analysing groundwater quality, integrating more than one mathematical technique for assessing more reliable WQI.

## Acknowledgement

The above research work is in reference to the ICSSR Project titled ‘Anthropogenic and Geogenic contamination of ground water in Bhubaneswar urban catchment -A systematic Investigation.’ (F.No. 02/147/2021-22/ICSSR/MJ/RP). Accordingly, the authors would like to thank ICSSR for the opportunity to explore the Ground water quality from different sources of ground water.

## REFERENCES

1. Singh, A.; Panda, S.N.; Uzokwe, V.N.E.; Krause, P. An Assessment of Groundwater Recharge Estimation Techniques for Sustainable Resource Management. *Groundw Sustain Dev* 2019, 9.
2. Mishra, P.; Jena, D.; Samal, K.P.; Dibat, N. Urbanization and Groundwater Quality: A Case of Bhubaneswar in Odisha, India. *Turkish Online Journal of Qualitative Inquiry* 2021, 12, 5520–5529.
3. Zingoni, E.; Love, D.; Magadza, C.; Moyce, W.; Musiwa, K. Effects of a Semi-Formal Urban Settlement on Groundwater Quality Epworth (Zimbabwe): Case Study and Groundwater Quality Zoning. *Physics and Chemistry of the Earth* 2005, 30, 680–688, doi:10.1016/j.pce.2005.08.008.
4. United Nations The United Nations World Water Development Report 2022. *Groundwater: Making the Invisible Visible*; Paris, France, 2022;
5. Central Groundwater Board (2014) *Groundwater Year Book; 2013-2014; 2014;*
6. City Sanitation Plan for Bhubaneswar, *Sanitation Action Plan 2017; 2017;*
7. Bu, J.; Sun, Z.; Ma, R.; Liu, Y.; Gong, X.; Pan, Z.; Wei, W. Shallow Groundwater Quality and Its Controlling Factors in the Su-Xi-Chang Region, Eastern China. *Int J Environ Res Public Health* 2020, 17, doi:10.3390/ijerph17041267.
8. El-Fadel, M.; Findikakis, A.N.; Leckie, J.O. *Environmental Impacts of Solid Waste Landfilling; 1997; Vol. 50;*
9. Houéménou, H.; Tweed, S.; Dobigny, G.; Mama, D.; Silmer, R.; Babic, M.; Ruy, S.; Chaigneau, A.; Socohou, A.; Dossou, H.-J.; et al. *Degradation of Groundwater Quality in Expanding Cities in West Africa. A Case Study of the Unregulated Shallow Aquifer in Cotonou; 2019;*
10. Kaown, D.; Hyun, Y.; Bae, G.-O.; Lee, K.-K. Factors Affecting the Spatial Pattern of Nitrate Contamination in Shallow Groundwater. *J Environ Qual* 2007, 36, 1479–1487, doi:10.2134/jeq2006.0361.
11. Ketchemen-Tandia, B.; Boum-Nkot, S.N.; Ebondji, S.R.; Nlend, B.Y.; Envoutou, H.; Nzegue, O. Factors Influencing the Shallow Groundwater Quality in Four Districts with Different Characteristics in Urban Area (Douala, Cameroon). *Journal of Geoscience and Environment Protection* 2017, 05, 99–120, doi:10.4236/gep.2017.58010.
12. Samal, K.P.; Pradhan, A.K.; Tarai, A. Assessment of Seasonal Variation of Water Quality in Bhubaneswar Urban Catchment Using Water Quality Index Method. In; 2023; pp. 76–94.
13. Miller, W.W.; Joung, H.M.; Mahannah, C.N.; Garrett, J.R. *Identification of Water Quality Differences in Nevada through Index Application; Wiley Online Library, 1986;*

14. Ponsadailakshmi, S.; Sankari, S.G.; Prasanna, S.M.; Madhurambal, G. Evaluation of Water Quality Suitability for Drinking Using Drinking Water Quality Index in Nagapattinam District, Tamil Nadu in Southern India. *Groundw Sustain Dev*2018, 6, 43–49.
15. Rajankar, P.N.; Gulhane, S.R.; Tambekar, D.H.; Ramteke, D.S.; Wate, S.R. Water Quality Assessment of Groundwater Resources in Nagpur Region (India) Based on WQI. *E-Journal of Chemistry*2009, 6, 905–908.
16. Štambuk-Giljanović, N. Comparison of Dalmatian Water Evaluation Indices. *Water environment research*2003, 75, 388–405.
17. Tyagi, S.; Sharma, B.; Singh, P.; Dobhal, R. Water Quality Assessment in Terms of Water Quality Index. *American Journal of Water Resources*2013, 1, 34–38, doi:10.12691/ajwr-1-3-3.
18. Dash, S.; Kalamdhad, A.S. Science Mapping Approach to Critical Reviewing of Published Literature on Water Quality Indexing. *Ecol Indic* 2021, 128.
19. Swain, S.; Sahoo, S.; Taloor, A.K. Groundwater Quality Assessment Using Geospatial and Statistical Approaches over Faridabad and Gurgaon Districts of National Capital Region, India. *Appl Water Sci*2022, 12, doi:10.1007/s13201-022-01604-8.
20. Ram, A.; Tiwari, S.K.; Pandey, H.K.; Chaurasia, A.K.; Singh, S.; Singh, Y. V. Groundwater Quality Assessment Using Water Quality Index (WQI) under GIS Framework. *Appl Water Sci*2021, 11, doi:10.1007/s13201-021-01376-7.
21. Subba Rao, N.; Srihari, C.; Deepthi Spandana, B.; Sravanthi, M.; Kamalesh, T.; Abraham Jayadeep, V. Comprehensive Understanding of Groundwater Quality and Hydrogeochemistry for the Sustainable Development of Suburban Area of Visakhapatnam, Andhra Pradesh, India. *Human and Ecological Risk Assessment*2019, 25, 52–80, doi:10.1080/10807039.2019.1571403.
22. Pandey, H.K.; Tiwari, V.; Kumar, S.; Yadav, A.; Srivastava, S.K. Groundwater Quality Assessment of Allahabad Smart City Using GIS and Water Quality Index. *Sustain Water Resour Manag*2020, 6, doi:10.1007/s40899-020-00375-x.
23. Karmakar, B.; Singh, M.K.; Choudhary, B.K.; Singh, S.K.; Egbueri, J.C.; Gautam, S.K.; Rawat, K.S. Investigation of the Hydrogeochemistry, Groundwater Quality, and Associated Health Risks in Industrialized Regions of Tripura, Northeast India. *Environ Forensics*2021, doi:10.1080/15275922.2021.2006363.
24. Kurakalva, R.M.; Kuna, G.; Vaiphei, S.P.; Guddeti, S.S. Evaluation of Hydrogeochemical Profile, Potential Health Risk and Groundwater Quality in Rapidly Growing Urban Region of Hyderabad, South India. *Environ Earth Sci*2021, 80, doi:10.1007/s12665-021-09661-z.
25. Tirkey, P.; Bhattacharya, T.; Chakraborty, S.; Baraik, S. Assessment of Groundwater Quality and Associated Health Risks: A Case Study of Ranchi City, Jharkhand, India. *Groundw Sustain Dev*2017, 5, 85–100, doi:10.1016/j.gsd.2017.05.002.
26. Baloch, M.Y.J.; Zhang, W.; Chai, J.; Li, S.; Alqurashi, M.; Rehman, G.; Tariq, A.; Talpur, S.A.; Iqbal, J.; Munir, M.; et al. Shallow Groundwater Quality Assessment and Its Suitability Analysis for Drinking and Irrigation Purposes. *Water (Switzerland)*2021, 13, doi:10.3390/w13233361.
27. Şener, Ş.; Şener, E.; Davraz, A. Assessment of Groundwater Quality and Health Risk in Drinking Water Basin Using GIS. *J Water Health* 2017, 15, 112–132.
28. Mishra, P.; Jena, D.; Thakur, R.R.; Chand, S.; Javed, B.; Shukla, A.K. Peri-Urban Floodscapes: Identifying and Analyzing Flood Risk Areas in North Bhubaneswar in Eastern India. *Water (Switzerland)*2024, 16, doi:10.3390/w16213019.
29. Das, M.; Nayak, A.K.; Das, B.; Verma, O.P. Groundwater Quality Assessment and Mapping Using Multivariate Statistics and Analytic Hierarchy Process in Bhubaneswar City, Odisha, India. *International Journal of Water*2018, 12, 195–207, doi:10.1504/IJW.2018.093668.
30. Srivastava, S.K.; Bhargav, J.S.; Kumar, Y.S. Contamination of Shallow Groundwater of Bhubaneswar City Due to Urbanization. *Pollut Res*2014, 33, 139–145.
31. Achary, G.S.; Mohanty, S.K.; Pattanaik, N. Comparative Study over the Years of Ground Water Quality in Bhubaneswar City. *International Journal of Current Engineering and Technology* 2013, 3, 1720–1729.
32. Majumdar, S.A.; Nayak, A.K.; Misra, S.N. The Perception Study of Water Supply and Drainage in the City of Bhubaneswar. *International Journal of Civil Engineering and Technology*2019, 10, 664–670.

- 
33. Groundwater Year Book India 2022-2023; 2023;
  34. Rice, E.W.; Bridgewater, L. APHA, 2012. Standard Methods for the Examination of Water and Wastewater; American public health association Washington, DC, 2012; Vol. 10;.
  35. Qureshimatva, U.; Maurya, R.; Gamit, S.; Patel, R.; Solanki, H. Determination of Physico-Chemical Parameters and Water Quality Index (Wqi) of Chandlodia Lake, Ahmedabad, Gujarat, India. J Environ Anal Toxicol 2015, 05, doi:10.4172/2161-0525.1000288.
  36. BIS (Bureau of Indian Standard) (2012) 10500, Indian Standard Drinking Water Specification, Second Revision; 2012;