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**GIS-Based Mapping of Groundwater
 Level Fluctuations and Their
 Impact on Groundwater
 Potential and Assessment of
 Groundwater Development Stage in
 Bhubaneswar (BMC), Smart City,
 Odisha, India.**



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Abstract

Since groundwater is almost always available, dependable, and requires little initial investment, it is the best supply of water for many different types of users in India. Aquifer recharge capacity and other significant environmental considerations are being disregarded in some regions of the nation due to the indiscriminate withdrawal of ground water, which is becoming increasingly necessary as a dependable source of water. A reliable database on groundwater resources is important for the efficient development and management of these resources. The current study was carried out in Bhubaneswar, the capital city of Odisha, India, in this regard. The study area's dynamic groundwater resources have been assessed in accordance with the recommendations of the Groundwater Resources Estimating Committee (GEC-1997), which is part of the Indian government's Ministry of Water Resources. Groundwater recharge had been estimated in this work employing the water table fluctuation method (WTFM), rainfall infiltration factor (RIF) approaches, and other conventional norms. Rainfall and water supply data for the study area had been collected from IMD, Pune & PHE department of Govt. of Odisha. Water table data were observed in 28 numbers of observation dug wells covering the study area, for a period of four years (2020 – 2023) during pre- and post-monsoon periods. The mapping of the WTF for the years 2020 to 2023 was done using ArcGIS 10.3 and their impacts on groundwater potential are studied. The minimum and maximum average water table fluctuation of all four years was found to be 0.1725 to 2.8775 mbgl respectively. The annual groundwater draft for domestic consumption is 2696.71 Ham. In the research region, it is computed that the net annual groundwater availability is 3666.89Ham., whereas the annual groundwater recharge is 4074.33 Ham. A study is done on the use of groundwater and its development stage. The research area's overall groundwater development stage is determined to be 73.54%, placing it in the semi-critical category. For improved groundwater development, appropriate monitoring systems, effective management techniques, and groundwater recharge structures are advised.

Keywords: Water Table Fluctuation Method (WTFM), Rainwater Infiltration Factor (RIF), Stage of Groundwater Development, GEC-1997.

1. INTRODUCTION

Because of the current rate of urbanization, economic growth, and climate variability, surface water supplies cannot keep up with the increasing demand for water (“Wada & Bierkens 2014; Kummu et al. 2016; Mersha et al. 2018”). Groundwater is therefore exploited as a substitute source of food production, water supply, as well as economic development. Due to its low cost and good quality, groundwater is favoured for many applications (Custodio et al. 2016). Numerous sources worldwide have reported on groundwater overexploitation (“Pophare et al., 2014; Shahid et al., 2015; Chang et al., 2017; Figueroa - Miranda et al., 2018; Molle et al., 2018; Li et al., 2020”). In addition to the effects of climate change and growing population pressure, the rate of overuse and groundwater depletion will make it challenging to manage the resource responsibly for future generations (Schewe et al., 2014; Zhou et al., 2016). Natural replenishment rates have not kept up with the water demands. Land degradation may be the cause of this. As per GEF_land_degradation_bifold_2019, 95percent of Earth's land areas may experience degradation by 2050 if the current pattern of degradation persists. Groundwater levels consequently decrease as a result. The long-term viability of groundwater extraction depends on the recharge of the ground. However, some of the rainfall that helps replenish the reservoir is insufficient. One of the requirements for efficient groundwater resource management is the quantitative assessment of natural groundwater recharge and discharge. Natural “groundwater recharge refers to the fraction of precipitation that infiltrates the Earth's surface and ultimately reaches the water table within the unsaturated zone. Groundwater recharge is the primary hydrologic factor affecting the availability and sustainability of groundwater resources (Vu & Merkel 2019; Sanford 2002”). An essential part of the groundwater system, recharge has a big impact on how water resource management plans are implemented (Tan et al. 2014). According to Ebrahimi et al. (2016) and Ali & Mubarak (2017), precise recharge estimation is crucial for maintaining groundwater use over the long term, making legitimate assessments about groundwater allocation, and evaluating the danger of groundwater contamination.

Various studies use various techniques for estimating groundwater recharge at various spatiotemporal scales. There are several ways to estimate “groundwater recharge, ranging from easy to difficult. Recharge has been determined employing a water table fluctuation (WTF) approach (Delottier et al. 2018), empirical approaches (Falalakis & Gemitzi 2020; Andualem et al. 2021”), lysimeter (Zhang et al. 2020; Gong “et al. 2021), an integrated surface water as well as groundwater modelling technique (Chemingui et al. 2015), soil moisture budget (Noorduijn et al. 2018), water balance

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approach (Dhungel & Fiedler” 2016), baseflow separation (Coes et al. 2007), seepage meter (Michael et al. 2003), stable isotopes (Jesiya et al. 2021), chloride “mass balance (Yin et al. 2011; Crosbie et al. 2018), Darcy’s method (Yin et al. 2011), geographic information system (GIS)-based technique and satellite imageries (Batelaan & De Smedt” 2007), modeling technique (Ebrahimi et al. 2016; Mogaji & Lim 2020), etc. Applying several recharge estimation techniques improves the accuracy of recharge estimates, claim Healy & Cook (2002). Many approaches are used to estimate recharge, but there are still many natural and man-made factors that make this field difficult to determine. According to “Holman (2006), Choi et al. (2012), Wu et al. 2021). Land use, land cover, slope of the landscape, subsurface” and surface interaction, soil properties, geologic heterogeneity, climatic change, human variables, and more are some of these. The choice of estimating approach is influenced by the researcher’s background and the accessibility of the intended data gathering.

This study presents the RIF and WTF approaches. The WTF approach is the most popular technique for calculating recharge; nevertheless, it necessitates knowledge of precise yield as well as variations in water levels over time. This strategy’s main advantages are its ease of use along with insensitivity to the way that water passes through the unsaturated zone. Therefore, this study’s goal was to use the WTF approach to better understand groundwater recharge. In order to standardize the process for recharge calculation, the Indian government created the Ground Water Calculation Committee (GEC), which approved the WTFM in addition to the rainfall infiltration factor method (RIFM). The groundwater balancing technique forms the foundation of the GEC-1997 methodology. First released in 1984, the comprehensive methodology and recommendations of the GEC were later updated in 1997.

India’s city with one of the quickest rates of growth, Bhubaneswar, the capital of Odisha State, is having a difficult time meeting the rising demand for water as a result of urbanization and population expansion. The primary source of freshwater in Bhubaneswar is groundwater. The Odisha PHE Department and WATCO state that groundwater provides 49.255 million liters per day (MLD) of the total 273.155 MLD of water supply in Bhubaneswar City (BMC) (Table 4- 4). In addition, substantial groundwater withdrawal is occurring via private wells to fulfil domestic and other demands.

This study uses ArcGIS 10.3 to analyse the unique distribution of water table fluctuations over four years (2020–2023) from groundwater dug well data. The assessment of groundwater resources is conducted by analysing various recharge processes in the research area, which is among India’s rapidly developing cities, utilizing the groundwater balancing methodology. The groundwater balance equation is used to determine the overall recharge and groundwater utilization status by applying the GEC-1997 methodology and guidelines for assessing the various components of groundwater recharge.

2. STUDY AREA AND ITS ENVIRON

2.1 Study Area

The Odisha city of Bhubaneswar is located in the Khurda district’s Bhubaneswar Block. It is located in geographic coordinates “between 20°12’N and 20°25’N and 85°44’E and 85°55’E. Location on toposheets 73 H/15 and 73 H/16 from the Survey of India” (CGWB, Bhubaneswar, Odisha, 2010), scaled at 1:50,000. Bhubaneswar is categorized as both a city and a Class I Urban Agglomeration based on the findings of the 2011 Census, which was carried out by the Indian government. The Municipal Corporation is in charge of running the city of Bhubaneswar, which is a component of the Bhubaneswar Urban Region. In Bhubaneswar, there are 886,397 residents. In total, there are 417,820 females and 468,577 males. (Source: Indian Government Census, 2011). The city master plan area of Bhubaneswar Municipal Corporation (BMC) spans 233 sq. km, despite the municipal boundary of BMC being just 186 sq. km. The fundamental governing divisions of the city are its 68 wards. At 45 meters above mean sea level, the city rises. (Figure 1).

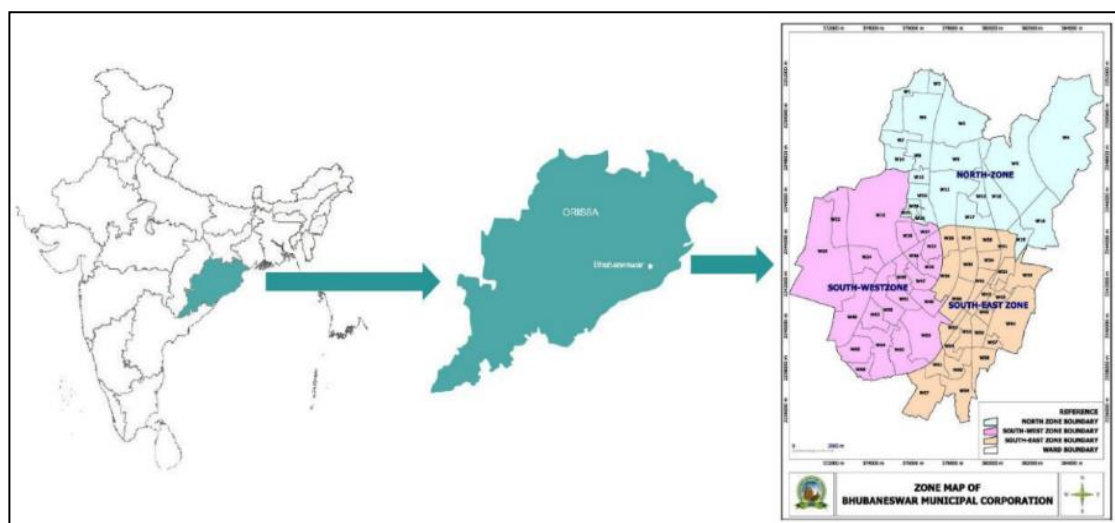


Fig-1. Map Showing the Study Area.

2.2. Topography

While eastern half of Bhubaneswar has a reasonably level topography with a moderate incline towards the east or southeast, the western as well as central regions of the city are characterized by undulating uplands. "Lateritic cover is found in the highland areas, whereas alluvial cover predominates in the gently sloping slopes, with a thin lateritic cover in certain places," the East Coast Railway line roughly demarcates the various physical configurations. The western highlands are dotted with hilltop outcrops made of the Upper Gondwanan shale-and-sandstone sequence known as the Athgarh Formation. The region has an eastern coastal plain that extends parallel to the Eastern Ghats Mountain range, with an average height of 15 to 60 meters above mean sea level (CGWB, Bhubaneswar-2010).

2.3. Climate and Rainfall

The research location experiences humid subtropical weather. The rainy season, occurring from June to September yields an average annual precipitation of 1596.44mm due to the southwest monsoon (1981 to 2023). The subsequent period is the dry season, occurring from early November until May. May is the warmest month, with a mean daily temperature of 38°C, while December is the coldest, averaging roughly 16°C daily. The summertime high is 48°C, and the wintertime low is 9.4°C. Relative humidity varies between 48% and 85%, with rare maxima exceeding 95%. At the time of summer and monsoon seasons, wind speed is fairly significant, with primary winds coming from the south and southwest. The wind speed is approximately 14km/h on average. The CGWB-2013 report reveals that the mean monthly potential evapotranspiration varies from 57mm in January to 248mm in May.

2.4. Geology

The study area is principally made up of Athgarh Formation formed during lower Cretaceous period belonging to Upper Gondwana Group. Quaternary alluvium covers the research area's eastern and southern regions. Sandstone, grit, conglomerates, and some white or reddish clays make up the Athgarh formation (Krishnan, 1982). The majority of the sandstone in the Athgarh Formation is categorized as quartz arenite, sub-lithic arenite, lithic arenite, as well as lithic waxes (Mishra, 1988). Along with conglomerates and grits, it also includes carbonaceous shales, variegated shales, and fine clay, the majority of which are tiny lenticular bodies that break up the monotonous expanse of sandstones. The results from the borehole drilling show that sandstone is commonly found deep in much of the research area. Shale is commonly found in the southern portion of the region. Athgarh Formation's upper portion has some lateralization. Laterites as well as alluvial deposits make up the majority of the quaternary formations. The laterite primarily covers the country rock in nearly every region of the Athgarh Formation. The maximum laterite thickness in the southeast region is 13 meters, with an average thickness of 2 to 5 meters. In general, thick laterites cover is seen in the research area's southeast. The research area's extreme eastern and southeastern regions are inhabited by thin layers of quaternary alluvial deposits made up of clay, silt, as well as fine to medium coarse sand, with a maximum thickness of about 30 to 40 meters. The Athgarh Formation lies beneath the alluvial deposits.

2.5. Soil

Alfisols and Ultisols are two categories for the soils in the study area.

Alfisols: This soil type, sandy loam, is found in the city's eastern section. The pH of the soil ranges from 6.5 to 7.3, and they are typically low in nitrogen and phosphorus.

Ultisols: The remainder of the city is covered by lateritic and laterite soils, commonly referred to as red clay soil. These soils are defined by a compact to vermicular mass in the sub-soil horizons; the surface horizons contain more than 40% clay, and the soil is mostly composed of a mixture of hydrated oxides of iron and aluminum, without any alkali or alkaline earth metals (2010, CGWB).

2.6. Aquifer Characteristics

2.6.1. Phreatic Aquifer

As per CGWB (2008) the dug wells on various phreatic aquifers of the study area, i.e. sandstone, laterite, valley fills, and alluvium has shown the specific capacity (C) varying from 9 to 18 lpm per one meter of drawdown in valley fills, 24 to 36 lpm per one meter of drawdown in weathered sandstones/laterites, and 48 to 72 lpm per one meter of drawdown in alluvium.

2.6.2. Confined, Semi-Confined and Leaky Aquifer

The drawdown and recovery test data collected during the pumping test of two bore wells in the deeper aquifers located at Central Reserve Police Force Campus (case A) and Central Poultry Farm Compounds (case B) by CGWB in 1985, in the study area which were critically analyzed (Nayak et al. 2008) for evaluation of aquifer parameters of deeper fractured zones. The depths of the wells are 150.07 mts. and 98.7 mts. The static water levels are 8.64 mts. and 12.3 mts with discharges of 33.23 m³/hour and 36.774 m³/hour with drawdowns of 5.742 mts. and 6.565 mts., cumulative thickness of the fractured zones is 64.5 and 50.2 mts. The Aquifer Performance Test (APT) was conducted for 480 minutes for case – A, and 360 minutes for case – B respectively. In general, the Athgarh formation (Sandstone) in the study area is extended from a confined to semi-confined (slightly leaky) aquifer with a Transmissivity (T) value that varies from 72.149 to

260.725 m²/day, Hydraulic Conductivity (K) value varies from 1.44 to 1.94 m/day and Storativity (S) varies from 0.015 to 0.087.

3. METHODOLOGY

3.1. Water Table Fluctuation Mapping

This section of the study work's general methodology is prepared as a flow chart (Fig. 2). 28 dug wells were surveyed and chosen for the present and upcoming research. To obtain the best possible spatial representation of the areas, a good selection is made. The study area was marked using a portable GPS (GARMIN GPSMAP® 86i) to determine its latitude as well as longitude. Water levels were determined with an electronic portable water-level meter (SOLINST-101). Seasons prior to and following the monsoon have been used for measurements. These seasonal data were used to calculate the variations in water level. The geostatistical toolbox in ArcGIS 10.3 had been employed to map the seasonal fluctuations in water level. One type of stochastic model that aids in precisely predicting random values in the intended places is geostatistical analysis (Uyan & Cay, 2013). One popular and useful interpolation method is kriging (Borges et al., 2016; Wu et al., 2019). It operates under the fundamental premise that locations closer to known points would comparable values that are similar to those of locations farther away (Kumar, 2007).

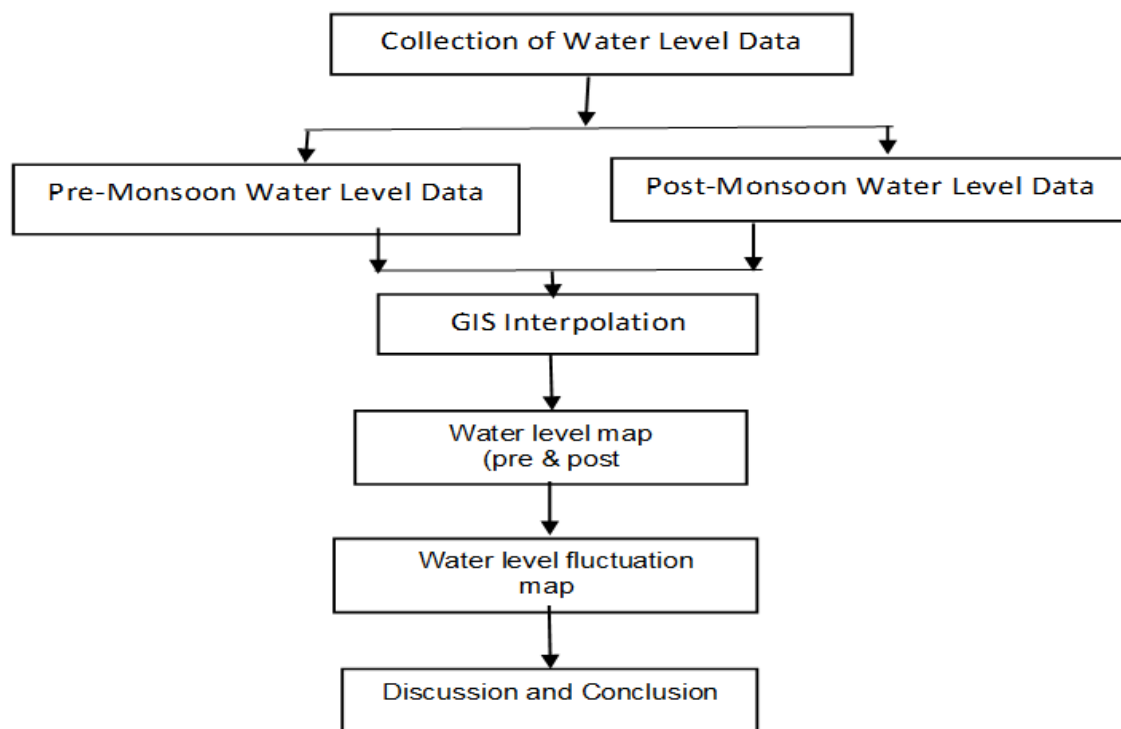


Fig- 2: Detailed Methodology for WTF Mapping.

3.2. Assessment of Groundwater Development and Staging

A group of specialists with experience in groundwater disciplines developed the GEC-1997 criteria, which are used to evaluate the state's dynamic groundwater resources (CGWB, 2004). The GEC-1997 model is predicated on the seasonal calculation of groundwater recharge in an assessment unit using an empirical norm during non-monsoon seasons and a lumped water balance technique during monsoon season. The Indian government created the committee, with participation from NABARD, several academic and scientific institutes, and federal and state authorities. The commencement of the monsoon season in one calendar year and the end of the monsoon season in the following calendar year constitute the groundwater year (12 calendar months) upon which a groundwater recharge assessment is based (CGWB, 2004). During May or June of one year and June or July of the following year, Bhubaneswar receives the southwest monsoon.

Since the research area (Bhubaneswar) receives the majority of its groundwater recharge from monsoon rainfall, there are two ways to determine rainwater recharge during the monsoon season.:

- Rainfall Infiltration Factor Method (RIFM) and
- Water Table Fluctuation Method (WTFM)

Governing Equations for Recharge Estimation

Since monsoon rainfall is the primary source of recharging in the research area and non-monsoon rainfall is neglected, recharge is approximated for the monsoon season.

a. Water Table Fluctuation Method (WTFM).

The overall change in storage and gross draft during the monsoon season (for an evaluative unit) is the possible recharge at the time of the monsoon season after subtracting natural discharges.

$$R = S + DG \quad \text{----- Eq}^n \text{ (i)}$$

$$S = h * S_y * A \quad \text{----- Eq}^n \text{ (ii)}$$

Here;

h = Water level fluctuation between pre and post-monsoon.

S = Change in the ground water storage.

A = Area of the assessment.

DG = Gross ground water draft.

R = Recharge during monsoon.

S_y = Specific yield of the aquifer.

The ratio of water that may be drained by gravity from a soil or rock after saturation to its own volume is known as the specific yield. Grain size, shape, pore distribution, stratum compaction, and discharge timing all affect specific yield values.

b. Rainfall Infiltration Method

$$R = F * A * P \quad \text{----- Eq}^n \text{ (iii).}$$

Here; R = Recharge during monsoon.

A = Area of the assessment.

P = Normal rainfall during monsoon season.

Percentage Difference (PD)

$$PD = \frac{[(R, \text{ by WLF Method}) - (R, \text{ by RIF Method})]}{(R, \text{ by RIF Method})} \times (100) \quad \text{-----Eq}^n \text{ (iv)}$$

If;	i) PD is within (- 20 % to + 20 %), then,	R = R (WTFM)
	ii) PD is less than (- 20 %), then,	R = 0.8 * R (RIFM)
	iii) PD is more than (+20 %), then,	R = 1.2 * R (RIFM)

Table- 1: Values of potential difference in %age (GEC-1997).

In Alluvial Area (water logged and shallow water table condition)

$$\text{Potential "Ground Water Resources"} = [(5-D) * A * Y]. \quad \text{----- Eq}^n \text{ (v)}$$

Where; D = Pre-monsoon depth of water level.

A = Area of the assessment.

Y = Specific yield of the aquifer.

Stage of ground water development

In accordance with GEC-1997 criteria, the" groundwater development stage (%) is determined as follows:

$$\% \text{ age development of groundwater} = \left[\frac{\text{Gross annual ground water draft}}{\text{Net annual ground water resources}} \right] \times 100.$$

Stage "of Ground Water Extraction/development	Category
≤70%	Safe
>70% and ≤90%	Semi-critical
>90% and ≤100%	Critical
>100%	Over" Exploited

Table- 2: Stage of Ground Water Extraction/Development and their Category ("GEC-1997)

Sl. no.	Rock type	Specific yield (Sy) as a fraction			Rainfall infiltration factor (F) as a fraction		
		Recommended	Maximum	Minimum	Recommended	Maximum	Minimum
1	Karstified limestone	0.080	0.15	0.05	0.06	0.07	0.05
2	Sandstone	0.030	0.05	0.01	0.12	0.14	0.10
3	Weathered granites, gneiss and schist with low clay content	0.030	0.04	0.02	0.11	0.12	0.10
4	Laterite	0.025	0.03	0.02	0.07	0.08	0.06
5	Limestone	0.020	0.03	0.01	0.06	0.07	0.05
6	Weathered granites, gneiss and schist with significant clay	0.015	0.02	0.01	0.08	0.09	0.05
7	Quartzite	0.015	0.02	0.01	0.06	0.07	0.05
8	Phyllites, shales	0.015	0.02	0.01	0.04	0.05	0.03
9	Massive poorly fractured rock	0.003	0.003	0.002	0.01	0.03	0.01
10	Alluvial areas:						
	Sandy alluvium	0.16	0.20	0.12	--	--	--
	Silty alluvium	0.10	0.12	0.08	--	--	--
	Clayey alluvium	0.06	0.08	0.04	--	--	--
	East Coast	--	--	--	0.16	0.18	0.14
	West Coast	--	--	--	0.10	0.12	0.08

Table 3: Norms for specific yield (GEC-1997)

Groundwater Draft (DG)

WATER SUPPLY DATA FOR BHUBANESWAR BY PHED & WATCO 2019-20 TO 2022-23													
YEAR	Name of the District /ULB	Name of the Office	Total Daily Supply (MLD)			Total Water Demand (MLD) @135/155 lpcd	Rate of Supply (lpcd)	Total No. of functional HPTWs	Total No. of Service Connections	Total No. of Stand-posts	Total No. of Wards	Sources	
			Ground water	Surface Water	Total							Surface Sources	Groundwater (P Wells & Open Wells)
2019-20	Khurda/ BBSR	PHD Division- I, II & III, BBSR	58.15	222.55	280.7	157.83	276	3459	105102	2883	67		331
2020-21		WATCO-I & II	46.29	224.35	270.64	180.27	233	2928	139261	1036	67	Mahanadi, Kuakhai, Daya	299
2021-22		WATCO-I	46.29	224.35	270.64	180.56	233	2928	140869	1036	67		299
2022-23		WATCO-I	46.29	224.35	270.64	180.56	232.71	1541	158900	250	67		299
4 years		Average	49.255	223.9	273.155								

Table 4: Groundwater and surface water data for Bhubaneswar City. Source: Govt. of Odisha.

I. Four years (2019-20 to 2022-23) Annual Average Groundwater draft by PHE Dept. & WATCO-I & II, for authorized domestic water supply to the Bhubaneswar (BMC) population estimated as = 49.255 MLD or 17,978.1 ML/Yr = 1797.81 Ham. (Table 4).

II. Draft of Groundwater extracted for other purposes including domestic in an unauthorized manner @ 50% of authorized supply, where water supply is not done by the Govt.

= (50/100) X 1797.81 Ham = 898.9 Ham (GEC-1997)

Hence, the gross annual groundwater draft = DG = (I + II) = (1797.81 + 898.9) = 2696.71 Ham.

Ground Water Resource Estimation

The study area, Smart City Region of Bhubaneswar (BMC), can be divided into two ground water assessment units: (A) Athgarh Formation Area (Semi consolidated Sandstone), and (B) Quaternary Alluvium (East Coast) Area. The ground water resources of the two units are estimated below;

(A) Athgarh Formation Area**(i) By Water Table Fluctuation Method (WTFM).**

Total Athgarh Formation Area (A) = 190 Sq. Km = 19000 Hect.

Average water level fluctuation (Table - 6) = h =

$[(1.2+1.091+1.264+1.381) / 4] = 1.234$ mts.

The specific yield of the aquifer, (Table -3), (S_y) = 0.03

The modification in ground water storage = $S = (h \times S_y \times A) = (1.234 \times 0.03 \times 19000) = 703.38$ Ham.

Total Ground Water Draft = DG = 2696.71 Ham

Annual groundwater recharge estimated by WTF method = R = (S + DG)

= (703.38 + 2696.71) = 3400.09 Ham.

ii. By Rainfall Infiltration Method (RIFM)

Average monsoon rainfall (average of 2020 to 2023) = $P = 1530.7525 \text{ mm} = 1.531 \text{ Mts.}$

Rainfall Infiltration Factor, as per Table-3, $(F) = 0.12$

Ground Water Recharge Estimated by RIF method = $R = (F * A * P)$

$= (0.12 \times 19000 \times 1.531) = 3490.68 \text{ Ham.}$

RAIN FALL in Millimeter (mm) from 2020 to 2023.					
YEARS → MONTHS ↓	2020	2021	2022	2023	Average
JANUARY	12.5	0	36.94	0	12.360
FEBRUARY	94.1	0	19.56	0	28.415
MARCH	58.9	5.27	0.2	62.6	31.743
APRIL	98.6	28.35	1.39	64.6	48.235
MAY	150	244.23	103.65	52	137.470
JUNE	88.4	228.39	106.65	186	152.360
JULY	134.3	250.39	365.99	276	256.670
AUGUST	591.2	189.35	381.15	339	375.175
SEPTEMBER	203.8	447.34	209.5	353	303.410
OCTOBER	211.2	147.01	155.9	41	138.778
NOVEMBER	2.8	72.6	0	10	21.350
DECEMBER	0	75.38	0.77	23	24.788
Total Annual Rainfall	1645.8	1688.31	1381.7	1407.2	1530.7525

Table-5: Average Annual Rainfall (Source: NDC, IMD, Pune.)

(iv) Percentage Difference (PD)

$$PD = \frac{[(\text{Recharge by WLF Method}) - (\text{Recharge by RIF Method})]}{(\text{Recharge by RIF Method})} \times 100$$

Percentage Difference (PD) = $[(3400.09 - 3490.68) / 3490.68] \times 100 = (-) 0.026 = (-) 2.6 \%$

As per GEC-1997, the value of PD is within $(- 20 \% \text{ to } + 20 \%)$, hence, groundwater recharge estimated by WTFM is accepted (Table-1).

Thus, Groundwater Recharge of Athgarh Formation Area = $R = 3400.09 \text{ Ham.}$ --- (A)

(B) Alluvium Area

Total Alluvium Area (A) = $43 \text{ Sq. Km} = 4300 \text{ Hect.}$

Pre-monsoon Water levels (Average of four seasons; 2020 to 2023) (Table- 6) = $D = [(3.77 + 3.77 + 4.03 + 4.5) / 4] = 4.0175 = 4.02 \text{ Mts.}$

Specific yield of the aquifer, (Table-3), $(S_Y) = 0.16$

Potential Groundwater Recharge = $[(5 - D) * A * S_Y]$.

----- as per Eqⁿ. (v)

$= [(5 - 4.02) \times 4300 \times 0.16] = 674.24 \text{ Ham}$

Hence, Potential Groundwater recharge estimated as = 674.24 Ham

----- (B)

Total annual replenishable groundwater resources of the study area Smart City Region of Bhubaneswar (BMC) = $(A + B) = 3400.09 + 674.24 = 4074.33 \text{ Ham.}$

Unaccounted annual natural discharge (10%) = $(10/100) \times 4074.33 = 407.433 \text{ Ham.}$

Net Annual Replenished Groundwater Resources in the Research Area

$= (4074.33 - 407.433) = 3666.89 \text{ Ham}$

WATER LEVEL & FLUCTUATION DATA FOR 28 NUMBERS OF DUG WELLS OF SMART CITY, BHUBANESWAR.															
Sl No	Well ID	Lat [0°]	Long [0°]	2020 Pre	2020 Post	2020 Fluctuation	2021 Pre	2021 Post	2021 Fluctuation	2022 Pre	2022 Post	2022 Fluctuation	2023 Pre	2023 Post	2023 Fluctuation
1	W1	20.243	85.797	2.42	0.60	1.82	1.32	0.79	0.53	2.50	0.87	1.63	3.06	1.30	1.76
2	W2	20.250	85.783	2.03	0.05	1.98	2.05	1.25	0.80	2.55	1.30	1.25	3.69	2.25	1.44
3	W3	20.255	85.791	3.86	1.20	2.66	3.77	2.45	1.32	4.10	2.05	2.05	4.89	2.75	2.14
4	W4	20.263	85.792	4.98	3.49	1.49	4.54	3.50	1.04	4.50	3.00	1.50	4.83	3.40	1.43
5	W5	20.289	85.816	5.48	4.55	0.93	4.97	4.31	0.66	5.15	3.85	1.30	7.05	5.35	1.70
6	W6	20.281	85.828	5.89	4.24	1.65	5.09	3.40	1.69	5.85	3.85	2.00	5.92	3.55	2.37
7	W7	20.280	85.837	6.91	6.80	0.11	7.36	6.10	1.26	7.05	6.43	0.62	8.46	7.40	1.06
8	W8	20.277	85.806	6.60	5.73	0.87	7.23	6.18	1.05	7.00	6.20	0.80	8.50	7.50	1.00
9	W9	20.268	85.808	3.72	2.95	0.77	4.22	3.70	0.52	4.50	3.90	0.60	4.60	4.10	0.50
10	W10	20.264	85.818	4.47	4.24	0.23	4.86	4.69	0.17	5.62	4.07	1.55	5.32	3.72	1.60
11	W11	20.237	85.803	6.99	6.17	0.82	7.46	6.35	1.11	7.65	5.25	2.40	7.55	5.90	1.65
12	W12	20.238	85.835	1.07	0.80	0.27	2.84	0.54	2.30	2.54	0.97	1.57	2.64	0.90	1.74
13	W13	20.242	85.840	0.52	0.15	0.37	0.26	0.20	0.06	0.30	0.00	0.30	1.24	0.40	0.84
14	W14	20.258	85.847	2.20	1.30	0.90	2.56	2.00	0.56	2.42	1.65	0.77	3.05	2.25	0.80
15	W15	20.251	85.851	4.61	4.30	0.31	5.23	4.20	1.03	4.75	4.50	0.25	5.18	3.95	1.23
16	W16	20.272	85.797	3.92	3.48	0.44	3.92	3.60	0.32	6.35	3.77	2.58	6.80	4.00	2.80
17	W17	20.299	85.822	2.78	2.06	0.72	2.54	2.05	0.49	3.50	1.23	2.27	4.50	2.40	2.10
18	W18	20.330	85.810	2.32	0.23	2.09	1.39	-0.05	1.44	2.05	0.28	1.77	1.14	0.20	0.94
19	W19	20.345	85.829	4.55	3.55	1.00	5.23	3.21	2.02	5.60	4.90	0.70	6.00	3.50	2.50
20	W20	20.301	85.834	4.86	2.41	2.45	5.09	3.35	1.74	5.35	3.85	1.50	4.90	3.50	1.40
21	W21	20.302	85.834	2.05	0.97	1.08	2.53	0.53	2.00	1.42	0.58	0.84	1.50	0.95	0.55
22	W22	20.307	85.844	1.85	0.75	1.10	1.23	0.33	0.90	1.75	0.38	1.37	1.45	0.65	0.80
23	W23	20.300	85.859	1.95	1.05	0.90	3.52	2.30	1.22	5.00	3.40	1.60	6.80	5.10	1.70
24	W24	20.275	85.859	3.28	1.80	1.48	4.23	3.80	0.43	4.25	4.00	0.25	4.47	4.20	0.27
25	W25	20.343	85.832	5.56	2.15	3.41	2.77	0.05	2.72	2.50	0.45	2.05	2.85	0.95	1.90
26	W26	20.317	85.852	2.82	2.10	0.72	2.28	1.65	0.63	2.40	1.94	0.46	2.90	2.10	0.80
27	W27	20.317	85.854	2.11	1.05	1.06	3.57	2.40	1.17	3.55	2.60	0.95	4.00	2.85	1.15
28	W28	20.289	85.872	5.68	3.70	1.98	3.38	2.00	1.38	2.55	2.08	0.47	2.60	2.10	0.50
Average Value				3.77		1.200	3.77		1.091	4.03		1.264	4.50		1.381

Table- 6: Monitoring Well locations, Water levels & fluctuations 2020 to 2023 Pre & Post Monsoons.

Stage of Groundwater Development

As per guidelines of GEC- 1997, the stage of ground water development (%) is calculated as;

$$\% \text{ age development of groundwater} = \left[\frac{\text{Gross annual ground water draft}}{\text{Net annual ground water resources}} \right] \times 100$$

$$= [2696.71 / 3666.89] \times 100 = 73.54 \%$$

Considering that ground water development is at a stage of 73.54%, which is between 70% and 90%, the study area comes under **semi-critical zone** or category.

Fluctuations Years	2020	2021	2022	2023	Average
Minimum (m bgl)	0.11	0.06	0.25	0.27	0.1725
Maximum (m bgl)	3.41	2.72	2.58	2.80	2.8775

Table-7: Min^m, Max^m and Average Fluctuations (2020-2023) in meters below ground level (mbgl).

4. Impact of Water-Level Fluctuations on Groundwater Potential

Variations in water level had an effect on the area's total groundwater reserve as well as the chemical components of the groundwater (Rajmohan & Elango, 2006; Sajil Kumar, 2016). Different anthropogenic and natural activities that raise or reduce the existing water table might cause variations in groundwater. However, the global decline in water tables is the most prevalent trend (Fan et al. 2013). Groundwater depletion results from excessive pumping from the existing resource, as this study region has previously demonstrated by being designated as semi-critical. The user may incur higher costs as a result of having to deepen the wells.

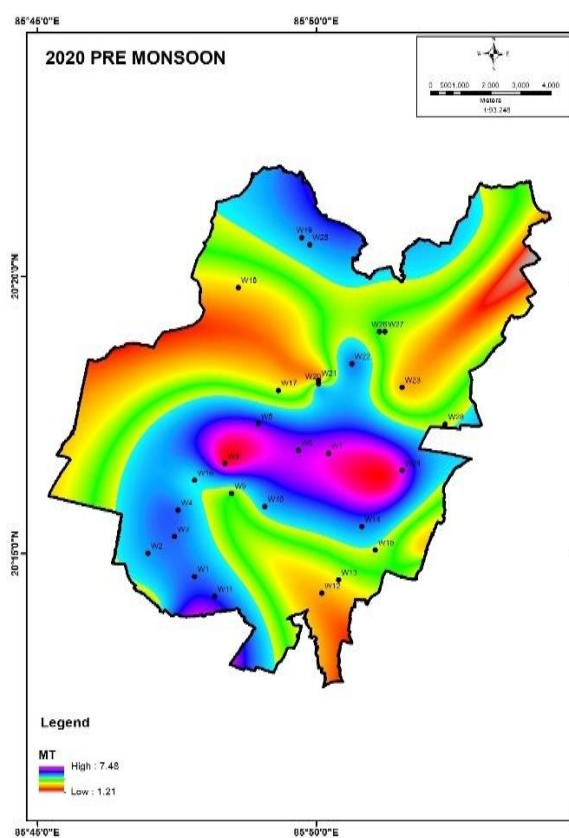


Fig- 3: Ground to Water Table Depth Map (Pre-Monsoon, 2020)

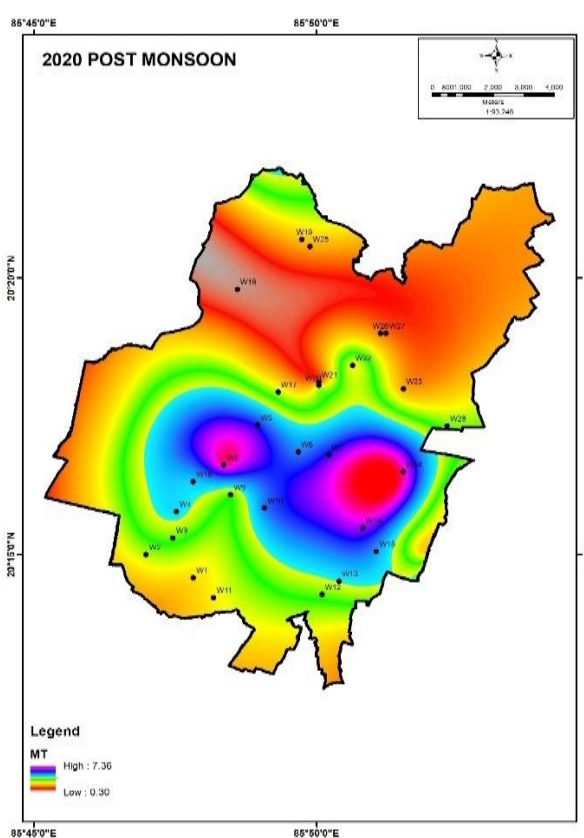


Fig- 4: Ground to Water Table Depth Map (Post-Monsoon, 2020)

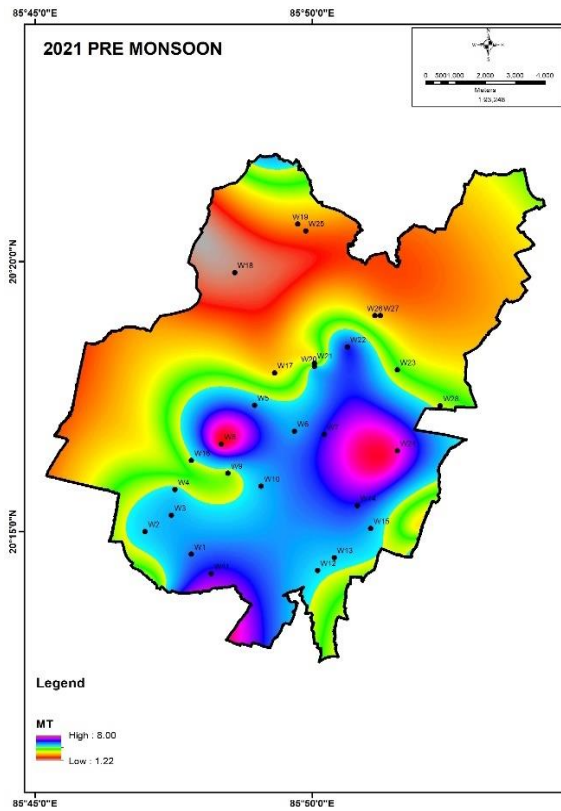


Fig- 5: Ground to Water Table Depth Map (Pre-Monsoon, 2021)

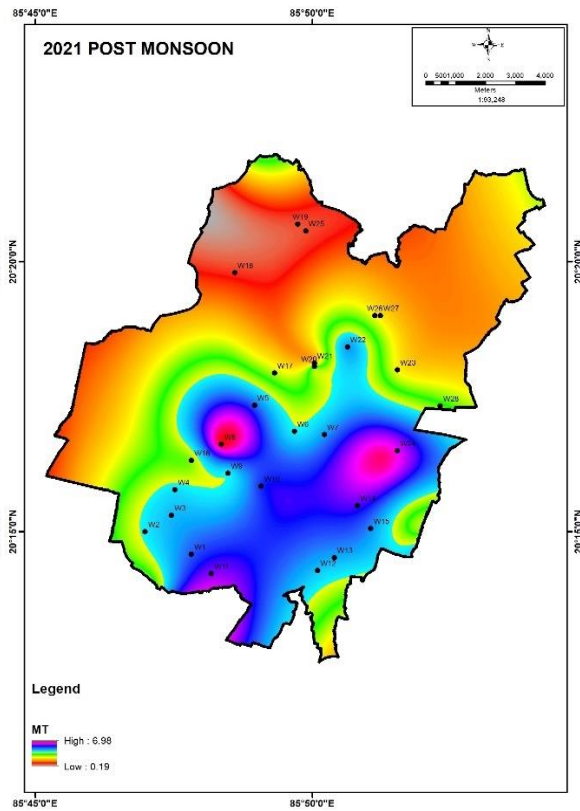


Fig- 6: Ground to Water Table Depth Map (Post-Monsoon, 2021)

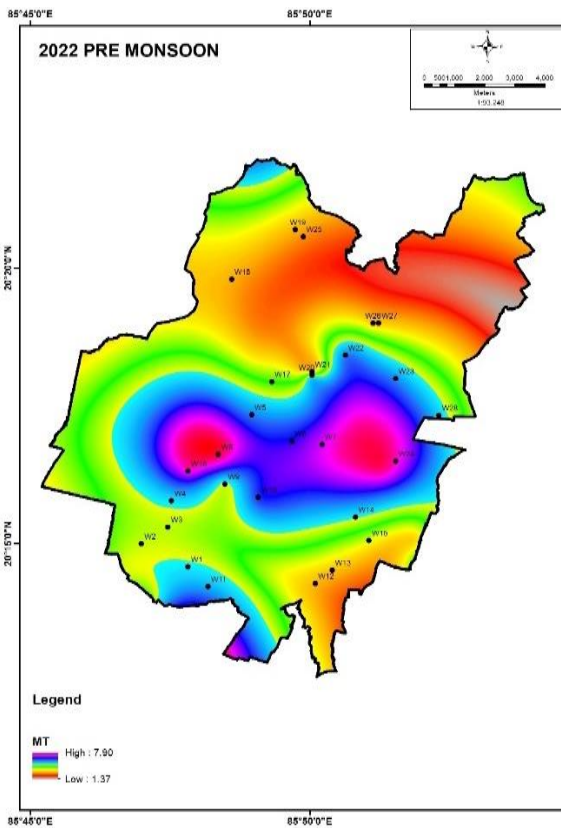


Fig- 7: Ground to Water Table Depth Map (Pre-Monsoon, 2022)

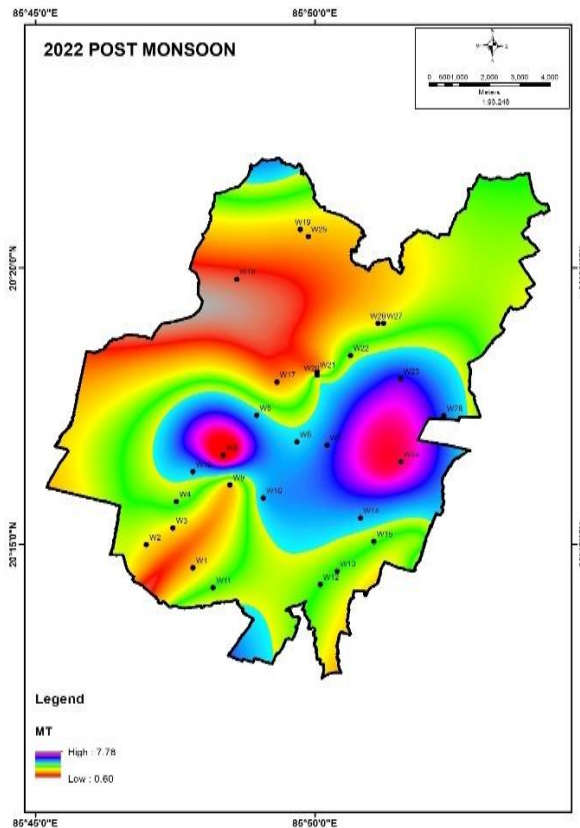


Fig- 8: Ground to Water Table Depth Map (Post-Monsoon, 2022)

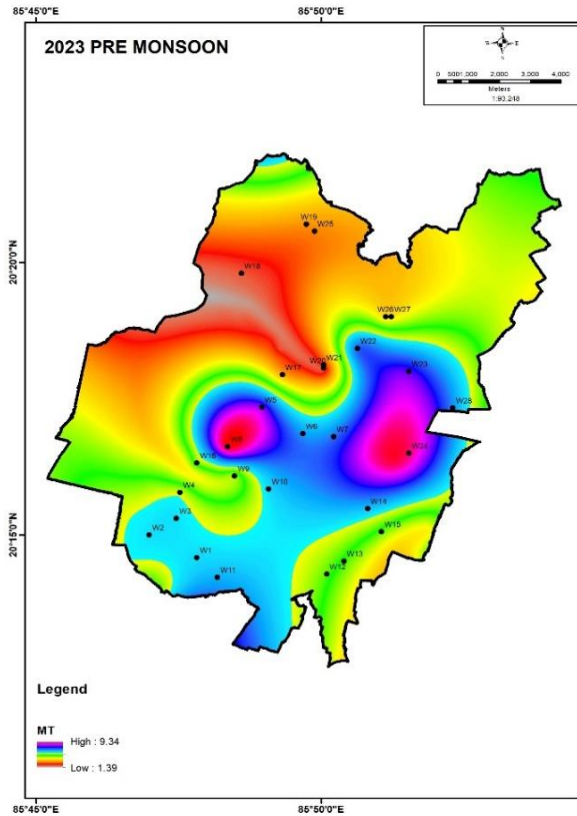


Fig-9: Ground to Water Table Depth Map (Pre-Monsoon, 2023)

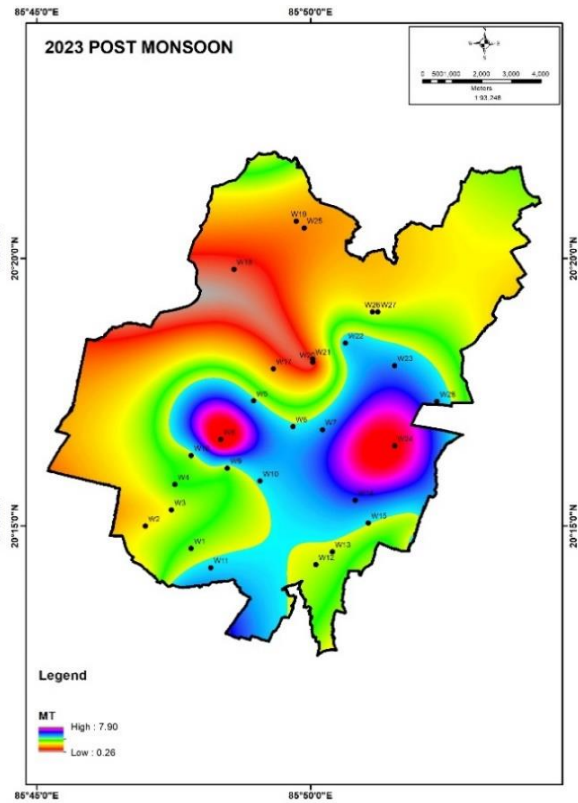


Fig- 10: Ground to Water Table Depth Map (Post-Monsoon, 2023)

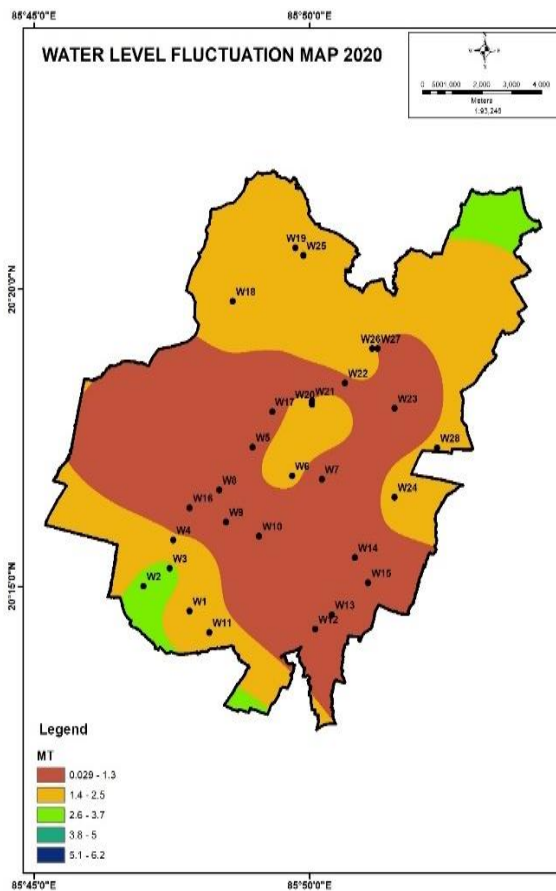


Fig-11: Water Table Fluctuation Map 2020

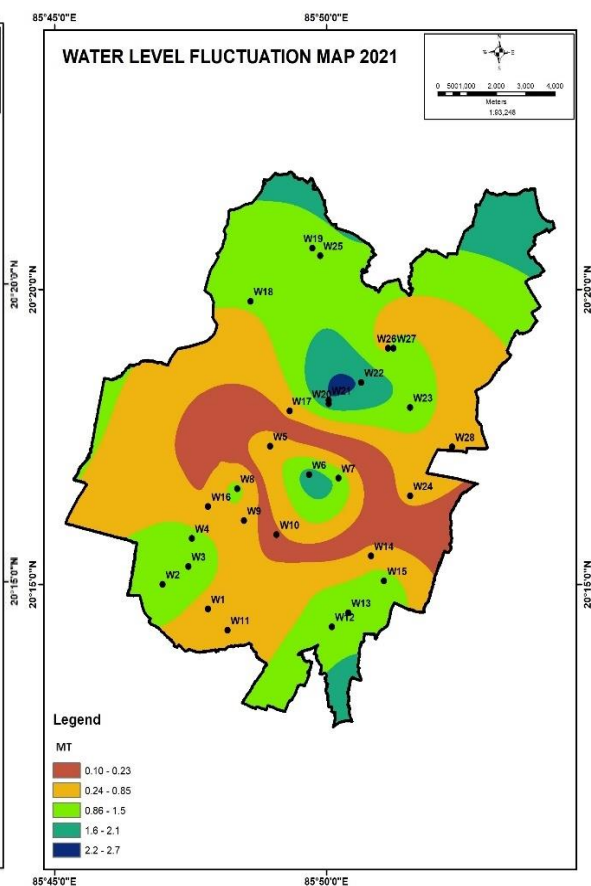


Fig-12: Water Table Fluctuation Map 2021

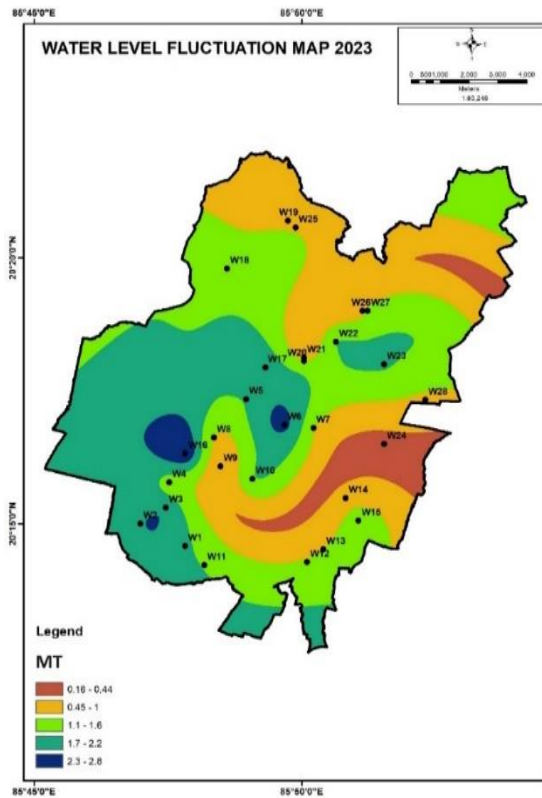


Fig-13: Water Table Fluctuation Map 2022.

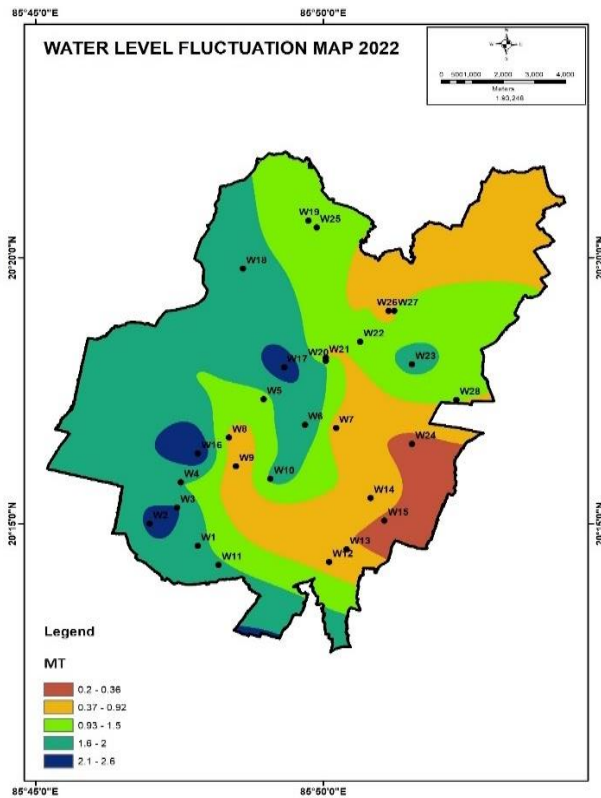


Fig-14: Water Table Fluctuation Map 2023.

According to Sajil Kumar, P. J. (2021) the main elements influencing the water level are soil, geology, land-use pattern, and elevation. Seawater intrusion in the coastal region is the main factor causing water-level dropping that affects groundwater quality and the availability of drinkable water (Mahlknecht et al., 2017; Sajil Kumar et al., 2014). On the other hand, excessive irrigation raises groundwater levels, which leads to waterlogging and an elevation in salinity (Park et al. 2018).

5. CONCLUSION

The groundwater level during the pre-and post-monsoon periods for 4 consecutive years, from 2020 to 2023 (Figs. 3 to 10) and the water table fluctuation maps (Figs. 11 to 14) in the research area are examined using hydrogeological and GIS mapping techniques. Table 7 demonstrates that throughout these four years, the maximum as well as minimum variations in the water table were 3.41 and 0.06mbgl in 2020 and 2021, respectively. The minimum and maximum average water table fluctuation of all four years was found to be 0.1725 to 2.8775 mbgl (Table- 7). The quality of groundwater is being threatened by excessive pump due to population growth, ensuing urbanization, as well as altered patterns of land use. According to the study, the yearly groundwater draft for residential purposes was 2696.71 Ham. In the research region, it was discovered that the net annual groundwater availability was 3666.89 Ham and the annual groundwater recharge was 4074.33 Ham. It was determined that the research area's overall groundwater development stage was 73.54%, falling into the semi-critical category. For improved groundwater development, this study suggests appropriate management techniques, efficient groundwater recharge structures, and a proper quantitative and qualitative quarterly monitoring system.

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