Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 6, July 2021: 5520-5529

Urbanization and Groundwater Quality: A Case of Bhubaneswar in Odisha, India

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Abstract

Bhubaneswar, the capital city of Odisha, has been declared as an outstanding smart city and is under continuous process of urbanization. The escalating population of the city along with massive influxes of migrants, is triggering unplanned, uncontrolled, and unrestricted urban sprawl, which is contributing to exorbitant changes in the spatial footprints of the city. It is irony that although being surrounded by rivers on three sides of the city, ground water resources are based for domestic, industrial and agricultural uses due to lack of piped water supply system in many parts of the urban area and the fringes. The rapid growth of the city has led to profound pressure on the precious groundwater resource degrading both quality and quantity. In addition, most of the unsewered parts of the urban areas are elevating the nitrate and other contaminants in the groundwater. The remediation of the resource under incessant threat by both contamination and inappropriate use may be practically impossible in future. Since trend detection of hydrologic data is useful in the investigation of water quality parameters, in this study, eight physical chemical variables of groundwater quality of Bhubaneswar obtained from Odisha Pollution Control Board from 2010 to 2017 were analyzed using the non-parametric Mann-Kendall test. Spatial variations of Sen Slope displaying the positive values with large magnitude in the Secretariat area indicates that the groundwater quality is declining at a higher rate. The quality may not be an issue presently but may be alarming in next few decades

Keywords: Groundwater quality, Contamination, Urbanization, Trend Analysis, Mann-Kendall

1. Introduction

More than half of the world's population resides in the urban areasas per World Bank, 2018, which is expected to increase to nearly 70% by 2050. Urban areas comprise of a wide range of various land use features, high population densities, huge infrastructure development, high resource consumption, and enormous waste production. Inappropriate land use, especially poor land management, results in widespread, long-lasting, and harmful pollutant inputs into groundwater, causing chronic groundwater quality issues (Lerner & Harris, 2009). Groundwater quality is being compromised by the upland and untreated disposal of domestic and industrial wastes, the increasing use of pesticides and chemical fertilizers, seepage from septic tanks, and sewage. Groundwater systems underneath cities serve as the "absolute drain" for urban contaminants, and degree to which contaminant loads affect groundwater greatly depends on the aquifer system's vulnerability (S. Foster et al., 2010).The change in land use land cover results in the alteration in vegetation, topography, natural drainage, soil permeability, and surface water body characteristics that further alters the recharge and groundwater dynamics (Brown et al., 2005), and affect the quality of groundwater (Vasanthavigar et al., 2010). Moreover, unsewered urban areas profoundly pollute the environment (Rayne & Bradbury, 2011; Schenck et al., 2015). Groundwater quality is being radically altered as a result of urbanization, indicating increasing salinity, nitrogen compounds, microbiological degradation and contamination by petroleum products as well (S. S. D. Foster et al., 1998). Cities may thus incite a higher risk of groundwater pollution compared to neighbouring agricultural areas (Marsalek et al., 2008). The effects of these influences can be seen in critical environmental issues, particularly in developing countries where urban growth is not always planned ahead of time and necessary infrastructure system lags far behind the population growth (Khazaei et al., 2004).

As an active part of the hydrologic cycle, groundwater is widely recognized as a valuable and fragile resource (Aeschbach-Hertig & Gleeson, 2012). In recent decades, dryingwetlands, rapid declining of aquifer water levels, seawater intrusion, and degradation of water quality have been observed (Famiglietti & Rodell, 2013), giving more potential to the groundwater research, covering a number of subjects, such as groundwater geochemical and hydrological processes, groundwater interactions, surface water, land use and climate change (El-Fiky, 2010).

The quality of groundwater is largely affected by the hydrogeology of the area. Natural processes alter the PH, alkalinity, phosphorus loading, fluoride content, sulphate and iron concentrations of the water. In comparison to the hard rock aquifers, alluvial regions are more prone to degradation at a faster rate. As a result, alluvial aquifer groundwater quality and health need more stringent monitoring, whichparticularly becomes relevant in the aspect of policy initiatives.

Anthropogenic factors affecting urban groundwater quality include industrial and domestic effluents, untreated biological wastes discharged fromhospitals, quarries, recreational activities, storm water runoff, leachate from landfills, wastelands and lot more. In many parts of the world, land filling of urban solid waste is a traditional waste management technique and one of the cheapest methods for waste management (El-Fadel et al., 1997). The leakage and spillage of petroleum-based fuels have mild influences on taste and odor, but cause toxicity in higher concentrations. Heavy metals, mercury, coliforms, and nutrient loads are all increasing as a result of these anthropogenic factors (Khatri et al., 2017). Moreover, infiltration of waste water effluents in urban areas increases the nitrogen and phosphorus and may contribute to eutrophication in surface water bodies (Holman et al., 2008).

In urban areas, leaking sewers and septic tanks can spread bacterial and viral diseases such as cholera and typhoid. As per the report of Central Groundwater Board, India, high levels of mercury may cause neurological disorders, impairment of brain functions, retarded growth in children, abortion and disruption of the endocrine system. Toxic or carcinogenic pesticides can damage the liver and nervous system. In more than 1.1 lakh habitations across the world, high levels of iron (>1.0 mg/l) have been detected in groundwater. Overabundance of iron can lead to serious health problems such as liver cancer, diabetes, cirrhosis of the liver, heart and nervous system disorders, infertility, and so on (V. Kumar et al., 2017). In almost all hydrogeological formations in India, high Nitrate concentrations in groundwater have been discovered. Nitrate concentrations in water that exceed the allowable limit of 45 mg/l have serious health consequences, such as methemoglobinemia (also known as blue baby syndrome), increased risk of cancer, especially gastric cancer (CGWB, 2014).

Various districts of Odisha reveal problems of salinity (EC>3000 micro siemens/cm), high concentration of iron, high Electrical Conductivity and high Chloride, Nitrate, and Fluoride content in groundwater (BOOK & Delhi, 2020).

The management of such problems necessitates a holistic approach as well as public policies that reinforce sustainable planning and management of land and water resources at a regional as well as local level. A strong connection needs to be developed between the economic forces, land use, and landscape effects (Singh, 1999).

2..Methodology

Mann-Kendall’s Test

This non-parametric trend test was proposed by Mann (1945) and Kendall (1975), which does not require any particular distribution of data. It has been commonly used in hydrology to check for randomness against trends. This test uses the relative values of all terms in the series X={x1, x2,…,xn} to be analyzed. The analysis by Mann-Kendall sets data time sequential order, and computes significance (Sgn) of the difference between consecutive sample output. The results of Sgn would be in the values 1, 0, or –1 according to the significance of Xj – Xi where j >i, the formula computes as:

- If Xj-Xi>0 .... Sgn(Xj-Xi)=1
- If Xj –Xi=0........ Sgn(Xj-Xi)=0
- If Xj-Xi<0......... Sgn(Xj-Xi)=-1

Here Xj and Xi are the sequential values in years J and i (J>i) respectively and a +ve value indicates an upward trend, and vice versa.

Xj represents the data point at time J. Mann-Kendall statistics (S) is defined as the total number of positive contrasts minus the number of negative contrasts as expressed in the following formula:

$$S = \sum_{(n-1)}^{(k=1)} \sum_{j=k+n}^{n} sgn(Xj - Xi)$$

The value of 'S' determines if the trend is positive or negative when it is high or low, and the probability associated is needful to calculate with 'S' and the sample size 'n'. The variance of S (Var S) when sample size > 10 is calculated as:

$$\text{Var S} = \frac{[n\ (n-1)\ (2n+5) - \sum_{g=1}^{m} tg\ (tg-1)(2tg+5)]}{18}$$

g= 1, 2,…, q

Where Var(S) is the variance of statistics Mann-Kendall; 'M' can be interpreted as the number of data that has the same value (tied group), and define 'n' as the sum of available data, also 'tg' is the sum of the data points in g[th] group, 'Z' (standardized test statistic) is calculated as:

$$When\ S > 0 \ldots\ldots Z = \frac{n-1}{\sqrt{var(S)}}$$

$$When\ S = 0 \ldots\ldots Z = 0$$

$$When\ S < 0 \ldots\ldots Z = \frac{n+1}{\sqrt{v}ar(S)}$$

Many values of 'Z' are there (1.645, 1.960, 2.576) to determine the significance level of 10, 5, and 1 percent respectively. A Z-score follows a standard normal distribution and it is better to use when the statistical significance is an upward or downward trend of values. Generally, if the result is found to be more than Za/2; it will be the trend of significance; where 'a' is the significance level, to test if the trend is an upward or a downward monotone (a two-tailed test).

Estimator (Sen's Slope)

This test provides the trend magnitude of trend data of the time series. Then, for all data pairs, the slope (Qi) can be calculated as follows,[21]:

$Qi = \frac{xj-xi}{j-i}$ for i = 1,2,…..N

Here at time (years J and i), it can be xj and xi as data values where (j>i) correspondingly. Qi (Sen's estimator of slope) is represented by the average of these N values and it is

given as: $Qi = \{Q_{[(N+1)/2]} \quad if\ \ N\ is\ odd0\, \frac{Q_{[N/2]}+Q_{[(N/2)/2]}}{2} \quad if\ \ N\ is\ even$

The +ve value of Qi shows an upward trend while a -ve value of Qi gives the opposite result. Qi is calculated at 100 (1-α) per cent confidence interval and by a both sided test.

In 2014, in the study by Achary, the Water Quality Index (WQI) was used to ascertain the appropriateness of groundwater quality for drinking purposes in the Bhubaneswar, in Khordha district of the state of Odisha, India. For the calculation of the water quality index, eight parameters (excluding TC (Total Coliform) and FC (Faecal Coliform)) were considered such as pH, conductivity, turbidity, chloride, total dissolved solid, total hardness, iron, nitrate from various samples in Bhubaneswar. The Nitrate, had been chosen as an ideal tracer to estimate the vulnerability of the area where hazardous pollutants from sewage seep into the underground water structures, along with the percolating water (Achary, 2014).

Study Area

Bhubaneswar, historically depicted as Ekamra Kshetra, is the capital and largest smart city of Odisha. This city is the hub of information technology along with economic, health and education sectors. The modern city was planned on a neighborhood concept by the German architect Otto Königsberger in 1946 that boasted of planned infrastructure with ample green spaces. Though the initial part of the city followed the plan, the city could not be at pace with the sprawl and resulted in uncontrolled, unplanned growth over the next few decades, resulting in sprawl beyond the reach of planning, as in case of many of the developing cities. The city presently lacks organized open spaces, parks and recreational areas that are an important component of the urban ecosystem. There has been a large scale degradation of Chandaka forest area and the green cover. The rural urban fringes are portraying more unplanned growth with shrinking of agricultural lands. Urban growth followed by increasing built-up areas and paved areas has damaged the natural land cover of the city.

Location of Bhubaneswar City

Bhubaneswar is situated between 20º12'N and 20º25'N latitude and $85^0$44'E to $85^0$55'E longitude crosses the main axis of the eastern Ghats in Khordha district. The city is divided into 67 wards and the Bhubaneswar Municipal Corporation has jurisdiction over an area of 186 square kilometers. The city is dumbbell-shaped with most of the growth towards the north, northeast and southwest. The growth of the city in the east is restricted by the Kuakhai River and the in the northwest by the Chandaka wildlife sanctuary. The population has seen a leap from 16,512 in 1951 to 1,131,000 in 2019. Figure 1 shows a map showing the location of Bhubaneswar.

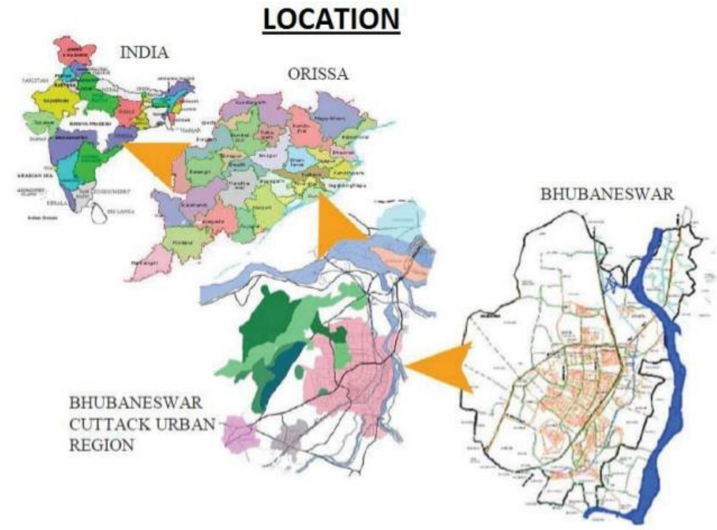

Figure 1. Location Map of Bhubaneswar City

This city is bordered on the south by the Dayanadi River and on the east by the Kuakhai River, which are both non-perennial and thus have low discharge during summers. In the city's extreme south-east corner, the River Kuakhai is split into the Bhargavi and Daya Rivers. Besides the rivers, from the western upland area, a variety of small streams originate in the city and flow mainly towards east and south east, eventually joining the Kuakhai or Daya Rivers. River Mahanadi in the North, though perennial, is under the stress of water due to obstruction of the river water through several barrages in Chhatisgarh. The rivers Daya and Kuakhai which get supplementation from Mahanadi and groundwater sources are in turn at a tremendous loss. Adding to the scenario, many natural drains in the city like Gangua, Buri, Chatra have been encroached and converted into Nullah, carrying the sewage and rainwater run-off and have turned out to be highly polluted (Joshi, A., Mishra, 2017).

Hydrogeomorphology of Bhubaneswar

The western and central parts of Bhubaneswar have undulating upland topography, while the east and south east have more or less level topography with a gentle slope. The upland areas have lateritic cover, and the western section is dotted with isolated hillocks made up of Upper Gondwana shale-sandstone sequences from the Athgarh Formation. The gently sloping areas are often covered in alluvial material, with or without a thin lateritic layer on top (CGWB, 2014). The altitudes ranging from 60 meters in the west to 15 meters in the far east. The lateritic and weathered sandstones have a water table depth of 5-12 m, while the broken and friable sandstones have a water table depth of 40-50 m, creating deeper aquifers that are semi-confined or confined. In December, the maximum depth of groundwater is upto 6m which drops to 8m in May (Achary, 2014). The natural slope of the city facilitates drains to flow into the rivers. The lineaments are very important for groundwater regime. They show secondary porosity and weak zone, which assists precipitation in reaching the groundwater and regenerating it The main lineament directions are W-S and N-W (Figure 2-3).

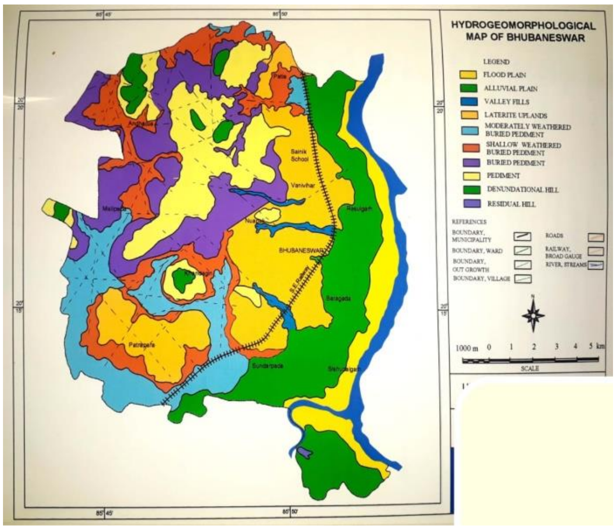

Figure 2. Hydrogeomorphological map of Bhubaneswar.

Source: CGWB.

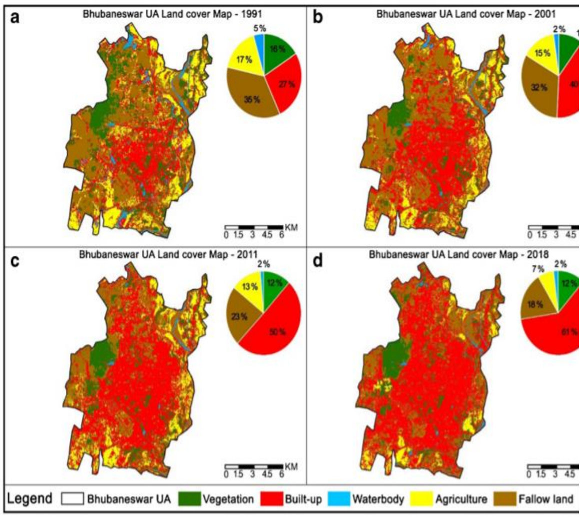

Figure 3. Spatiotemporal land cover map of Bhubaneswar urban area from 1991-2018. Source: Chettry, 2020.

Urbanization and Groundwater Quality

According to the 2011 census, the decade population growth rate of Bhubaneswar was about 30%, which is significantly high. Owing to rapid urbanization, the city has undergone major changes in land use land cover with 77% increase in the built-up area (Anasuya et al., 2019), Between 2000 and 2015, there was a massive 89 percent decrease in dense vegetation and an 83 percent decrease in crop fields (Swain et al., 2017). There is also a dominant expansion of the industrial and residential areas (Thandar, 2012). Urban built up area has seen a huge leap from 49.94sq km in 1991 to 112.95 sq km 2018 (Chettry & Surawar, 2020). In addition to this, the area under inland surface water has decreased to 27.06% (4.3415 sq km) from 16.0390 sq km in 1995 to 11.6975 sq km in 2016 owing to rapid urbanization, urban sprawl, and inadequate solid waste management (S. A. Kumar & Biswajit, n.d.). The changes in land cover in Bhubaneswar has been shown in Figure 4.

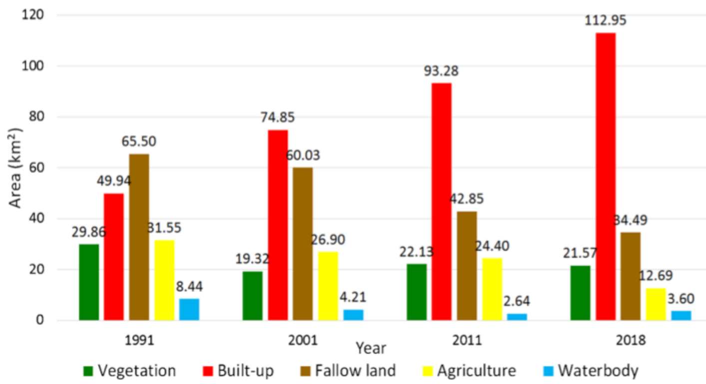

Figure 4. Land cover classification of Bhubaneswar (1991-2018)

Source: Chettry, 2020.

The built-up area has increased dramatically, with significant increases in residential, vacant land, institutional, and industrial areas. Residential construction that is unplanned is more costly than development that is planned at the expense of agricultural and forest land. The consequences of urbanization not only cause changes in land use, resulting in landscape degradation, land encroachment, and decline of vegetation cover, but they also cause unnoticed groundwater disruption. The major challenges to groundwater have been identified in Table 1 (Thandar, 2012).

Table 1 Major Groundwater quality challenges in Bhubaneswar

Aspect	Situation	Gap
Drains	• Drain length of 340 km. • 10 are natural drains with a total length of 71 km. • Drain coverage is 45% of the road network length in Bhubaneswar. • Most of the area's natural drains have now been converted to Nullah, such as Gangua, Buri, Chatra, and others, which carry sewage and rainwater run-off from most of the area.	• 54.78% of total 90 MLD generation of sewage of the city is flowing through these storm water drains. 49.3 MLD of waste water, which includes septic tank overflows in the absence of soak pits, as well as black water from toilets that are directly attached to the drains (1.08 percent) and wastewater from the sewerage network (33%) is conveyed to the open drains in the absence of sewage treatment plant (Service Level Improvement Plan, Bhubaneswar, 2015). • The encroachment of these drains have reduced the groundwater recharge and are posing a threat to groundwater quality.
Fecal Sludge Management		
Containment	• Septic tanks are used by 41.4 percent of the population (with and without soak pits), • Toilets linked to pits are found in 6.8% of households (this includes pits with and without slabs and latrines serviced by humans and animals) • 1.1% of the households release their liquid waste directly into drains and • 4.2 percent of toilets are connected to other containment units.	• Presently there are no standards followed or enforced for the containment size and the construction mostly depends on space available within the house. • Design of septic tanks is not controlled through building/ planning rules. • In many cases, septic tanks are inaccessible for cleaning, as they are built with no accessible manhole for cleaning. • Most septic tanks are built with no soak pits, and the outlets of these tanks are let into the open environment through storm water drains.
Disposal and treatment	• There are 4 dumping sites for the municipal owned trucks for disposing the fecal sludge. • There is no existing treatment facility in the town • The construction of 75 Cu m STP is under process and which would cater to around 14-18 wards (nearly 20% of the town)	• Currently, there are unsafe fecal sludge/septage disposal procedures (STP was due in Oct, 2017, but not yet functional) • The disposal point/treatment plant site is farther away from the city center. • There is currently no incentive system or legislation in place to encourage the disposal of waste at a treatment facility.
Solid Waste Management		
Generation	• Households and small commercial= 420MT • Bulk waste generators= >100MT • 520 MT of waste is created every day.	-
Collection	• Both the Municipal Corporation and private service companies are responsible for waste disposal. • Out of total 67 total wards 10 wards are handled by MC and 57 wards outsourced	• The cost of collection has increased as a result of the collection of non-segregated waste. • Low frequency of door to door waste collection in slums and lower income settlements. • Absence of collection system in fringe areas.
Segregation and Treatment	• No household segregation • No treatment of waste • All collected waste is dumped at dumping yard at Bhuasuni without any treatment and processing • There is no separation between biomedical and sanitary waste disposal.	• No incentives are given to promote segregation at source • Increase in garbage heaps is affecting environment • There is no scientific landfill for inert waste disposal.

Source: City Sanitation Plan for Bhubaneswar, 2017.

In the city, there is a lack of a proper sewage system. There are several places where septic tanks are used to discharge to open drains, and the septic tanks are overburdened (most parts of all the administrative Units from Unit-1 to Unit-9, and Jaydev Vihar, Jharpada, Old Town, Bhauma Nagar), and including areas where discharge is to open drains through oxidation ponds, but the oxidation ponds are overburdened. The proposed treatment plants and sewage disposal system is facing delays in construction and functioning may take another few years. These areas are highly dense areas with lack of proper, overused or damaged system available. This is posing a huge threat to the quality of groundwater.

Existing groundwater sensitive areas in Bhubaneswar include Reserved forests, parks and open spaces, agricultural lands, river Daya and Kuakhai, wetlands and natural drains. The fertile and hydrogeologically crucial tracts of the rivers, lakes and drains are being rapidly encroached by unorganized/ illegal housing, indiscriminate dumping of garbage, sewage, and construction wastes. The wetlands are facing the challenges of conversion and encroachments. This is further affecting the flora and fauna. Large developments in the flood prone areas which are marginally suitable for development, obstructing the natural drainage systems is further imposing threat to groundwater quality.

3. Findings

In trend analysis, it is important to determine the rate from which the trend is either decreasing or increasing. For calculating rate, Sen slope has been estimated for all parameters. Spatial variations of slope are shown in Table 1 and 2. The negative values with large magnitude show that the water quality is declining at a higher rate.

Eight parameters- pH, Conductivity, BOD, Turbidity, TDS, TH, Nitrate, Iron have been taken for the study for six locations in Bhubaneswar city by Odisha State Pollution Control Board. The Mann-Kendall trend test results show they do not have a significant variation for all locations.

Table 2 Mann-Kendall test (Z) and Sen's Slope (Q) estimator results during the period 2010-2017

Location	Location	Ph		CONDUCTIVITY		BOD		Turbidity	
	Code	Z	Q	Z	Q	Z	Q	Z	Q
Khandagiri Area	1	1.36	0.21	-0.12	-11.117	-1.5	-0.2	1.75	4.37
Capital Hospital	2	0.62	0.083	0.12	2.667	-1.63	-0.125	0	0.254
Samantaraypur	3	0.12	0.079	0.37	16.429	0	-0.2	-1.36	-2.125
Jharpada/ Laxmisagar	4	-0.87	-0.285	1.36	10.292	-0.88	-0.112	-1.11	-2.158
Chandrasekharpur	5	0.5	0.055	-0.37	-7.217	-0.87	-0.125	-1.11	-4.283
Secretariat	6	-0.12	-0.071	**1.86***	24.567	**-1.75**	-0.183	-1.61	-9.025

***significance level = 0.01; **significance level = 0.05; *significance level = 0.1

Table3 Mann-Kendall test (Z) and Sen's Slope (S) estimator results during the period 2010-2017

Location	Location Code	TDS		TH		Nitrate		Iron	
		Z	Q	Z	Q	Z	Q	Z	Q
Khandagiri Area	1	-0.12	-9.25	0	0	-0.12	-0.463	0.15	0.171
Capital Hospital	2	-0.12	-1.833	-0.5	-2.333	0.87	0.825	0	0.555
Samantaraypur	3	0.12	5.946	-0.12	-2.25	0	-0.119	-0.3	-0.009
Jharpada/ Laxmisagar	4	1.11	6.875	0.39	0.286	1.36	2.822	0.3	0.335
Chandrasekharpur	5	-0.25	-2.083	-0.75	-2	1.61	0.951	**-2.1****	-1.732

Secretariat	6	**1.86***	13.1	1.06	8.083	0	0.45	-1.2	-1.312

***significance level = 0.01; **significance level = 0.05; *significance level = 0.1

Ph: The acidic character of the water rises marginally in the summer relative to the rainy and winter seasons. It may be attributed to the drop in water level during the summer (Figure 5).

Conductivity: In the Secretariat area**,** the parameter Conductivity experienced a major upward trend throughout the study period, presumably due to the rise in charged ions that formed in the water body. High precipitation results in more soil erosion that normally contributes to the washing down of the charged ions into the water body. (Figure 6)

BOD & COD: Clear hydro-chemical relationship can be readily inferred with high and positive correlation for BOD and COD. (Figure 7)

Total Hardness: The samples from the Secretariat region showed a significant increase in values. For drinking water BOD has to be less than 5 mg/L

TDS: Meanwhile, parameter TDS also shows the greatest amount of upward trends in Secretariat from the year 2010 until 2017. Leaching of salts from soil and also domestic sewage percolating into the groundwater result in high concentration of TDS. In comparison to other seasons, summer samples have a higher concentration of TDS. The degradation of minerals by infiltrating water during the recharge cycle may have been caused by the drying up of the clay material above the water table during the summer (Figure 9).

Turbidity: It is caused by particles like clay and silt, fine organic and inorganic matter, soluble colored organic compounds suspended or dissolved in water and algae and other microorganisms. The taste and odor of drinking water is affected by turbidity and it can act as a shield to pathogens. Point source pollution and land use affect turbidity levels in a body of water.

Iron: Chandrasekharpur area recorded less values. The iron occurs naturally in the aquifers but Due to natural aerial oxidation of iron to its oxides, which then separate out, the iron content in surface water is very low.

Nitrate: Though the levels are under permissible limits, there is a significant increase in levels of nitrate in Jharpada, Samantarapur and Secretariat areas.

The changes in the quality may not be notable presently as compared to the deterioration in quality of other environmental parameters in the region, but the situation would be grave in next few years if suitable actions are not taken for the control.

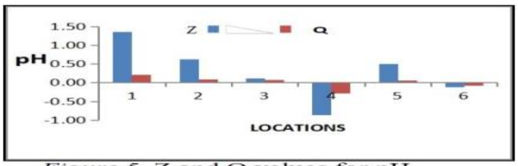

Figure 5. Z and Q values for pH

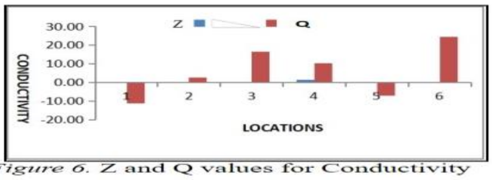

Figure 6. Z and Q values for Conductivity

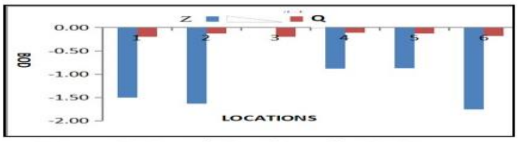

Figure 7. Z and Q values for BOD

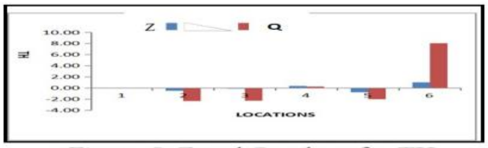

Figure 8. Z and Q values for TH

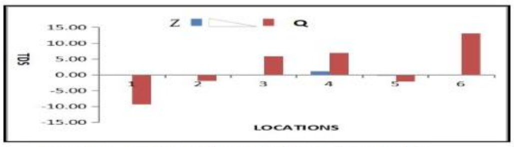

Figure 9. Z and Q values for TDS

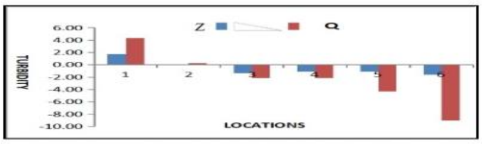

Figure 10. Z and Q values for Turbidity

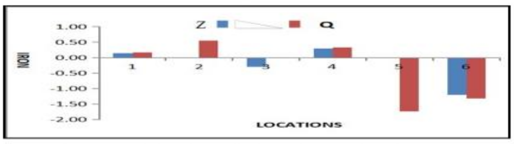

Figure 11. Z and Q values for Iron

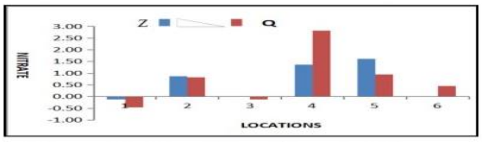

Figure 12. Z and Q values for Nitrate

4. Discussion and Conclusion

To overcome disputes between groundwater and land use, it is important to understand the intimate relationship between groundwater and urban growth and land use, as well as groundwater vulnerability and resistance to anthropogenic influence and climate change. Overall spatial planning approach in areas along with the mapping for groundwater potential and sensitive zones is required to guide the future development. Since contamination of large aquifers is a gradual and imperceptible process, it can take decades until the full extent of pollution becomes evident. As a result, it's important to recognize the early signs of groundwater contamination by regular monitoring and to focus on reduction rather than remediation. A holistic and interdisciplinary approach for urban water supply and sewage system needs to be mapped out.The disposal of sewage in natural drains only after achieving permissible standards of wastewater, provision of reed bed on drains to further clean up the organic and inorganic matter, regular cleaning and maintenance of the septic tanks, maintenance of drains, strict norms for planning and approval of the projects by the development authority are primary requisites to improve the efficiency of the sewage system of the city. Existing reserved forests require protection from land use conversion. The relationship of urban development and green space preservation is often viewed as a fight between growth and green. A spatial structure of multifunctional green areas can help to ensure the long-term development of groundwater while also improving the quality of life in cities. Regular maintenance and cleaning of the water bodies, ponds and natural wet lands, upgradation of existing parks and open spaces need an immediate action. The natural drains may be widened at some stretches and developed as recreational zones with landscaped areas along the sides that would not only protect the groundwater quality but also improve socio-economic and environmental quality and add aesthetics to the surroundings as well. Little planning interventions may bring great results.

Each city, each area is unique in terms of groundwater potential and demands policies and guidelines that are locally sensitive and relevant, based on socio-economic, environmental and political conditions and future aspirations. Further research can integrate the socio-economic and other ecological parameters to ascertain the further specific effects of urbanization on the groundwater quality.

Acknowledgement

The authors acknowledge the comments by Dr. Usharani Patnaik, Environmental Scientist, State Pollution Control Board, Odisha, Bhubaneswar and Saswat Kumar Pani, Research Schoilar, KIIT Deemed to be University on the paper’s first draft.

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