Delineation of groundwater potential zones in Samoda watershed, Chhattisgarh India, using Remote Sensing and GIS techniques

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Abstract. The availability of resources and its demand made people select suitable places for the population's growth. Rapid growth in population and urbanization lead to exploitation of the groundwater and its quantity. The Samoda watershed in the Durg District of Chhattisgarh state is also a growing urban area. It is essential to consider the existing groundwater scenario of the city and industrial area of Samoda watershed for the safe consumption, management, and also need to identify the groundwater prospect zones for further groundwater exploration. This can be easily done cost-effectively with the help of remote sensing and Geographical Information system (GIS) by integrating the different factors that support groundwater availability. This study carried out by the integration of data sets and maps such as satellite imagery, drainage, groundwater level, rainfall, land use land cover, slope, and existing maps of as geology, soil type, for the delineation of the groundwater prospect zone by the application of Analytical Hierarchy Process (AHP) Multi-Criteria Decision Making method. The groundwater potential zones that are delineated from integrating each factor are categorized into five different zones: very low, low, moderate, high, and very high.

Keywords: AHP, MCDM, Groundwater Potential Zones.

1. Introduction

Growth and existence of a population over an area depend on the natural and available resources around it. Among the natural resources, the water has its own importance due to its necessity for running the lives of living beings and running of various industrial and agricultural units. Considering the studies [1] of water availability in the Indian continent indicate that most of them are concentrated in the groundwater due to its increasing demand in modern society. Utilization of the surface water for domestic and agricultural activities still exists, but most farmers and industrial persons are forced to withdraw the groundwater to fulfill their annual water demand. Most of the water crisis arises due to weather conditions and the improper storage and utilization of the precipitation and the surface water [2, 3, 4, 5]. The observation of an average decline in water table whole over India reveals that the whole country is experiencing a drop in the groundwater level [6].
One of the best steps that can make a decision on the balanced extraction and the utilization of the groundwater is, locating the groundwater available area or the groundwater depleted areas. There are various methods useful for locating suitable areas of groundwater extraction [7, 8, 9, 10, 11, 12]. Among the various methods and tools, the remote sensing and Geoinformatics system (GIS) method is suitable for its low-cost approach during the pre-field survey. The introduction of new technologies and its applications helps peoples in the various fields in a manner that half of their workload became lighter [13]. Similarly, the application of remote sensing and GIS in the field of hydrogeology helps the professionals do things in a cost-effective manner and in less time.

Prediction of the groundwater potential zones is very important. These zones can be obtained from conventional and scientific methods such as different geophysical, especially resistivity methods. Most of these methods utilize plenty of money, time, and manpower and the probability of the same on obtaining a fruitful result is fifty out of fifty only. Hence, the remote sensing and GIS method's application can help locate a suitable location where one can expect groundwater availability. It can validate the result with the proper planning using other methods.

Researchers in all over the world are aware of the importance of remote sensing and GIS on locating and exploring the probable groundwater zones of the area. As per remote sensing and GIS, different methods exist. One can choose the appropriate method according to its special quality in solving the complicated nature of the addressed area. One can locate some of the water-rich areas by considering the presence of groundwater indicators. Even though this is one method, various other applications are also available in remote sensing and GIS [14]. Among these, AHP (Analytical Hierarchy Process) is considered one of the effective methods due to its ability to make decisive decisions on a complex problem. It is one of the multi-criteria decision-making techniques developed by Thomas L. Saaty in 1980 to reduce the complexity of a problem for better decision making. It is carried out by dividing the problem into different subsections and organizing the influencing factor according to their hierarchy and finalizing the decision based on each factor's importance on that particular decision [15, 16]. This method is successfully applied to delineate groundwater potentials zones by various researchers [17, 18, 19, 20, 21, 22, 23, 24, 25].

Since the Samoda watershed is one of the essential watersheds of the Durg district, Chhattisgarh state, it has considered the analysis of groundwater potential area, with the help of different thematic layers AHP method.

2. Study area
Samoda Nala watershed (Figure.1) is situated in the Durg district of Chhattisgarh state. The watershed is 117.45 km² in area; it consists of one of the major industrial areas in Chhattisgarh- Bhilai steel plant (BSP), Associated Cement Companies Limited (ACC) mines agricultural areas. The area is located between Latitude 21°07’ to 21°018’ and Longitude 81°17’ to 81°24’ in the Survey of India (SOI) Toposheets No.64G/7 64G/8. Warm- semiarid climate with annual rain fall of 1230 mm, supports the area's agricultural and socio-economical lifestyle. The southwest monsoon is the major source of rainfall in the area. The area's surface temperature varies from 10°C to 40°C with more than 55% humidity [26].

3. Material and Methodology
In the present study, the potential zones have been delineated using the step-wise methods given in the flow chart (Figure 2). The location of the study area (Figure 1) along with the watershed is delineated with the help of SOI map series 64G/7, 64G/8 and Digital Elevation Model (DEM) downloaded from Earth explorer. Geology of the area has been digitized from the geology Map collected from the GSI. Map representing the soil types of the study area is digitized from the existing soil map [26]. Drainage density and slope map has been developed from the DEM. The map's drainage density has prepared with the help of line density tool in the spatial analyst tool, whereas the slope has developed from the surface tool. Land use land cover of the area has prepared with the help of satellite imagery accessed from the earth explorer. The study area’s water table map during pre-monsoon was created with IDW interpolation from the 2019 fieldwork data. Lineaments in the area accessed from thematic services of
Bhuvan used for the generation of lineament buffer zones. Average annual rainfall was collected from the State Water Resource Department; the Government of Chhattisgarh has used to develop the spatial distribution of rainfall. The overall data used and the corresponding source are given in Table 1.

Figure 1. Study area Location
Figure 2. Flow Chart representing the methodology

| S. No | Data Used      | Data Description | Month & Year | Source                           |
|-------|----------------|------------------|--------------|----------------------------------|
| 1.    | SOI Toposheet   | 64G/7, and 64G/8 | -            | Survey of India                  |
| 2.    | DEM            | n21_e081_1arc_v3_tif | -            | https://earthexplorer.usgs.gov/  |
| 3.    | Geology Map    | Geological Map series 64G/7, and 64G/8 | -            | Geological survey of India       |
| 4.    | Soil Map       | -                | -            | CGWB Report                       |
| 5.    | Water level Data | -              | May 2019    | Field survey                      |
| 6.    | LANDSAT Data   | LC08_LITP_143045_20181114_20181128_01_T1.tar | Nov 2018 | https://earthexplorer.usgs.gov/  |
| 7.    | Lineament      | CH_LN50K_0506    | -            | https://bhuvan-vec2.nsc.gov.in/bhuvan/wms |
| 8.    | Rainfall       | -                | Avg of 1990-2000 | Department; Government of Chhattisgarh |

Further, the different influencing factors were collected from the various source subjects to the AHP analysis for finding out the normalized weight. AHP is a useful method opted by professionals in different fields to reach a proper decision against a complex problem [27, 28, 29, 30].
AHP is firstly introduced by Saaty (1980). The AHP helps to determine the priority of the factors on a particular problem and its relative importance over other factors. This method calculates each individual parameter by dividing it into matrices consisting of a relative comparison of two factors with respect to each other. Researchers in the field of groundwater studies seek the help of AHP through remote sensing and GIS to arrange the factors, compare the factors with each other according to their influence on the groundwater potential zone, and finally deciding on the spatial distribution of groundwater prospect zones [17, 19, 31, 22].

The AHP process starts with,
- Selection of influencing factors for a particular decision-making process.
- Comparison of each factor with each other and value has been assigned (Table 4) to them from the saaty’s 1 to 9 scale, (Table 1, Table 2) with respect to the priority each factor compared to the other on the potential zone.
- Arrangement of Values in a matrix format which will help to find out the priority vector (Table 4).
- Derivation of Normalised weight from the priority vector (Table 4).
- Calculation of Eigen value and Consistency Index (eq.1).

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

| Table 2. Saaty’s Saaty’s 1-9 Scale of Relative Importance |
|----------------------------------------------------------|
| Equal Importance Two                                      | activities contribute equally to the objective |
| Weak or slight                                           | Experience and judgement slightly favour one activity over another |
| Moderate importance                                      | Experience and judgement strongly favour one activity over another |
| Moderate plus                                            | An activity is favoured very strongly over another; its dominance demonstrated in practice |
| Strong importance                                        | The evidence favouring one activity over another is of the highest possible order of affirmation |
| Strong plus                                              | A reasonable assumption |
| Very strong or demonstrated importance                   | Maybe difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities. |
| Very, very strong                                        |                                    |
| Extreme importance                                       |                                    |

If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.
\textbf{Table 3. Random consistancy Index}

| n  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI | 0   | 0   | 0.58| 0.89| 1.12| 1.24| 1.32| 1.41| 1.45| 1.49|

\textbf{Table 4. Comparison Matrix}

|      | Geology | LULC | Rainfall | Soil | Slope | Water Table | Lineament | Drainage density |
|------|---------|------|----------|------|-------|-------------|-----------|-----------------|
| Geology | 1.00    | 1.20 | 3.00     | 2.00 | 4.00  | 1.50        | 6.00      | 8.00            |
| LULC  | 0.83    | 1.00 | 3.00     | 4.00 | 1.50  | 1.20        | 6.00      | 7.00            |
| Rainfall | 0.33    | 0.33 | 1.00     | 1.50 | 0.33  | 1.50        | 4.00      | 1.80            |
| Soil  | 0.50    | 0.25 | 0.67     | 1.00 | 1.40  | 0.50        | 3.00      | 2.00            |
| Slope | 0.25    | 0.67 | 3.00     | 0.71 | 1.00  | 1.20        | 3.00      | 2.00            |
| Water Table | 0.67    | 0.83 | 0.67     | 2.00 | 0.83  | 1.00        | 3.00      | 2.00            |
| Lineament | 0.17    | 0.17 | 0.25     | 0.33 | 0.33  | 0.33        | 1.00      | 2.00            |
| Drainage density | 0.13    | 0.14 | 0.56     | 0.50 | 0.50  | 0.50        | 0.50      | 1.00            |

\textbf{Table 5. Priority vector}

| Geology   | LULC | Rainfall | Soil | Slope | Water Table | Lineament | Drainage density | Normalize -d vector | Consistency vector |
|-----------|------|----------|------|-------|-------------|-----------|-----------------|---------------------|--------------------|
| Geology   | 0.26 | 0.26     | 0.25 | 0.17  | 0.40        | 0.19      | 0.23            | 0.31                | 0.25               | 8.68               |
| LULC      | 0.22 | 0.22     | 0.25 | 0.33  | 0.15        | 0.16      | 0.23            | 0.27                | 0.22               | 8.61               |
| Rainfall  | 0.09 | 0.07     | 0.08 | 0.12  | 0.03        | 0.19      | 0.15            | 0.07                | 0.10               | 8.39               |
| Soil      | 0.13 | 0.05     | 0.05 | 0.08  | 0.14        | 0.06      | 0.11            | 0.08                | 0.08               | 8.62               |
| Slope     | 0.06 | 0.15     | 0.25 | 0.06  | 0.10        | 0.16      | 0.11            | 0.08                | 0.12               | 8.74               |
| Water Table | 0.17 | 0.18     | 0.05 | 0.17  | 0.08        | 0.13      | 0.11            | 0.08                | 0.12               | 8.43               |
| Lineament | 0.04 | 0.04     | 0.02 | 0.03  | 0.03        | 0.04      | 0.04            | 0.08                | 0.03               | 8.45               |
| Drainage density | 0.03 | 0.03     | 0.05 | 0.04  | 0.05        | 0.06      | 0.02            | 0.04                | 0.04               | 8.60               |

\(\lambda_{\text{max}}\) represents the largest eigen value and ‘n’ is the number of factors considered. The derived consistency matrix will be acceptable only when the consistency ratio (CR) (eq.2) is $\leq 10\%$.

\[\text{CR} = \frac{\text{CI}}{\text{RI}}\]

The RI in the equation represents the random index defined by the number of factors ‘n’ [15]. The random consistency index (Table 2), for the different values of ‘n’ has been defined by saaty to derive the consistency ratio. The process has to continue, and the judgment needs to revise if the CR >10%.

As per the above equations, eight influencing factors were considered for the generation comparison matrix (Table 4), priority vector (Table 5), and the normalized vector (Table 5). The normalized value derived from the priority vector processing is further subjected to creating a 1x8 matrix consisting of the \(\lambda_{\text{max}}\) values. Average of \(\lambda_{\text{max}}= 8.5\) (eq. 3) value then applied in the equation 1, for the calculation of CI= 0.071 (eq.4). The value of “n” indicates the total number of factors involved in the process.

The consistency index derived from the above calculations and the value of the random consistency index (1.41) is utilized to calculate CR. The CR value derived from the calculation is 0.05, which is below 10%, which is considerable.

\[\lambda_{\text{max}} = (8.6+8.6+8.3+8.6+8.7+8.4+8.4+8.6)/ 8 = 68.2/ 8 = 8.5\]

\[\text{CI} = \frac{\lambda_{\text{max}} - n}{n - 1} = \frac{8.5 - 8}{7} = 0.071\]

\[\text{CR} = \frac{0.071}{1.41} = 0.05\]
Likewise, the major influencing factors' assigned weight, each sub-factors' rank, is also essential. Each factor's rank is assigned by considering their influence on the potential zones on a particular area. The rate of each sub-factor rated from 1 to 5 according to their priority. The one that has much influence on potential zone rated as 5 and the least important rated as 1.

The finalization of each sub-factors rate and weight and a significant factor is followed by the generation of Groundwater potential zones (GWPZ). The rate assigned to each sub-factor utilized for the reclassification of each thematic layers. The resulted reclassified thematic layers, then subjected to the weighted sum analysis for the generation of the potential zone by applying the corresponding unique normalized weight of each factor. The weighted sum is calculated by,

$$GWPZ = \sum[(GG_w \ast GG_R) + (LULC_w \ast LULC_R) + (Rf_w \ast Rf_R) + (S_w \ast S_R) + (Sl_w \ast Sl_R) + (Wl_w \ast Wl_R) + (Lmt_w \ast Lmt_R) + (DD_w \ast DD_R)]$$

Where, GG= Geology, LULC= Land Use Land Cover, Rf=Rainfall, S= Soil, Sl= Slope, Wl= Water level, Lmt= Lineament, DD= Drainage Density. The subscript “w” and “R” are representing the corresponding weight (w) and Rate (R) of the influencing factors.

4. Result and Discussion

4.1 Geology
Geology is an important factor that controls the existence of groundwater in the area. As per the lithology map of GSI, the study area consists of mainly 3 types of rocks (Figure 3). Almost 97 percent of the Samodana watershed is covered with the Stromatolitic Dolomitic Limestone. Some patches of laterites (1.7 %) are visible at top surface of limestone terrain in the North and North-East part of the area. A small part of Ferrugious sandstone's extension in the southwest part of the area contributed to its geological diversity.

4.2 Rainfall
The study area is fallen in the region, which comes under the semiarid tropical climate. The South-Eastern monsoon mainly feeds the rain fall of the area, and it receives the precipitation during the month of June to September. The average annual rainfall of the area is computed as ~1120 mm. The annual rainfall of the area, ranges from <1090 to >1150 has classified in to 5 zones (Figure 4), according to its importance in the generation of the potential zones.

4.3 Lineament
Lineament is the linear feature present at the earth's surface and is the surface expression of the underlying geologic feature [32]. As per the geology of the area, the lithology consists of mainly a single rock formation, which is the stromatolitic dolomitic limestone. Even though it is massive, the fractures present in the formation contribute to the area's aquifer. Among them, some of the prominent fractures are expressed as a linear feature at the surface as lineaments. The lineaments present at the surface of the study area and the buffer zones indicate the influence of groundwater existence's lineament. An increase in the buffer zone area away from the lineament (Figure. 5) decreases the impact of lineaments on groundwater potential zones.

4.4 Slope
As one of the geographic factors, Slope is directly proportional to the water flow on the surface and at subsurface. The terrain of the terrain can indicate the infiltration condition of the area; gentler, the slope means higher the infiltration capacity of water. The slope map generated from the DEM has classified into six different categories as 0-2%, 2-5%, 5-8%, 8-15% and 15-30% and > 30% (Figure. 6).
classification shows that more than 70% of the terrain is coming under the <5% category, which is flat to undulating in nature and highly supports the groundwater storage potentiality.

Figure 3. Lithology Map of the Study area

Figure 4. Rainfall Map of the Study area

Figure 5. Lineament Map of the Study area

Figure 6. Slope Map of the Study area
4.5 Drainage network and Drainage density
The drainage network (Figure 7) of the area depends entirely on the area's rock formation, geological structures, and slope. Since the Samoda Nala is on a soft rock terrain with an almost gentle slope, it develops a dendritic pattern on the surface. It is a small Nala which is of 3rd order, has a maximum length of 21 km. The Nala has natural as well as the artificial origin and is ending up in the Seonath River.

Drainage density of the Samoda Nala (Figure 8), which represents the stream length per unit area [33, 34], acts as an indirect entity that helps determine the influence of drainage on the groundwater potential zones in the area. Greater the drainage density, greater the chance of runoff, and lessen the chance of infiltration. The area's drainage density has divided into 5 sub-divisions such as Very-Low, Low, Medium, High, and Very-High. The rank of each subdivision assigned in such a manner that the Very-Low Drainage density is having ‘5’ and Very-High is having ‘1’.

![Drainage Network Map](image1)
![Drainage Density Map](image2)

Figure 7. Drainage network Map of the study area  
Figure 8. Drainage Density Map of the study area

4.6 Landuse Landcover
Land use land cover represents the effective utilization of land for various purposes, naturally and artificially. Samoda Nala watershed is covered with numbers of land use and land cover utilities (Figure 9) such as industrial areas, settlements, agricultural areas, mine, water bodies, roads etc. Consideration of such factors is much more important because it can indirectly control the region's runoff/ infiltration capacity. The cultivated land categories have covered ~ 40 percentage of land, followed by the settlement ~33%. The LULC of the area has been verified by the field check.

4.7 Soil
Types of soil in the area have their importance on the water infiltration and movement through the soils. The soil contents and properties clearly define whether the soil favors water infiltration or movement. The study area mainly consists of three types of soil (Figure 10), Lateritic soil, Vertisol deep black, and Vertisol medium black. Vertisols are the soils that consist of 30% clay materials and are subjected to a
series of shrinking and expanding processes. The presence of clay materials slows down the soil's capacity to transmit water through it.

![Figure 9. LULC Map of the study area](image)

![Figure 10. Soil Map of the study area](image)

### 4.8 Water level

The water level is the measurement of the top surface of the water column from the land surface. The water level is measuring in meters. The groundwater level's spatial variation measured from borewells in the study area shows that the middle part of the area has very shallow water. However, the uppermost part of the region consists of deep groundwater existence (Figure 11). The aquifer system in the area is unconfined in nature hence the importance of the water level measurement also. The area's water level has been classified into 5 different depths: <4m, 4-8m, 8-12m, 12-16m and >16m, which are shallow, shallow, medium, deep, and very deep. The depth of the water level itself can give a conclusion about the groundwater scenario of the region. However, the presence of shallow water levels in the highly-populated area near the Bhilai Steel plant may be resulted from the high utilization of the municipal water compared to the consumption of water from the borewell.

### 4.9 Groundwater potential zone

The area's groundwater prospect zones have been generated by applying the weighted sum method opted from the spatial analyst tool. The assigned rate and weight (Table 6) of each major and sub-factor were considered during the calculation.

The potential zones derived after conducting the weighted sum have divided into five zones (Figure 12) such as Very-Low, Low, Medium, High, and Very High. Generated potential zones further validated with the yield data (Table 7, Table 8) collected from the CGWB [35] for its finalization. The validation has been done with the help of six borehole data. The yield of observation wells was distributed in various locations compared with the potential zones and concluded that, among 6 boreholes, 5 of the
borehole yields agreed with the potential zone classification, but one strongly disagrees with it. The observation reveals that the calculated potential zone's accuracy is 83% and is acceptable as a reliable result.

![Water Level Map](image1.png) ![Groundwater Potential Zone Map](image2.png)

**Figure. 11** Water Level Map of the study area  
**Figure. 12** Groundwater Potential zones of the study area

**Table 6.** Weight and Rate of the major criteria and sub-criteria

| Main criteria | Sub-criteria | Rank | Normalised weight | Main criteria | Sub-criteria | Rank | Normalised weight |
|---------------|--------------|------|------------------|---------------|--------------|------|------------------|
| Geology       | Ferruginous Sandstone | 3    |                  | Water level   | 0-2          | 5    |                  |
|               | Laterate     | 4    | 0.26             |               | 2- 5 %       | 4    |                  |
|               | Stromatolitic Limestone | 3   |                  |               | 8-15 %       | 2    |                  |
|               | Canal        | 3    |                  | Slope         | 5-8 %        | 3    | 0.12             |
|               | Cultivated land | 4   |                  | 8-15 %        | 2            |
|               | Industrial Area | 1   |                  | 15-30 %       | 1            |
|               | Mine         | 2    |                  | >30 %         | 1            |
|               | Pond         | 5    | 0.23             | <4m           | 5            |
| LULC          | Road         | 1    |                  | 4-8m          | 4            |
|               | Samoda nala  | 5    |                  | Water level   | 8-12m        | 3    | 0.12             |
|               | sand Bar     | 4    |                  | 12-16m        | 2            |
|               | Settlement   | 1    |                  | 16-22m        | 1            |
|               | Vegetation   | 3    |                  | 0-50          | 5            |
|               | <1090        | 1    |                  | 50-100        | 4            |
| Rainfall      | 1090-1110    | 2    | 0.10             | Lineament     | 100-200      | 3    | 0.04             |
|               | 1110-1130    | 3    |                  | 200-300       | 2            |
|               | 1130-1150    | 4    |                  | 300-400       | 1            |
|               |              |      |                  | Very low      | 5            | 0.04 |
Table 7. Classification of yield and the corresponding potential zone category

| Yield          | Groundwater potential as per yield |
|----------------|-----------------------------------|
| <3             | Low                               |
| 3 - 6 lps      | Medium                            |
| >6             | High                              |

Table 8. Comparison and validation of observed yield and the calculated potential zones

| Sl No. | Wl No | Location          | Latitude  | longitude  | Discharge (lps) | Potential Zone as per the yield | Calculated Potential zone | Agree/Disagree |
|--------|-------|-------------------|-----------|------------|-----------------|---------------------------------|--------------------------|-----------------|
| 1      | Du18  | Dundera-I         | 21.151    | 81.394     | 0.27            | Low                             | Low                      | Agree           |
| 2      | Du26  | Kurud             | 21.243    | 81.356     | 2.25            | Low                             | Low                      | Agree           |
| 3      | Du72  | Ghughwa           | 21.142    | 81.373     | 12              | High                            | High                     | Agree           |
| 4      | Du83  | Dhour             | 21.268    | 81.356     | 1.8             | Low                             | High                     | Disagree        |
| 6      | Du89  | Bilai (Sector I)  | 21.182    | 81.334     | 0.5             | Low                             | Low                      | Agree           |
| 7      | Du90  | Bilai (Sector IV) | 21.189    | 81.334     | 0.5             | Low                             | Low                      | Agree           |

5. Conclusion
The groundwater potential map generated by the Multicriteria Decision-making (MCDM) technique by the AHP method for the Samoda Nala Durg District, Chhattisgarh, India, has utilized a number of influencing factors such as Geology, LULC, Rainfall, Soil, Slope, Water level, Lineament, and Drainage Density. The thematic maps prepared from different data sets were classified according to their influence on the groundwater potential zone. The Normalized weight was calculated by the AHP method, and the rank assigned according to the sub-factors classification by considering its priority was applied. There are 5 zones of groundwater potential has been derived from the process. Developed zones then validated with the yield data of observation wells, with 83% accuracy. Further, the validated potential zones can be considered reference data for any other civilian activities directly or indirectly linked with the area’s groundwater scenarios.

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