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Delineation of Groundwater Potential Zones in Smart City Bhubaneswar, Odisha, India, Using Geographic Information System, Remote Sensing and Analytical Hierarchy Process.

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Abstract
The lack of sufficient, high-quality surface water has left many urban and rural populations around the world dependent on groundwater for domestic consumption and other uses. Studying the nature of groundwater is essential for sustainable development and use, as there is a noticeable high spatiotemporal variation in its occurrence and distribution. Groundwater potential zoning has a new avenue due to the amazing effectiveness of geospatial technology. This research uses remote sensing (RS), geographic information systems (GIS), and the analytical hierarchy process (AHP) to try and identify the groundwater potential zones (GWPZ) in Bhubaneswar, Odisha, India's smart city.

As per the Saaty's scale, differentiable characteristics like land use/cover, land slope (LS), geomorphology (GM), type of soil, drainage and lineament density (LD), geology, and rainfall had been provided weights on the basis of their impact on ground water potential. The weights were then normalized utilizing the Eigen vector approach and AHP. Later, Arc Gis 10.3 was employed to integrate all of the aforementioned thematic layers to create the GWPZ map of Smart City Bhubaneswar. The study area was then demarcated into 5 GWPZ named “very high”, “high”, “moderate”, “low”, “very low”, covering, 7.3 %, 64.68 %, 21.48 %, 6.05 %, 0.47 % area respectively of the study area and validated with dynamic water tabledata & map. The outcomes of this investigation will be beneficial in forming appropriate management strategies for Bhubaneswar's groundwater resources.

Keywords: Remote sensing, Groundwater potential zones, Thematic layers, GIS, AHP.

1. Introduction

Over the years the rise in population, changing lifestyle, and growing industrialization have significantly increased the global water demand. Undoubtedly ground water is a precious resource, particularly in arid as well as in semiarid regions where the availability of surface water is limited. Groundwater has historically served as the predominant water source for households in both developed and emerging countries, regardless of whether they are located in urban or rural areas. The overexploitation of groundwater over the past decades has put the resources under tremendous pressure (Arulbalaji et al. 2018). Growing population, food production, and industrial demands can be sustainably supported and maintained by well-managed ground water. Considering the current rates of extraction, further scientific research regarding this resource's potential zones and sustainability is necessary in order to comprehend its significance. Also, a thorough study is required regarding the significant spatial and temporal variation of ground water, especially for its potential. Thorough research is crucial to monitor and preserve this valuable asset (Chowdhury et al. 2009). Making specific decisions regarding groundwater management and sustainability issues is greatly aided by the identification as well as mapping of potential zones for groundwater.

Currently, it is estimated that ground water resources provide fifty percent “of the world's drinking water (United Nations 2003). Even though surface water is more readily available than usable groundwater resources in India, a sizable portion of the population still depends on groundwater for drinking and" agriculture (Suhag. R, 2016). The ground water is more readily accessible than surface water due to its decentralized availability, which is the reason.

In India, the use of groundwater for irrigation accounts for 89% of total withdrawals, with domestic use following in second at 9% and industrial use at 2%. Groundwater alone provides for 85% of domestic requirements in rural regions and 55% of requirements in urban areas (Suhag. R, 2016). Almost all the studies related to groundwater adopt empirical methods for resources assessment which do not highlight the spatiotemporal variability, which raises concern about its sustainability.

It is very expensive and time-consuming to identify and assess potential groundwater zones through field observation. Because of lack of sufficient data, managing water resources, particularly ground water, involves integrating socioeconomic, legal, and technical aspects. This is challenging to accomplish in developing nations like India. RS and GIS facilitate the speedy identification of possible ground water zones. Large-scale spatial data management and processing have shown GIS to be a very helpful tool. However, RS is extremely helpful for gathering and categorizing spatiotemporal data (Panda. B.C, s 2005).

By using a weighted overlay process, GIS has proven to be highly effective in analyzing and evaluating multiple thematic layers. This process has the potential to address various queries pertaining to the mapping as well as identification of GWPZ. The process of stacking and comparing various features, like soil type, LS, rainfall, drainage density (DD), LULC (Land Use Land Cover), and soil type, with one another on the basis of location, results in the spatial analysis of GWPZ. For the purpose of mapping potential of ground water, the spatial scale of all the data is essential.

Numerous researchers have effectively employed multicriteria decision-making (MCDM) when combined with RS as well as GIS approaches to recognize GWPZ ("e.g., Vittala et al. 2005; Pothiraj. P and Rajagopalan. B, 2011; Abdalla. F, 2012; Ramamoorthy et al. 2014; Sharma et al. 2014; Sahoo et al. 2015; Indulekha et al. 2019; Saranya and Saravanan 2020). Depending on the" site circumstances and data accessibility, different studies require different numbers of thematic layers for potential ground water mapping. Researchers have used all or some of the following layers; LD, soil type, LS, drainage density, LULC, geomorphology, lithology, water bodies, rainfall, weathering depth, etc. to find the responses they received. Dwivedi et al. (2016) successfully mapped the GWPZ of the Ukmeh watershed in the upper Vindhya region using only four thematic layers: slope, lithology, drainage density, and LD. Meanwhile, Benjmel et al. (2020a, b) successfully mapped Morocco's Ighrem region employing 11 layers. In contrast, Atmaja et al. (2019) mapped the ground water potential zones in an Indonesian region using five layers. Eight theme layers were taken into consideration by Celik (2019) when mapping ground water potentials in Turkey. In the Megech watershed in Ethiopia, Berhanu and Hatiye (2020), studied GM, geology, LD, and slope were found to be the dominant factors for ground water mapping. The statistical techniques used to weigh these layers and each of their constituent features are an essential part of groundwater potential mapping, and they vary amongst studies. Most of the studies ("Chowdhury et al. 2009; Patra et al. 2018) gave weights to the thematic layers as well as their features on the basis of the opinions of experts, prior research, and local experience. Several scholars have employed AHP in MCDM approaches to standardize the weight of various thematic layers as well as their groups (Abijith et al. 2020; Ahirwar et al. 2020; Das et al. 2019; Agarwal as well as Garg 2015; Fenta et al. 2015; Manap et al, 2013; Adiat et al. 2012). The" state capital of Odisha, Bhubaneswar, lacks surface water to fulfill the domestic as well as other requirements of a rapidly expanding population. In the end, groundwater is under more pressure. Programs for managing ground water potential and sustainability will be implemented more successfully and sustainably if ground water potential zones are successfully mapped (Sahoo et al. 2015). AHP, GIS, and RS techniques have been utilized in countless investigations conducted worldwide to map ground water potential, as could be inferred from the literature mentioned above. However, very few studies have identified the study area's GWPZ. Therefore, employing GIS, RS, and AHP, this research aims to identify and demarcate GWPZ in Bhubaneswar city. Potential sites or zones for ground water exploitation or recharge can be found using the findings.

2.Materials and Methods

2.1 Overview of the Study Area

2.1.1 Location and Demography

The Bhubaneswar Block in the Khurda district is home to the city of Bhubaneswar, Odisha. Geographically, it lies "between 20°12′N and 20°25′N and 85°44′E and 85°55′E. Location on the Survey of India, 1:50,000 Scale toposheets 73 H/15 and 73 H/16 (Central Ground Water Board, Southeastern Region, Bhubaneswar, Odisha). Based on the findings of the Government of India's 2011 Census, Bhubaneswar is categorized as both a City and a Class I Urban Agglomeration. The Municipal Corporation is in charge of running the" city of Bhubaneswar, which is a part 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).

Despite having a small municipal territory of 163 square kilometers, the city master plan area of Bhubaneswar Municipal Corporation (BMC) is 233 square kilometers. The fundamental governing divisions of the city are its 68 wards. At 45 meters above mean sea level, the city rises. (Fig-1).

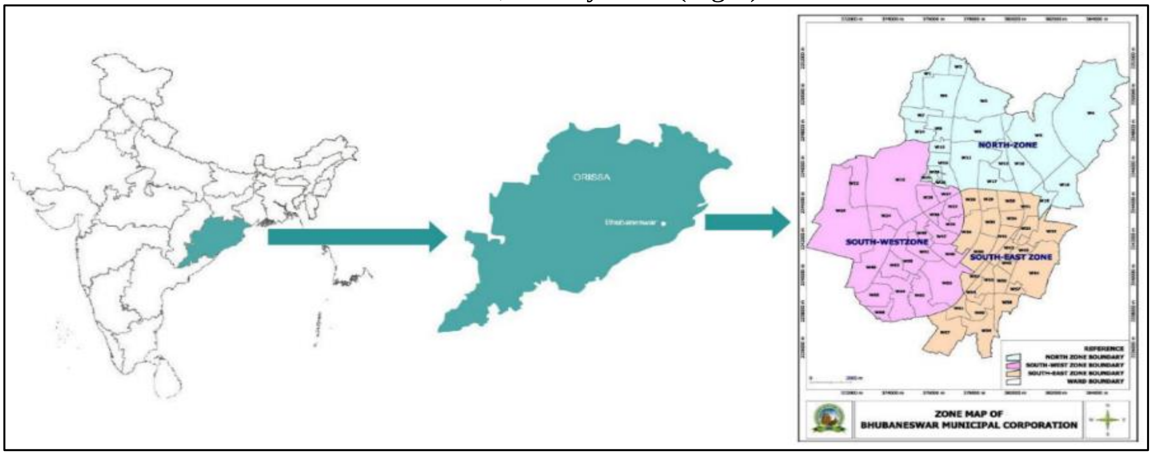


Fig-1. Map Showing the Study Area.

2.1.2 Topography

The western as well as central parts of Bhubaneswar are made up of "undulating uplands, whereas the eastern half of the city has a comparatively level topography having a slight incline towards the east or southeast. The physical configurations are roughly defined by the East Coast Railway line. While alluvial cover is more common on gently sloping slopes, lateritic cover is observed in highland areas, with a thin layer of lateritic cover in some locations. Athgarh Formation, an Upper Gondwanan shale-and-sandstone" series, is represented by hilltop outcrops that are scattered throughout the western highlands. The region features an eastern coastal plain that extends parallel to the Eastern Ghats Mountain range, 15 to 60 meters above mean sea level on average (CGWB, Bhubaneswar-2010).

2.1.3 Climate and Rainfall

The study area experiences humid sub-tropical weather. The southwest monsoon yields an average annual precipitation of 1596.44mm (1981 to 2023) throughout its rainy season, which extends from June-September. Following this is the "dry season, which lasts from early November to May. May experiences the highest temperatures, with an average daily temperature of 38 °C, whereas December has the lowest temperatures, with an average daily temperature of only 16 °C. The" summertime high is 48°C, and winter months low is 9.4°C. Relative humidity ranges from 48 to 85%, with occasional highs of 95%. During the summer and monsoon seasons, wind speed is fairly strong, with major winds coming from the south and southwest. On average, the wind speed is about 14km/h. The average monthly potential evapo-transpiration varies from 57mm in January to 248mm in May, according to the CGWB (2013).

2.1.4 Geology

The area of research is primarily composed of the Upper Gondwana Group's Athgarh Formation, which was formed during the Lower Cretaceous period. Quaternary alluvium covers the eastern as well as southern regions of the study area. According to Krishnan (1982), the Athgarh Formation is composed of sandstone, grit, conglomerates, and certain white or reddish clays. The majority of the sandstone in the Athgarh Formation is categorized as lithic wakes, quartz arenite, lithic arenite, and sub-lithic arenite (Mishra, 1988). Conglomerates and grits, carbonaceous shales, variegated shales, and fine clay are also included; the majority of these appear as tiny lenticular bodies that break through the monotonous expanse of sandstones. According to the data from borehole drilling, sandstone is commonly found at depth in most of the area of study. Shale is a common occurrence in the southern region. Athgarh Formation's upper region exhibits partial lateralization. Subterranean deposits and laterites constitute the majority of the quaternary formations. The majority of the Athgarh Formation area is covered in laterite, which covers the country rock. The laterites have an average thickness of 2 to 5 m, with the southeast region having the thickest laterites at 13 m. The southeast region of the research area is usually where thick laterite cover is found. There are thin layers of quaternary alluvial deposits with a maximum thickness of about 30 to 40 meters along the extreme eastern as well as southeastern portion of the study area. Clay, silt, and fine to medium coarse sand comprise these deposits. The Athgarh

Formation is located beneath the alluvial deposits.

2.1.5 Soil

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

Alfisols: They are found in the eastern section of the city and have a sandy loam texture. The pH of the soil ranges from 6.5 to 7.3, and they are usually low in nitrogen and phosphorous.

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

2.2 Methodology

GIS, AHP, and RS methods had been employed to detect GWPZ in Bhubaneswar city. The sources of various data as well as the detailed procedure adopted to attain the objective are listed in the following order.

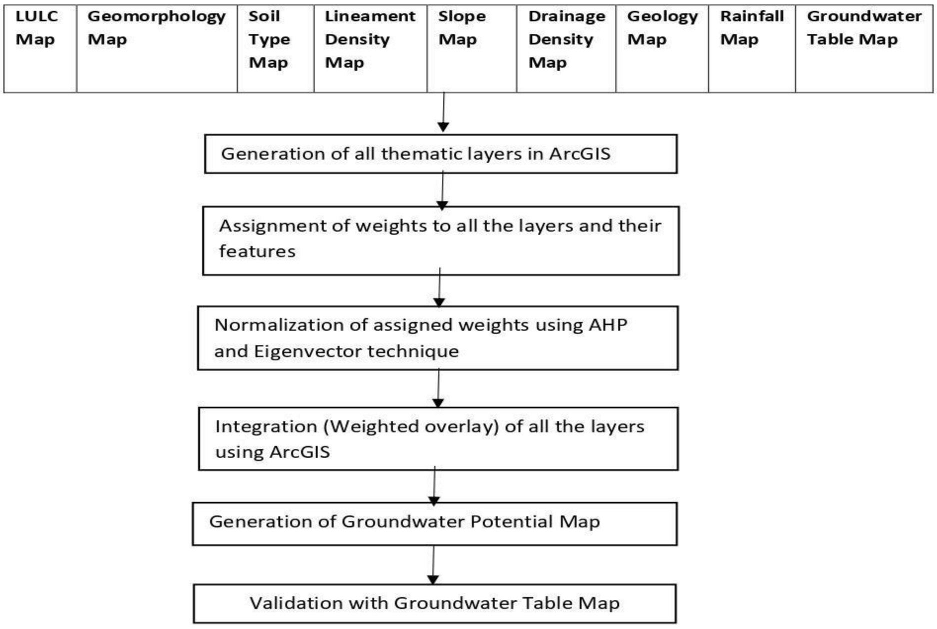


Fig- 2: Flowchart for Groundwater Potential Zoning.

2.2.1 Sources of Data and Thematic Layers Generation

Data	Source	Scale/resolution
1. Base map	National Remote Sensing Centre NRSC, (Bhubaneswar).	1:50000
2. Soil	Odisha Space Application center (ORSAC), Bhubaneswar	1:50000
3. Geomorphology	Odisha Space Application center (ORSAC), Bhubaneswar	1:50000
4. Geology	Odisha Space Application center (ORSAC), Bhubaneswar	1:50000
5. LULC	Odisha Space Application center (ORSAC), Bhubaneswar	1:50000
6. Lineament density	Odisha Space Application center (ORSAC), "Bhubaneswar	1:50000
7. Land slope	Shuttle Radar Topography Mission (SRTM), Digital Elevation Model (CEM), USGC, Earth Explorer	90m
8. Drainage density	Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (CEM), USGC Earth Explorer	90m
9. Rainfall	IMD, Pune.	
10.Groundwater table	Central" Ground Water Board (CGWB), Bhubaneswar.	

Table-1: Sources of Data

Eight different factors were taken into consideration in this research, including geomorphology, geology, rainfall, soil type, LS, drainage density, LD, as well as LULC. These factors affect ground water potential both directly and indirectly, as well as controlling ground water storage and movement. The data sources are listed in Table 1. Thematic layers were created using the data in various formats. Using ArcGIS 10.3, soil maps, geology, and geomorphology were utilized for the corresponding thematic layers. These maps are scanned, and put into a geographic information system (GIS), and thematic layers are created. The LULC map, which is created employing a supervised classification technique, was obtained from ORSAC, Bhubaneswar. The SRTM DEM had been employed to create the city's LD and drainage density layers. The draining layer had been created by filling the DEM, specifying the flow direction as well as accumulation, and then utilizing the ArcGIS line density tool. This process involved the use of the spatial analysis tool.

The area of study slope layer was also created using DEM. The map was created by interpolating rainfall values derived from rainfall data that were gathered from IMD, Pune. The ground water table data for the years 2020 to 2023 was utilized to create thematic layers of dynamic ground water employing the inverse distance weighting (IDW) technique.

2.2.2 Analytic Hierarchy Process (AHP)

It is a structured multicriteria approach to decision-making that relies on expert judgment to develop a priority scale through pairwise comparison of multiple features (Maheswaran et al. 2016). The AHP is superior to other approaches because it allows for the determination and modification of statistical measures for assigned weight consistency as needed (Silwal and Pathak, 2018). It is a two-step process: in the first, the system's hierarchical structure was created, and the elements were assessed. In the second, the assessment' consistency was verified. The thematic layers as well as their distinctive attributes were given weights on the basis of a scale of 1-9 (Table 2), taking into account the potential influence on ground water.

2.2.3 Assigning weights and Normalization

Weights had been allocated to each thematic layer and its individual features on the basis of expert opinions and a number of previous studies. Based on Satty's scale, weights were assigned (Satty 1980). Higher scores had been given to the factors that had greater influence, and vice versa. Weights must be normalized in order to lessen the bias related to the weights assigned to the individual features of thematic layers (Machiwal et al. 2011). Using the Eigenvector technique and AHP, the various layers' assigned weights had been normalized.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the object.
3	Moderate importance	Judgment and experience incline slightly toward one activity over the other.
5	Strong importance	Judgment and experience incline slightly toward one activity over the other.
7	Very strong or demonstrated Importance	An activity if favored very strongly over another and its dominance demonstrated in place.
9	Extreme importance	The strongest level of affirmation is provided by the evidence that supported one activity over another.
2,4,6,8	Intermediate value between the two adjacent judgments	When compromise is needed.

Table-2: Fundamental scale of AHP (Satty, 1980)

Matrix size:	1	2	3	4	5	6	7	8	9	10
RCI:	0	0	0.56	0.90	1.12	1.24	1.34	1.41	1.45	1.49

Table-3. Random Consistency Index (RCI) for different matrix sizes.

2.2.4 Pairwise Comparison Matrix

To compute the relative weights and normalized weights pertaining to the thematic layers as well as their features and determine their percentage of influence on the groundwater potential, a "pairwise comparison matrix is constructed. The comparison matrix was created utilizing a scale of absolute judgments that indicated how much one element outweighed the other in relation to a particular attribute (Silwal and Pathak 2018). The relative weight matrix was computed by dividing each comparison matrix column element by its sum. In the relative weight matrix, the total of the elements in each column" equals one. The corresponding thematic layer's normalized principal eigenvector (λmax) can be found by calculating the "row average of the relative weight matrix. Using the consistency ratio (CR) and Equation (1), the consistency of the matrix was examined (Saaty, 1980).

CR = (CI / RCI).-- Eq^n (1)

Here; CR denotes the consistency ratio, RCI represents the randomconsistency index and CI represents the consistency index (Table-3) Saaty, 1980.
CI = [(λmax - n) / (n-1)]. --- Eq^n (2)

Where λmax, the average principal eigen value, was determined employing the eigen vector approach, and n represents the number of criteria" or factors.

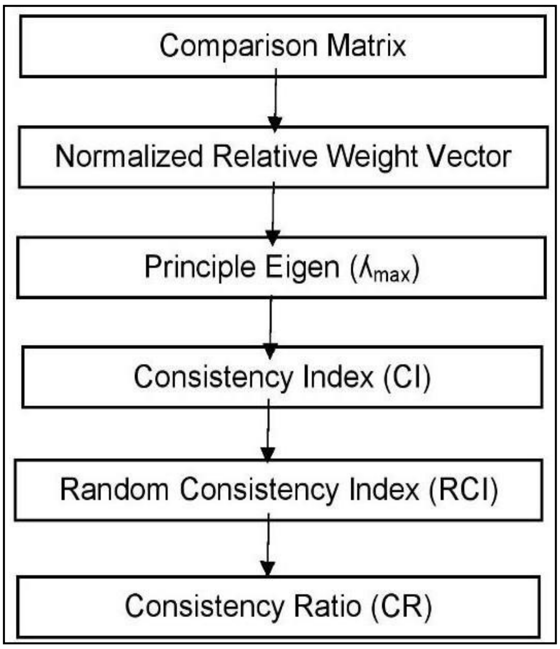


Fig-2 Flow chart analysis of CR for assigned weight in AHP

2.2.5 Assignment and Normalization of Weights

For consistency of criteria weights, the CR value must not be greater than 0.1 (10%). In the instance that the consistency is less than 10%, the procedure must be repeated in order to reevaluate the weights. The matrix and weights are less consistent when the CR value is high (between 0 and 10%). Fig. 2 displays a flowchart for the analysis of the CR of assigned weights in AHP. All eight themes—GM, geology (GG), LULC, LS, LD, DD, rainfall (RF), and soil type (ST)—were given appropriate weights to examine the influence of each of them on groundwater potential. After that, the weights had been normalized employing the eigenvector and AHP techniques as specified in the methodology. "All of the thematic layers were combined into a pairwise comparison matrix of order [8 X 8]; (Table 4).

The thematic layers influence (Table 5) on ground water prospect mapping was examined, as well as the relative weights of the thematic layers as well as" normalized eigen values. Since the thematic layers' as well as their features' CR was less than ten percent, it was determined that the weights that had been assigned were consistent. The study area's GWPZ was determined by integrating all eight thematic layers (Fig. 11). Ground water potential areas are further split into 5 zones: very high, high, moderate, low, and very low. The area of study ground water prospect is shown in Table 7 as a percentage of the entire area. Excellent groundwater potential zones are those that are adjacent to bodies of water, as this indicates a well-connected aquifer system with surface water bodies. Drinking water can be drawn from shallow tube wells and bore wells in large quantities.

CRITERIA	GM	RF	DD	LD	LS	GG	LULC	ST	Assigned Weights
GM	1	5	4	4	5	3	6	6	7
RF	1/5	1	4	4	3	3	3	3	8
DD	1/4	1/4	1	2	4	1/2	5	3	3
LD	1/4	1/4	1/2	1	4	1/3	4	2	2
LS	1/5	1/3	1/4	1/4	1	1/5	2	1/3	4
GG	1/3	1/3	2	3	5	1	6	4	5
LULC	1/6	1/3	1/5	1/4	1/2	1/6	1	1/4	2
ST	1/6	1/3	1/3	1/2	3	1/4	4	1	6

Table-4: Pairwise Comparison Matrix of the Thematic Layers with assigned & relative weights.

Assigned Weights	CRITERIA	GM	RF	DD	LD	LS	GG	LULC	ST	Normalized Weight (w)	Eigen value(λ_{max})
7	GM	1	5	4	4	5	3	6	6	0.330	9.96
8	RF	1/5	1	4	4	3	3	3	3	0.230	9.47
3	DD	1/4	1/4	1	2	4	1/2	5	3	0.102	8.70
2	LD	1/4	1/4	1/2	1	4	1/3	4	2	0.078	8.49
4	LS	1/5	1/3	1/4	1/4	1	1/5	2	1/3	0.034	8.31
5	GG	1/3	1/3	2	3	5	1	6	4	0.147	8.87
2	LULC	1/6	1/3	1/5	1/4	1/2	1/6	1	1/4	0.024	8.60
6	ST	1/6	1/3	1/3	1/2	3	1/4	4	1	0.055	8.26

Table-5: Pairwise Comparison Matrix of the "Thematic Layers with Normalized Weights & Eigen Values.

Average Eigen value = λmax = 8.83; No. of factor = n = 8, RCI = 1.41 (Table – 3)

Consistency Index = CI = $[(\lambda_{max} - n) / (n-1)]$ = (8.83 - 8/8-1) = 0.12.

Consistency Ratio = CR = (CI / RCI) = (0.12/1.41) = 0.085 or 8.5%

2.2.6 Assessment of Groundwater Potential

The produced thematic layers were incorporated into ArcGIS, and the study area's GWPZ was identified by estimating the groundwater potential index" (GWPI). GWPZ in any region can be identified using the dimensionless GWPI measure. Equation (Eq^n-3) was utilized to estimate the GWPI (Berhanu and Hatiye, 2020, Rao and Briz-kishore, 1991).

$$GWPI = (GM_{nm} \times GM_{nwi}) + (GG_{nm} \times GG_{nwi}) + (RF_{nw} \times RF_{nwi}) + (DD_{nw} \times DD_{nwi}) + (LD_{nw} \times LD_{nwi}) + (ST_{nw} \times ST_{nwi}) + (LS_{nw} \times LS_{nwi}) + (LULC_{nw} \times LULC_{nwi}).$$

---------Eq^n-3

where LS denotes land "slope, LULC is land use and cover, GM is geomorphology, RF represents rainfall, DD represents drainage density, LD represents lineament density, and ST is soil type. The geology of the study area is" represented by GG. Each theme's normalized weights and each of its individual features are illustrated by the subscripts "nw" and "nwi," respectively. The GWPZ of the area of study is classified into five groups: "Very High," "High," "Moderate," "Low," and "Very Low" depending on the extent of the GWPI value. The weighted sum overlay tool in ArcGIS was utilized to create the GWPZ map (Fig. 11).

3. Results and Discussion

3.1 Geomorphology Map

An area's land form and landscape are shaped by its geomorphology. According to Arulbalaji et al. (2018), it is one of the essential characteristics used to define the GWPZ. In order to understand the geologic controls, lithology, structures, and processes included in ground water occurrence as well as movement all necessary to determine ground water prospects a region's geomorphological map must highlight its significant geomorphic units and land forms that support its geology (Machiwal et, al.2011). By combining hydrological characteristics with the geomorphic units of a region, one can readily realize the spatial distribution, occurrence, and behavior of ground water (Siva et al., 2017). The three components of Bhubaneswar's geomorphology are water bodies, flood plains, and hills and plateaus (Fig. 3). Waterbodies and flood plains are considered to have good groundwater potential.

3.2 Rainfall Map

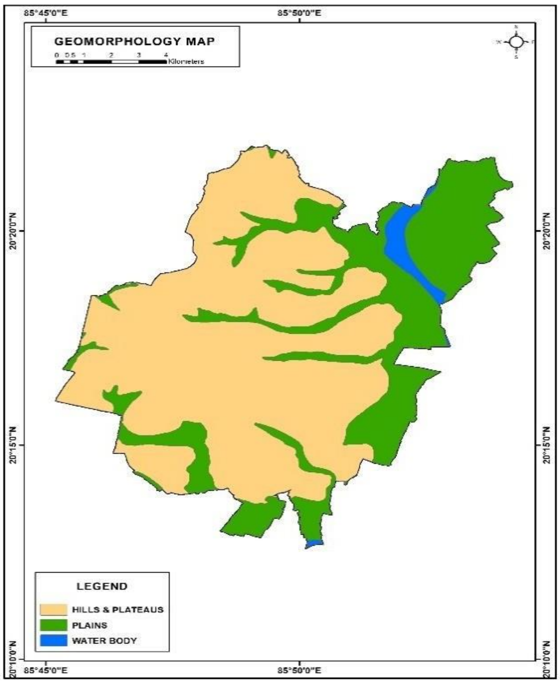
Rainfall is considered as the main water source and dominating factor for groundwaterpotential of an area. The IDW interpolation method in ArcGis10.3 is employed to create the rainfall map for 2023, which ranges from 1100 to 1576.8 mm (Fig. 4). The rainfallis reclassified into 3 categories low (1100-1250), medium (1251-1400) and high (1401- 1576.8). Rainfall duration and intensity affect infiltration. Low infiltration results from high intensity and short duration, and vice versa.

3.3 Drainage Density

According to Hutti and Nijagunappa (2011), DD is the inverse of soil permeability and reveals the type of surface material as well as the proximity of stream channels regarding spacing. It is useful to describe the infiltration and runoff of a region. Because drainage density depends on slope and topography, it offers a crucial indicator of soil infiltration. According to Arulbalaji et al. (2018), DD is an important parameter for estimating groundwater potential. Furthermore, it aids in comprehending how the earth's crust has evolved (Deepa et al. 2016).

Sl.no.	Parameters	Normalized Weights (%)	Individual Features	Ranks
1	Geomorphology	33	Hills & Plateaus	5
			Flood Plains	7
			Water Bodies	9
2	Rainfall	23	1401 - 1576.8	8
			1251 - 1400	6
			1100 - 1250	4
3	Drainage Density	10.2	6,400 - 16,000	9
			17,000 - 25,000	8
			26,000 - 34,000	6
			35,000 – 43000	5
			44,000 - 52,000	2
4	Lineament Density	7.8	0 - 0.565	2
			0.566 - 1.13	3
			1.14 - 1.69	4
			1.7 - 2.26	6
			2.27 - 2.82	8
5	Land Slope	3.4	0 – 0.84	8
			0.85 – 2.3	6
			2.4 – 5.3	4
			5.4 – 11	3
			12 – 31	2
6	Geology	14.7	Alluvium Clay Dominant	3
			Alluvium Sand & Silt Dominant	5
			Laterite	8
			Sandstone	6
			Water Bodies	9
7	LU/LC	2.4	Agriculture	6
			Forest	8
			Horticulture	6
			Wastelands	2
			Built-up	2
			Water bodies	9
8	Soil Type	5.5	Clay	2
			Clayey Loam	3
			Loamy Sand	7
			Sandy Clay	4
			Sandy Clay Loam	4
			Sandy Loam	8
			Settlement	2
			Water Bodies	9

Table- 6: All Criteria with normalized weights, Individual features with their ranks



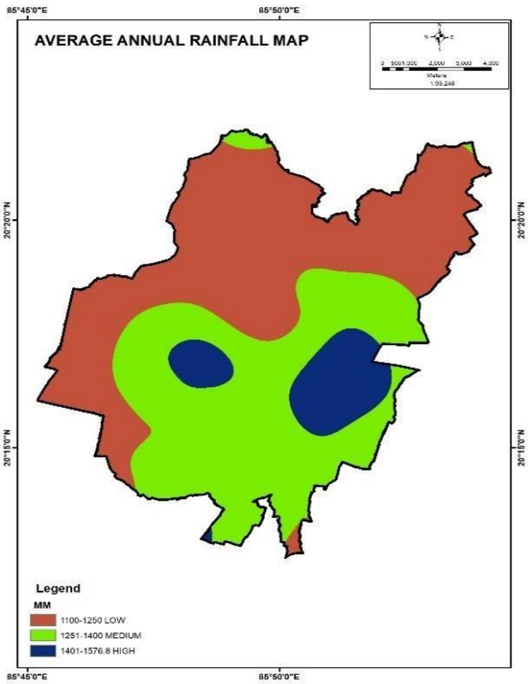


Fig-3: Geomorphology Map of the Study Area   Fig-4: Annual Rainfall Map of the Study Area

Greater infiltration as well as rapid run-off disposal are associated with low drainage density, whereas reduced infiltration opportunity time is indicative of high drainage density. Drainage densities that are low to moderate are regarded as having a high potential for groundwater (Jenifer and Jha, 2017). A study area's DD map was created with ArcGIS 10.3's line density tool. It was discovered that the drainage density varied from 6,400 to 52,000 Mt/Mt^2 (Fig-5). Five classes were identified based on the density range: 6,400-16,000, 17,000-25,000, 26,000-34,000, 35,000-43,000, and 44,000-52,000 Mt/Mt^2. The city's predominant drainage density, which ranges from 35,000 to 43,000 Mt/Mt^2, falls into the moderate to poor category.

3.4 Lineament Density

Rocks with linear or curvilinear features have structurally controlled fractures called lineaments (Arulbalaji et al. 2018). In hard rock areas in particular, lineaments play a critical part in groundwater exploration due to their increased permeability and porosity. According to Elewa and Qaddah (2011), joints and fractures have the ability to retain water, which allows groundwater to move through them. Due to the high infiltration rate in those areas, the zones have excellent ground water possibilities and a very high lineament density. Poor water infiltration is also influenced by low lineament density (Andualem and Demke, 2019). (Fig. 6-) depicts the lineament map of the area of study. Five classes were identified based on the lineament density: 0.0-0.565, 0.566-1.13, 1.14-1.69, 1.7-2.26, and 2.27-2.82 m/m^2. Density ranges 2.27–2.82 m/m^2 and 0.0–0.565 m/m^2 were deemed to be the highest and lowest, respectively (Table 6).

3.5 Land Slope

Land slope regulates both the velocity of overland flow and the soil's capacity for infiltration (“Paul et al., 2018; Rukundo and Dogan, 2019”). Compared to surfaces with steep slopes, which promote infiltration and expand the potential for ground water recharge, flat surfaces have a longer capacity to hold water. Slopes that are excessively steep for the soil to infiltrate through promote overland flow. The area of study slop map (Fig. 7) was created employing Arc Gis's spatial analysis tools from DEM. On the basis of significance in replenishing the groundwater, the region of study slope is split into 5 classes (0 - 0.84, 0.85 - 2.3, 2.4 - 5.3, 5.4 -11, and 12 - 31%).

3.6 Geology

The geology of any subsurface formation represents its physical properties. The properties of different water-bearing strata have a major effect on the incidence and flow of groundwater. The research area's geology has been digitally transformed from toposheets and is divided into five primary groups: water bodies, laterite, sandstone, alluvium clay dominant, and alluvium sand and silt dominant (Fig. 8). Their ability to hold water determines which ones are given priority when allocating “weight.

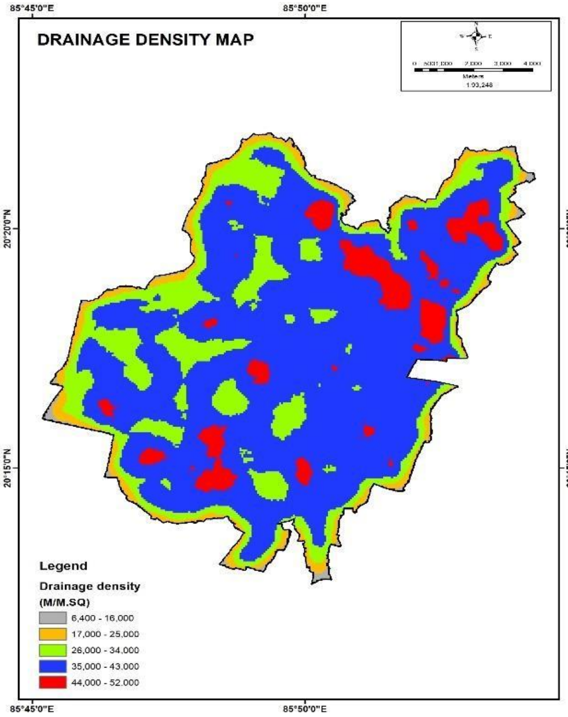


Fig-5: Drainage Density Map of the Study Area

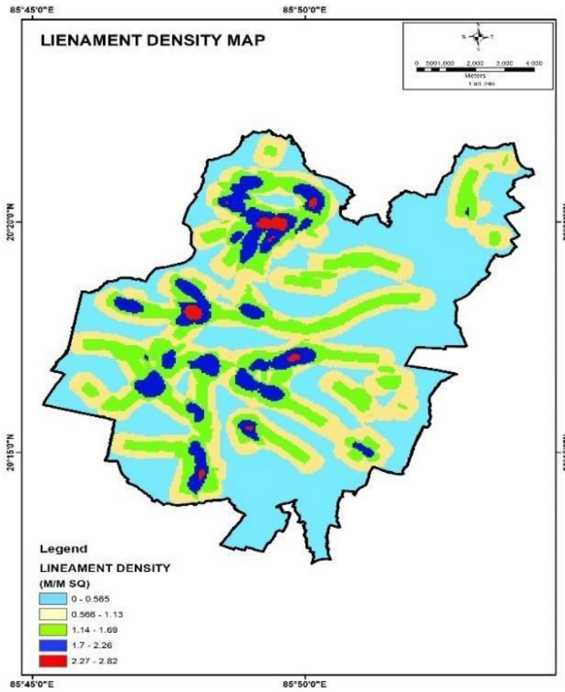


Fig-6: Lineament Density Map of the Study Area

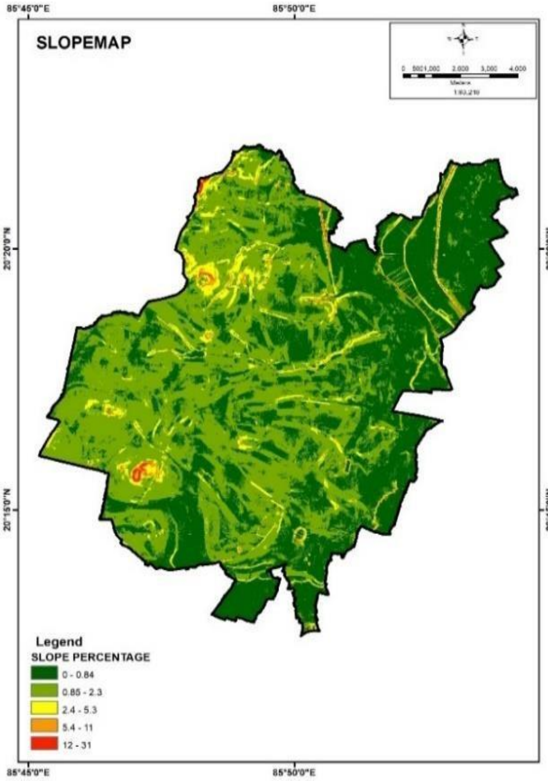


Fig-7: Slope Map of the Study Area

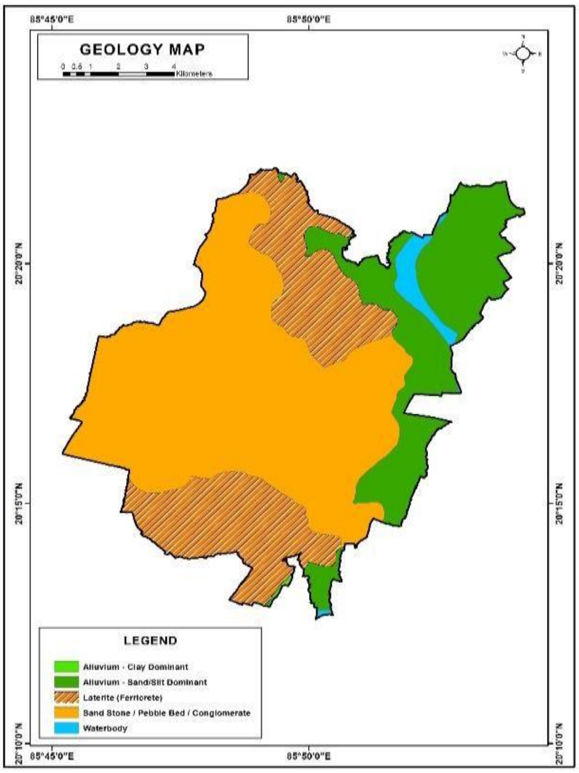


Fig-8: Geology Map of the Study Area

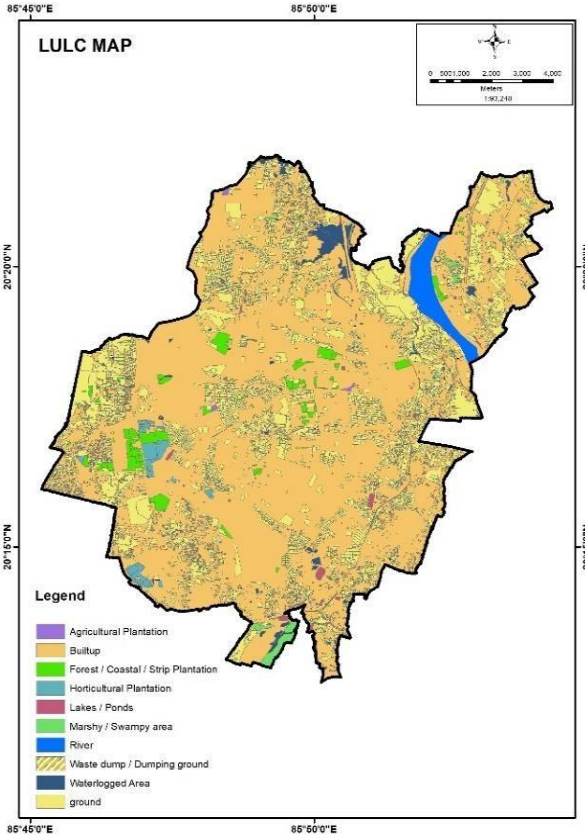


Fig-9: LULC Map of the Study Area

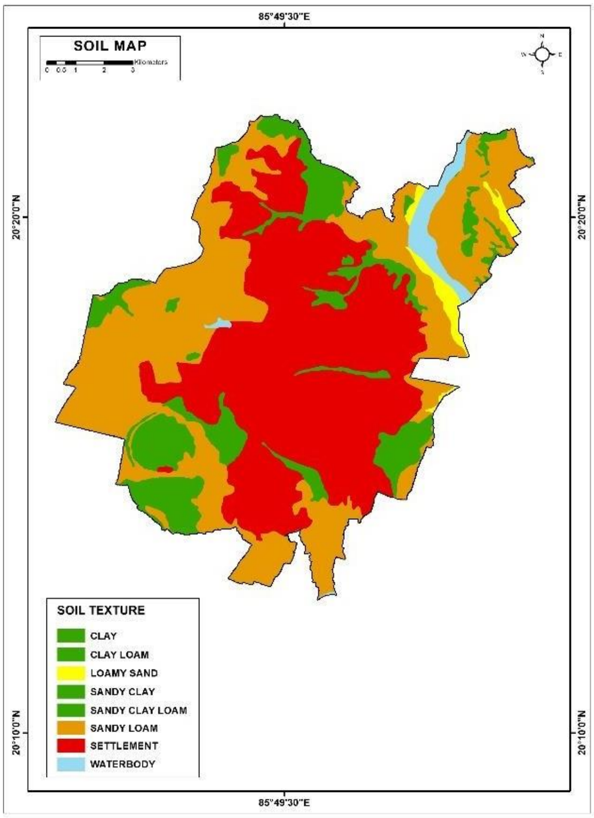


Fig-10: Soil Map of the Study Area

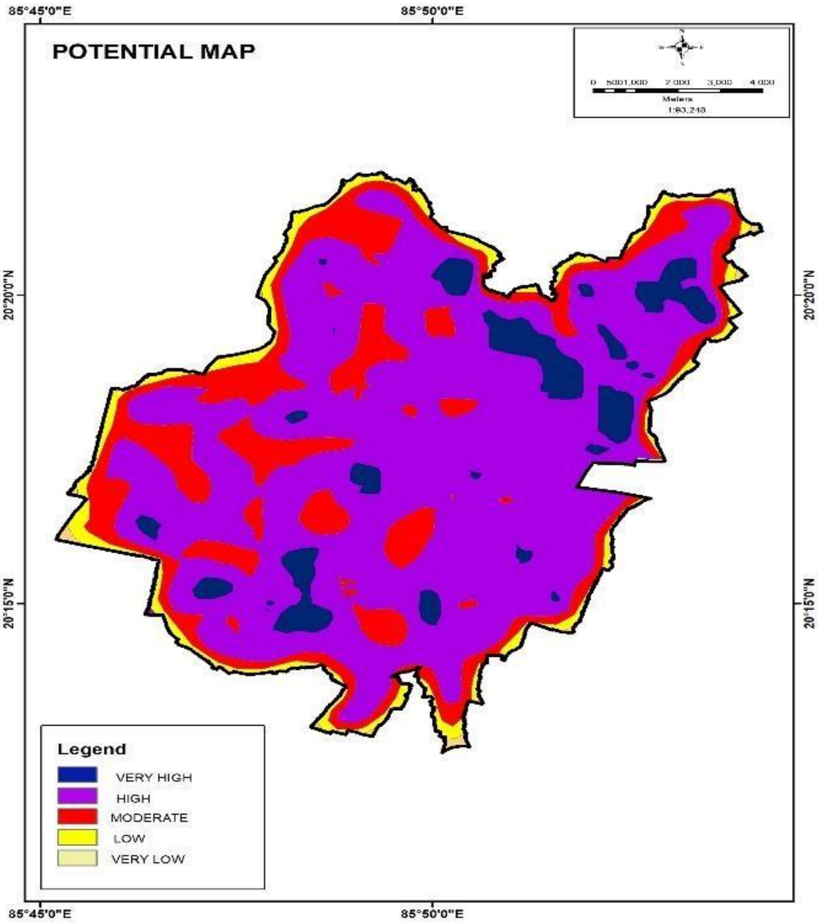


Fig-11: Groundwater Potential Zone Map of the Study Area

3.7 Land Use and Land Cover

Residential area" distribution, forest type, and vegetative cover are all considered aspects of LULC (Yeh et al.). Because of its significant impact on runoff management, LULC affects groundwater recharge. Groundwater is influenced by agriculture in order to meet crop water requirements. Wastelands and populated areas experience ground water depletion, while forest areas typically experience an increase in water tables (Siva et al. 2017). Similar to this, a surface with a high vegetation cover can absorb more energy than a barren area. According to Li et al. (2018), regions covered in both forest and agricultural land have excellent prospects for ground water potential. Ten LULC classes have been established within the research area (Fig. 9). The region that is built up is 94 km^2, the area that is undeveloped is 41 km^2, the area that is made up of lakes and other bodies of water is 5.2 km^2, and the area that is covered by forests and plantations is 4.0 km^2.

3.8 Soil Type

As infiltration and runoff rely on soil properties, particularly soil texture, the recharge of ground water is dependent on soil type and also affects ground water quality (Deepa et al., 2016). (Silwal and Pathak 2018). Due to their extremely low permeability and consequent unfavourability for ground water recharge, fine-textured soils encourage "overland flow more than course-textured soils (Rukundo and Dogan 2019). However, for ground water recharge, coarse-textured soils are even more advantageous than land use (Anuraga et al. 2006). Seven major classes—clay, sandy clay loam, clayey loam, sandy clay, loamy sand, sandy loam, and settlement—are distinguished in the soil of the study area (Fig. 10).

Sl.No.	Category	Area (Km^2)	%age Area
1	Very Low	0.742	0.50
2	Low	9.050	6.10
3	Moderate	31.855	21.48
4	High	95.921	64.68
5	Very High	10.841	7.31

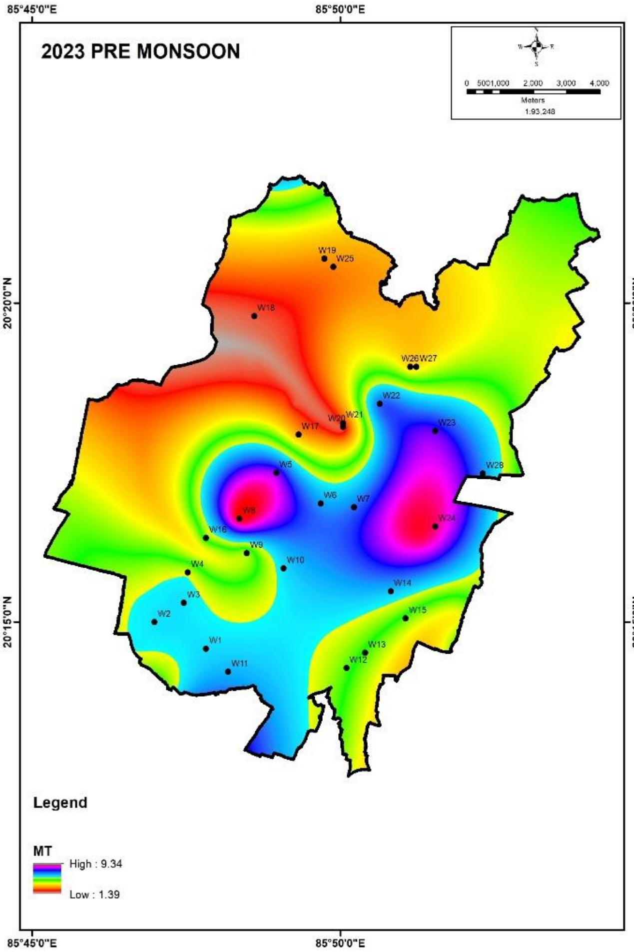
Table-7: Groundwater prospect as percentage of the total area

3.9 Development of Groundwater Potential

The GWPZ map had been created by applying the APH approach to all eight" thematic layers that were developed in a GIS environment. These layers had been then given weights and ranks during the weighted overlay process (Fig. 11). On the basis of their index "value, the outcomes were split into 5 groups, ranging from very low to very high (Eqn-3). Due to the alluvial deposits and low lineament density covering 7.31% of the area, very high groundwater potentials were found in the northeast and very low potentials in the peripheral area, which constituted 0.5percent of the entire area. Comparably, 64.68% of the research area has the highest potential area, and 21.48% has a moderate groundwater potential. The various kinds of GWPZ and the study area's corresponding area are displayed in Table -7.

3.10 Validation of Groundwater Potential Zones

The "water levels recorded in 28 observation wells within the research area at the time of the pre-and post-monsoon seasons of" 2023 were cross-checked against the developed GWPZ. The potential map (Fig. 10) is validated by the observation that all of the wells exhibit a rising trend in the water table at the time of the post-monsoon period contrasted with the pre-monsoon. Additionally, it is evident from the graph (Fig. 14) and maps (Figs. 12 & 13) that other influencing factors cause the recharges in wells 9, 13, 14, 18, 21, 22, 24 and 28 to be extremely low during the post-monsoon period.



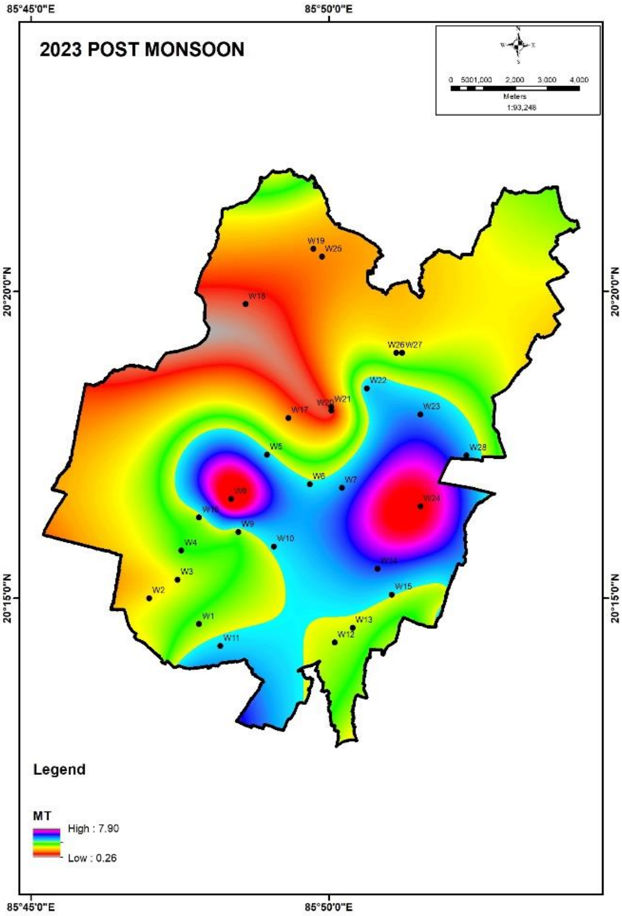


Fig-12. Pre-Monsoon Water Level Map of Study Area   Fig-13. Post- Monsoon Water Level Map of Study Area

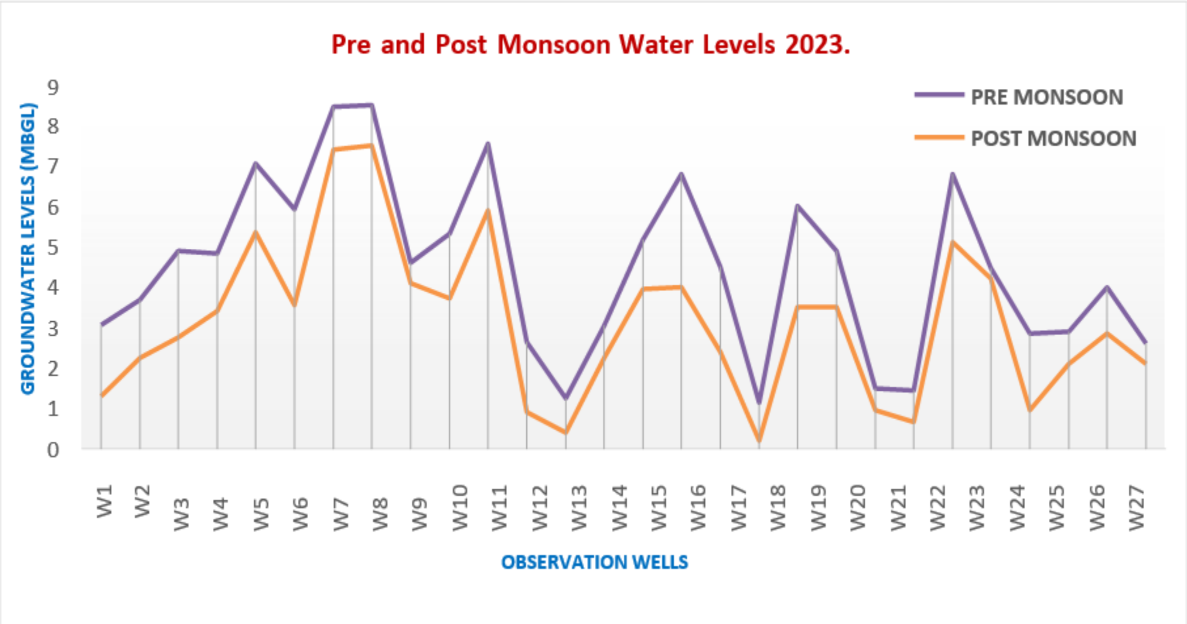


Fig- 14: Pre & Post Monsoon Water Levels for Year 2023 of the Study Area.

4. Conclusion

The study's goal is to locate possible groundwater zones in the smart city of Bhubaneswar, the Indian state of Odisha's capital. For this, an MCDM technique utilizing GIS, RS, and AHP is being applied. Thematic layers of eight hydrogeological parameters—like GM, LD, LULC, soil type, land slope, geology, RF, and DD—that influence ground water flow and availability were developed for the research area using satellite images, preexisting maps, and attribute data. The parameters were determined taking into consideration previous research, professional judgment, and the accessibility of spatial data. Using Satty's scale, weights had been allocated “to the chosen thematic layers and their individual features based on their impact on groundwater potential. Afterward, the eigen vector approach had been employed to examine the consistency of the strategy after the assigned weights had been normalized utilizing AHP. Finally, the GWPZ map of the study area was created by integrating all eight thematic layers” in ArcGIS.

The study area's ground water potential index (GWPI), which covers 7.31, 64.68, 21.48, 6.1, and 0.5 percent (%) of the region, was split into 5 groups: "very high," "high," "moderate," "low," and "very low." It was discovered that the low as well as very low regions constitute 6.6% of the total area, with the remaining 93.4% falling into the moderate to very good zones. In regions with moderate to very good water quality, ground water development and management initiatives can be put into place. This will help the study area's drinking water demand during periods of water scarcity. In areas with very low to low groundwater, artificial groundwater recharge structures can raise water tables. In order to identify possible groundwater zones in the smart city of Bhubaneswar, this study outlines the effectiveness and potential of combining RS, GIS, and AHP. The outcomes of this research could be useful in creating successful ground water management strategies to ensure the long-term sustainability of this vital resource.

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