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Multi-Criteria Decision Making and Dempster-Shafer Model Based Delineation of Groundwater Prospect Zones From A Semi-Arid Environment

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Interest Statement

The present research work doesn't have any conflict of interest with the researchers who have done the work in this area. The findings of the present research work will provide a road map for making the plan for water management.

Abstract

The present study illustrates the delineation of the groundwater potential zones in one of the most critical and drought affected areas under Bundelkhand region of Uttar Pradesh. Hydrological evaluations were carried out in district Mahoba using GIS tools and remote sensing data which ultimately yielded several thematic maps, such as lineament density, land use/land cover, drainage density, lithology, slope, geomorphology, wetness index (WTI), altitude and soil. CartoDEM data which have spatial resolution of 30m i.e. equivalent to one arc second were used to create digital elevation model, drainage density, altitude, WTI and slope. The thematic layers were assigned relative weightages as per their groundwater potential prospects under multi-criteria decision making (MCDM) method through analytical hierarchy process (AHP). To recognize the groundwater potential zone, weighted overlay analysis was performed using ArcMap software. Additionally, for testing of the Dempster-Shafer model, 16 borewells in high potential areas have been selected. Based on the probability of the groundwater occurrence, the belief factor was equated. Further combining the weighted layers, groundwater potential zones were obtained. The groundwater potential maps illustrate five zones having different potential in the Mahoba district. According to the AHP model the north-west side of the study area is characterized with very good potential zones whereas the north-east and south-east region constitute medium and poor groundwater potential zones respectively. It reflects that more than 50% of the area is having medium groundwater potential while 30 percent of the area falls under low potential zone. 10% of the study area falls under very good groundwater potential zones. According to the DS model, very high groundwater zones constitute only 7% and the remaining area falls under poor potential. Overall accuracy of the DS model was higher than AHP model.

Keywords: Multi-criteria decision making (MCDM); Analytical hierarchy process (AHP); Groundwater potential; Bundelkhand; Hydrological evaluations.

Introduction

Rainwater is the only source of freshwater and the occurrence of rainfall is seasonal in nature, resulting into mild to severe droughts (Adimalla et al. 2018). Groundwater has key impacts on human life such as agriculture, industries and ecological diversity. With the increment in the demand for adequate and better quality water to meet the growing needs, a proper planning of groundwater management is essential (Agrawal 2013). As per the assessment by Central Ground Water Board India (CGWB 2017), total annual groundwater recharge is 432 billion cubic meters (BCM), and the annual exploitable groundwater resources is 393 BCM. The annual groundwater withdrawal for all uses is 249 BCM out of which 221 BCM (89%) is used for irrigation and 25 BCM (10%) is used for domestic purposes. According to a World Bank (2016) report, India will become a water-stress country by 2025 and a water-scarce country by 2050, if not enough measures are taken. Due to rapid urbanization and population growth, excessive and unjustified use of groundwater has caused depletion of groundwater tables which reiterate the need for better understanding of groundwater potential zones (Islam et al. 2021).

In the recent past, many methods have been used by several researchers to delineate the groundwater potential zone. Weights-of-Evidence (WOE) technique was used as an effective method for delineation of groundwater potential zones by Ozdemir, (2011); Pourtaghi and Pourghasemi, (2014). Some researchers like Oh et al. (2011); Moghaddam et al. (2015) have also used the Frequency Ratio (FR) technique for identifying groundwater potential zones. The Analytical Hierarchy Process (AHP) analysis by GIS technique was used by Pande et al. (2019); Singh et al. (2010); Shekhar and Pandey (2014); Rahmati et al. (2014); Murmu et al. (2019) and Adiat et al. (2012) to delineate the groundwater potential zone.

GIS and analytical hierarchy process (AHP) is the most useful technique for decision making and geospatial data management. This is applicable in various fields of hydrological, geological and environmental science (Gnanachandrasamy 2018). AHP technique is proven to be a very practical, rapid and cost effective technique to map the groundwater potential zones and in producing accurate results while traditionally groundwater exploration was costly and time consuming. Because it needed ground survey using geophysical, geological and hydrological tools (Arulbalaji 2019). Nowadays, remotely sensed data is being widely used to provide baseline information such as digital elevation model (DEM), digital terrain model (DTM), land use/land cover etc., which are further used for preparation of several geospatial thematic maps required for the delineation of groundwater potential zones. Suja and Krishnan (2009), Nag and Ghosh (2012), Suganthi (2013), and Etishree (2013) Weightages based on Saaty's (1980) scale for distinct thematic maps utilized to identify groundwater potential zones. According to Doke et al. (2018), Das (2019), Adimalla (2020), and Arjun et al. (2021) geological and geomorphological setup are the most influencing factors for groundwater occurrence. As per Debasis et al. (2020) shallow unconfined aquifers, deeper fractures and joints under semi-confined conditions are the important indicators of groundwater potential in hard rock terrains. Many researchers Adimalla et al. (2018); Arulbalaji (2019); Gangadharan et al. (2016) have used various thematic layers like drainage density, geology, lineament density, slope, soil and lithology for the identification of groundwater potential zones.

Another approach to delineate the groundwater potential map is the Dempster-Shafer (*DS*) model, which has been predominantly used by many researchers (Mogaji et al. 2018; Ali et al. 2017; Nithya et al. 2018; Sahereh et al. 2021) around the world. The main reason to use the DS model is that it provides a set of probabilistic degrees such as Belief, Disbelief, Plausibility and Uncertainty. The link between obtained thematic layers of probabilistic degree illustrates groundwater potential zones, which is further classified into five categories; Very High, High, Medium, Low and Very Low.

As the groundwater is an extractable asset with this intervention most groundwater management authorities ignore support services and other in situ groundwater functions, the authorities need to adopt an integrated approach to control excessive extraction of groundwater considering environmental management (Gun 2021). The AHP and DS model for the accurate mapping of groundwater potential have been used in the present study.

Study Area

The district Mahoba is located in Uttar Pradesh state of India, lies between 25° 01'30" and 25° 39'40" north latitude and 79° 15'00" and 80° 10'30" east longitude (Fig. 1). The total geographical area of the district is 2,884 km². It has four administrative blocks and five towns. According to the Census of India (2011) the total population of the district is 875958. The district experiences a typical subtropical climate punctuated by long and intense summers. Mild winter and moderately heavy rainfall during the rainy season. The maximum mean monthly atmospheric temperature has been recorded 47.5° C during the month of May and minimum 8.3° C in January. Temperature generally starts rising from March and reaches highest in May. June onward temperature starts decreasing and almost establishes around 36° C during August and September. During the monsoon period (July to September) the relative humidity attains at its highest level which varies between 80 to 85% while it is lowest at 30% during peak summer months of April and May. Major soil type is sandy deep loamy while average rainfall for the last 10 years is estimated to be 770mm. There is no meteorological observatory located in Mahoba district, however five rain gauge stations have been established by the UP irrigation department (Pandey 2002).

The rock formations of the Bundelkhand massif is characterised by compact and partially granite which do not allow rain to percolate and store under subsurface. Secondary porosity in the form of joints and cracks, allows some water to pass through weather zones into phreatic aquifers (Pant 2011). The hilly and hard rock terrain cause heavy overland flow and water during the rainy season. As a result, base flow occurs in the river as a part of groundwater.

Agriculture being the main source of livelihood for the people of Mahoba district requires excessive extraction of groundwater, both groundwater and surface water are used for irrigation purposes. Most of the agricultural land depends upon precipitation. Swami Brahmanand Dam with storage capacity of 89.8 Billion liters and Arjun Sagar Reservoir with storage capacity of 16.6 Billion liters are the two major basins which collect most of the rainwater through run-off. Total length of the irrigation canals is approximately 455 km. Dhasan, Urmil, Birna and Arjun rivers follow through the district, these rivers and streams form the natural drainage lines of the district and separate many administrative boundaries.

Fig. 1 Location map of the study area

142 Data and Methodology

Fig. 2 Flow chart of methodology adopted for the delineation of groundwater potential maps

Pre-processing of remotely sensed data i.e. Sentinel 2 was done using ArcGIS software, which is used for preparing thematic layer of land use/land cover, the data have a spatial resolution of 10m for blue, green, red and infrared bands which gives more accurate details about features of the earth surface (Cavur 2019). Analysis of thematic layers such as geomorphology, lithology, soil, land use/land cover, slope, drainage density, lineament density, altitude and topographic wetness index (*TWI*) were considered. The data pertaining to the study area were downloaded from the European Space Agency website (<https://scihub.copernicus.eu/>). CartoDEM data were used for generating Digital Elevation Model (DEM), altitude, lineament density, and topographic wetness index, which have 30m of resolution and downloaded from National Remote Sensing Center's website called Bhuvan (<https://bhuvan-app3.nrsc.gov.in/data/download/>). It is processed in ArcMap platform to generate flow accumulation with direction. Flow direction of streams represent the drainage network of the study area, and resulted into a thematic layer of drainage density. The DEM data is also used for the preparation of slope which is an important factor for delineation of groundwater potential zone. It mainly represents movement of water on the surface which is known as surface run-off. The steps involved to delineate the groundwater potential zone have been depicted in Fig. 2.

Ancillary data pertaining to thematic layers as geomorphology (scale 1:250K) and lithology (scale 1:50K) were collected from Bhukosh portal (<https://bhukosh.gsi.gov.in/Bhukosh/Public>) of Geological Survey of India, Whereas; soil map was downloaded from (<http://www.nicra-icar.in/nicrarevised/images/statewiseplans/Uttar%20Pradesh/UP50-Mahoba-26.07.14.pdf>) National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) Regional center Delhi. According to the report of NBSS & LUP, the

soil type for the selected region of Mahoba district is deep loamy soil with very low slope (<3%-5%). Selected thematic layers were further processed using multi-criteria decision making (MCDM) technique of AHP and DS model. Finally weighted overlay analysis has been carried out to calculate overall weightages for each thematic layer. The maps were further classified into five categories under groundwater potential zones. Borewells data have been used for the validation of the groundwater potential zones. The receiver operating characteristics (ROC) curve method was also employed to compare the groundwater potential zones maps obtained from both the models.

Analytical Hierarchical Process (AHP)

Analytical Hierarchical Process (AHP) is a practical and most common method based on GIS to delineate the groundwater potential zones. This method is useful to integrate several hydrological thematic layers (Arulbalaji 2019). Out of nine thematic layers only seven were selected to delineate the potential zones in the study area. The weightage for the selected thematic layers was computed using Saaty's scale (1980). According to Gangadharan et al. (2016) Weight assignment, pairwise comparison matrix, weight normalisation, and consistency assessment are all part of the AHP model. This strategy is capable of decreasing the problem complexity and assisting in the adoption of simplified decisions based on comparisons (Kannan 2010; Celik 2019).

All the thematic layers were given importance which were used for weightage calculation (Table-1). The proposed ranking of the thematic features defines weightages values. Further, to compare all of the factors, a pair-wise comparison matrix (W) was created (Eq. 1). Using the eigen-vector technique described by Saaty, the process of normalizing weights (W_{ij}) is derived (Eq. 2) from the matrix table (Table 2). (Neissi et al. 2020; Nithya et al. 2019). The geometric mean of the i^{th} factor is m .

Table 1: Importance of Thematic layers for weightage calculation

Thematic layers						
Lineament density	Geomorphology	Slope	Lithology	Soil	Drainage Density	LULC
6	4	4	3	3	3	2

$$W = \begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & 1 & a_{23} & \dots & a_{2n} \\ a_{31} & a_{32} & 1 & \dots & \dots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \dots & \dots & 1 \end{bmatrix} \quad \text{---(Eq. 1)}$$

Where, $a_{ij} = \frac{\text{weight for attribute } i}{\text{weight for attribute } j}$

190 Table 2: Pairwise comparison matrix for the selected thematic layers

Thematic layers	Thematic layers							Normalized Weightage
Factors	Lineament density	Geomorphology	Slope	Lithology	Soil	Drainage Density	LULC	
Lineament density	6/6	6/4	6/4	6/3	6/3	6/3	6/2	0.24
Geomorphology	4/6	4/4	4/4	4/3	4/3	4/3	4/2	0.16
Slope	4/6	4/4	4/4	4/3	4/3	4/3	4/2	0.16
Lithology	3/6	3/4	3/4	3/3	3/3	3/3	3/2	0.12
Soil	3/6	3/4	3/4	3/3	3/3	3/3	3/2	0.12
Drainage Density	3/6	3/4	3/4	3/3	3/3	3/3	3/2	0.12
LULC	2/6	2/4	2/4	2/3	2/3	2/3	2/2	0.08
Total	4.17							1.00

191

Normalization of the eigenvector of the largest eigenvalue of the pairwise comparison matrix computes relative importance of each element. Factors of the class that are expected to have high groundwater potential are given higher comparative weightage (Suganthi 2013).

The Consistency Ratio (*CR*) is used to validate the consistency of a judgement. It is calculated by dividing the *CI* by the Random Consistency Index (*RCI*) and is represented algebraically in the equation below (Debasis 2020).

$$CR = \frac{CI}{RCI} \quad \text{--- (Eq. 2)}$$

If the *CR* value is less than 0.1, the judgement value must be accepted; otherwise, a new comparison matrix must be constructed with fresh judgement value for all parameters until the *CR* value is less than 0.1. The following expression is used to calculate the *CI*:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \text{--- (Eq. 3)}$$

where λ_{max} is the maximum eigenvalue of “*W*”, and the sequence of the square matrix is known as *n*. If *W* is entirely constant, then λ_{max} equals *n*, resulting in a zero *CI*. As the level of inconsistency rises, so does the value of λ_{max} (Saaty 1980).

An overlay analysis was performed to determine overall weightages for all thematic layers. The potential zone for groundwater has been computed as follows:

$$GWPZ = \sum_{i=1}^n FiWi \quad \text{--- (Eq.4)}$$

Or;

$$GWPZ = \sum (\text{Geomorphology rank} \times \text{weight} + \text{Lithology rank} \times \text{weight} + \text{Soil rank} \times \text{weight} + \text{Lineament density rank} \times \text{weight} + \text{Slope rank} \times \text{weight} + \text{Drainage density rank} \times \text{weight} + \text{Land use/land cover rank} \times \text{weight})$$

Where *Fi* denotes the relative weighting of several geo-environmental parameters used to estimate groundwater potential, and *Wi* denotes the ranking of those elements (Achu 2020). The groundwater potential zone was created by dividing the study region into five classes: 1. Very good, 2. Good, 3. Medium, 4. Low, and 5. Very low.

Dempster-Shafer model

The theory was first introduced by Dempster (Dempster 1967) which was further developed by Shafer (1976), the DS model represents spatial integration of mathematical calculations (Sahereh et al. 2021). To use the DS model, weighting of the factors of the thematic layers are calculated, which offers the following probability layers: Belief, Disbelief, Uncertainty and Plausibility. All factors in the same course are united, to create a predicted underground water zone (Ali et al. 2017). If we divide each data layer into numerous classes, then the weight values of each class Belief (*B*) and Disbelief (*D*) are calculated as follows:

$$B = \frac{Wi}{pi} = \frac{\text{the percent of groundwater wells in the domain}}{\text{the percent of pixels in the domain}} \quad \text{..... (Eq. 5)}$$

$$D = \frac{Wi}{pi} = \frac{\text{the percent of groundwater out of the domain}}{\text{the percent of pixels out of the domain}} \quad \text{..... (Eq. 6)}$$

The following equations are used to calculate Plausibility (*P*) and Uncertainty (*U*):-

229 $U = 1 - D - B \dots (Eq. 7)$

230 $P = 1 - D \dots (Eq. 8)$

231 The groundwater potential map can be obtained using the following equation (Ali et al. 2017):

232 $GWPM = ([Altitude_Bel] + [Slope\ Angle_Bel] + [TWI_Bel] + [Landuse_Bel] + [Drainage\ Density_Bel] + [Soil_Bel]$
 233 $+ [Geomorphology_Bel] + [Lineament\ Density_Bel] + [Lithology_Bel] \dots (Eq. 9)$

234 After preparing the following thematic layers: geomorphology, lithology, land use/land cover, soil type, altitude, slope,
 235 drainage density, TWI index and lineament density, class and weight values were calculated for each of these layers
 236 based on the actual groundwater well data (training data). According to the impressive factors which received grater
 237 belief (Bel) values have more efficiency on groundwater potential (Ali et al. 2017).

238

239 **Results and Discussion**

240 After preparing 9 data layers and classification of each layer into its factors, the weight values of each factor were
 241 calculated using the DS model based on actual groundwater well training data. In AHP model TWI and altitude were
 242 not considered as they have very less importance value, therefore only 7 data layers were considered for the analysis,
 243 characteristics of considered thematic layers according to its importance value have been depicted. Each layer has
 244 played an important role for determining the groundwater potential zones in the study area. The results obtained during
 245 the entire study have been discussed below;

246 **Geomorphology**

247 It is one of the important parameters widely considered for the delineation of the groundwater distribution in various
 248 landforms (Table 4). Higher water retention capability is denoted by river/water bodies and active floodplain which
 249 is considered as the best landform for groundwater potential. Alluvial plains deposited along with the river channel
 250 and flood plains are given highest rank while moderately dissected hills and valleys are given least ranking (1-5). The
 251 accumulated weightages for different geomorphological factors vary from 16 to 80 which indicates that factors with
 252 higher weightages influence groundwater potential.

253 North west side of the study area (Fig. 3 a) is covered by alluvial plains which indicate higher possibility of
 254 groundwater. In the DS model belief factor varies from 0 to 0.53 and disbelief 0.16 to 0.50. Uncertainty rate varies
 255 from 0.12 to 0.51. It reflects higher groundwater occurrence in low uncertainty zones which are classified as dams
 256 and reservoirs.

257

258 **Lineament Density**

259 As a result of faulting and jointing, lineaments relate to zones of enhanced porosity and permeability in hard rock area,
 260 hence they are very much important in groundwater investigations (Sreedevi et al. 2001; Koch & Mather 1997). Higher
 261 groundwater potential is expected where the geological linear features are more intensive. The lineament trends North
 262 East and South West direction (Fig. 3 b). In the AHP model, the accumulated weightages varies from 24 to 120, since
 263 the layer received the highest weightages it is the most influencing factor for the groundwater potential delineation.
 264 Lineament density was classified into following intervals: <0.03, 0.03–0.10, 0.10–0.18, 0.18–0.28, 0.28–0.48 km/km²
 265 as very low, low, medium, high, and very high respectively (Table 4) the maximum is 0.49 km/km². The highest
 266 lineament density interval received the top ranking. In the DS model the belief factors varies from 0.20 to 0.54 (Table
 267 3) which is considered as one of the most influencing thematic layers, higher beliefs are present along with low
 268 lineament density.

Lithology

Lithology controls soil porosity and water permeability and affects the specific storage of groundwater. Obtained weightage from the AHP comparison matrix is 0.12 and the overall weightages varies from 12 to 60 (Table 4). Several lithological features of the study area are marked in the map (Fig 3-c). Coarse grained porphyritic granite is dominant lithounits. Alluvium is characterized by silt, clay admixed with kankar. Gray sand, silt and clay are given the highest rank which constitute very low geographical coverage. In the DS model the belief factor varies from 0 to 0.64 (Table 3), higher in belief reflects high groundwater zone thus it is an important factor for groundwater potential mapping, Coarse Grained, Porphyritic Granite are associated with high beliefs(0.64) rate.

Slope

Slope expresses the steepness of the ground surface or terrain. The nature of geological and geodynamic processes, surface runoff and infiltration rate are affected by slope. Here steep slopes imply low recharge because of the rapid flow of water while gentle slopes indicate higher groundwater recharge. The map reflects that the majority of the region in the study area constitutes slope ranging from 0 to 4 degree (Fig 3 d). The calculated normalized weight for the slope from the AHP comparison matrix is 0.16 and overall weightages vary from 16 to 80 (Table 4). The slope is classified into the following intervals: 0-1.26, 1.26-2.40, 2.40-4.17, 4.17-10.74 and more than 10.74 degree. The high rank is given to the flat and gentle slope. The Northwest side of the study area has a gentle slope varying from 0 to 2 degrees while the North East side is characterized by 2 to 4 degrees. Steeper slopes are observed in the south west region of the study area which varies from 4 to 32 degrees (Fig 3 d). The run-off is also coherent to the direction of steeper slope (NE-SW). In the DS model, belief rates vary from 0 to 0.64, area under zero belief rate indicates unavailability of groundwater while higher belief associated with gentle slope indicates availability of groundwater.

Fig. 3 Groundwater conditioning factors; (a) Geomorphology, (b) Lineament Density, (c) Lithology, (d) Slope, (e) Soil, (f) Land use/land cover, (g) Topographic Wetness Index, (h) Drainage Density, (i) Pie-Chart of LULC, (j) Altitude

Soil

Soils surface condition influences the infiltration as well as transmission rate. Soil varies in its composition and has different slopes and textures. Loamy soil as observed in the study area is formed with the mixture of silt, clay and sand. These soils are considered to be fertile and easy to work with, they also provide good drainage. It is further classified as sandy or clay loamy depending on their predominant compositions. These soils are highly permeable which contain good amount of groundwater. The calculated normalized weight for the soil from the comparison matrix is 0.12 and the overall weightages vary from 24 to 48 (Table 4), low weightages indicate less influence in delineation of groundwater zones. Fine smectitic soil was given high ranking as 4 and deep loamy soil was given lowest ranking as 2. Different types of soil have been depicted in Fig 3 e. In the DS model belief rate varies from 0.31 to 0.53 (Table 3) with uncertainty rate which varies from 0.05 to 0.20. It reflects low groundwater availability with higher disbelief (0.42 to 0.50).

Land use/Land cover (LULC)

The LULC map (Fig 3-f) provides information about forests, built up, impervious surfaces, agriculture, and water

bodies etc. The given pie chart (Fig. 3 i) illustrates land cover in the Mahoba district. Agriculture accounts for 62% of the total land where commercial activities like mines cover less than 1%. Approximately 16.8% of the district land is covered by wetland followed by barren land i.e. 9.3%. Water Bodies in the district is less than one percentage of the total land cover. Since, the district is densely populated the built up area accounts for more than vegetation and water bodies, i.e. 6.9%. The calculated weight from the AHP comparison matrix is 0.08 and the overall weightages vary from 8 to 40 (Table 8.0). Water bodies and forest cover were given high ranking as 5 and 4 respectively, built-up area was given low weight as 1. In the DS model the belief rate varies from 0 to 0.67 while uncertainty varies from 0.06 to 0.51 (Table 3). Here agriculture is associated with higher belief (0.67) indicating occurrence of groundwater.

Fig 3 (continued)

Drainage Density

Drainage density, defined as the total length of drainage channels per unit area, helps to evaluate and understand the characteristics of runoff and groundwater infiltration (Suganthi 2013). The region was classified (Fig 3-h) as very high, high, medium, low and very low, which are ranked as 1,2,3,4 and 5, respectively. The calculated normalized weight from the AHP comparison matrix was 0.12, overall weightage varies from 12 to 60 (Table 4). In the study area, high runoff density indicates high surface runoff and low infiltration rate, while low and very low runoff density indicates low runoff and high infiltration rate. The percolation of rainwater takes place in low drainage density areas therefore occurrence of groundwater is estimated as high rank for the same. In the DS model belief rates varies from 0.42 to 0.51 and uncertainty rates varies from 0 to 0.07 (Table 3), which indicate low uncertainty rate for presence of

325 groundwater.

Fig 3 (Continued)

328 Topographic Wetness Index

329 *Topographic Wetness Index (TWI)* is one of the important factors considered to study the groundwater potential zone,
 330 it describes the relationship between **the diversion of the water accumulated in the site part and the gravity that**
 331 **pushes** the water according to the slope. The following equation is used for the calculation of *TWI* factor (Moore et
 332 al. 1991):

$$TWI = \ln(\alpha/\tan\beta)$$

333 Where α is the contributing upslope area and β is the topographic gradient at the same point in the terrain. In the
 334 present study *TWI* map was prepared using a digital elevation model of CartoDEM data. The map is classified into
 335 five categories as illustrated in the (Fig 3 g). The lower wetness index value varies from 3.42 to 6.66 while high values
 336 vary from 10.53 to 16.75. According to Moghaddam et al. (2015), Rodhe and Seibert (1999) and Sahereh et al. (2021)
 337 thematic layers representing topographic factors play a conclusive role in the estimation of the groundwater flow
 338 zones. Several researchers (Pourghasemi et al. 2014; Falah et al. 2016, Sahereh et al. 2021; Pourtaghi et al. 2014) have
 339 used *Topographic Wetness Index (TWI)* for groundwater potentiality mapping. This thematic layer was not considered
 340 as an effective factor for the groundwater potential under AHP model of investigation.
 341

342 Elevation

343 The relationship between groundwater occurrence and altitude, High altitude reduces the ability to recharge
 344 groundwater, thereby reducing groundwater potential. Elevation map was prepared using CartoDEM data which has
 345 spatial resolution of 30m. The map altitude value varies from 56m to 288m. The map is classified into five categories
 346 as shown in the fig. 3-j.

347 Table 3 Spatial relationship between each effective factor and borewell locations of the DS model

Class	Factors	No of pixels	No of Borewell	Bel	Dis	Unc	Pls	SI
Lithology	Alluvium	3113	5	0.48	0.49	0.03	0.51	-0.01
	Coarse Grained, Porphyritic Granite	23192	49	0.64	0.31	0.05	0.69	0.27
	Granite Gneiss	1399	2	0.43	0.49	0.08	0.51	-0.12
	Medium Grained Leucogranite	26	0	0.00	0.49	0.51	0.51	-
	Medium Grained Pink Granite	962	0	0.00	0.50	0.50	0.50	-
	Pegmatite/Acid Intrusives/Quartzofeldspathic Veins	17	0	0.00	0.49	0.51	0.51	-
	Porphyritic Granite	98	0	0.00	0.49	0.51	0.51	-
	Sand Silt And Clay	2843	3	0.32	0.50	0.18	0.50	-0.43
	Silt-clay With Kankar	15939	20	0.38	0.54	0.08	0.46	-0.25
Soil	Deep Fine Smectitic Soil	1042	1	0.31	0.49	0.20	0.51	-0.47
	Deep Fine Soil	9914	14	0.45	0.50	0.05	0.50	-0.08
	Deep Loamy Soil	32033	53	0.53	0.42	0.05	0.58	0.08
	Shallow Loamy Soil	1530	2	0.42	0.49	0.09	0.51	-0.16
	Rock Outcrops	5758	7	0.39	0.50	0.11	0.50	-0.23
LULC	Water	1033810	0	0.00	0.50	0.50	0.50	-
	BuiltUp Area	1181778	2	0.29	0.49	0.22	0.51	-0.53
	Agriculture	18042970	58	0.67	0.27	0.06	0.73	0.31
	Barren Land	10748400	14	0.27	0.59	0.14	0.41	-0.59
	Mines	164179	0	0.00	0.49	0.51	0.51	-
	Forests	1614137	3	0.39	0.49	0.12	0.51	-0.23
	Wetland	1783751	0	0.00	0.50	0.50	0.50	-
WTI	3.42-6.66	882728	22	0.53	0.47	0.00	0.53	0.08

	6.67-7.71	1237633	28	0.48	0.49	0.03	0.51	-0.02
	7.72-8.96	703111	15	0.45	0.50	0.05	0.50	-0.08
	8.97-10.53	312639	7	0.47	0.49	0.04	0.51	-0.03
	10.54-16.75	208840	5	0.51	0.49	0.01	0.51	0.04
Drainage Density	0-0.245	8639	16	0.51	0.48	0.00	0.52	0.05
	0.245-0.457	10930	20	0.51	0.48	0.01	0.52	0.04
	0.458-0.670	10457	16	0.42	0.51	0.07	0.49	-0.14
	0.671-0.898	8957	16	0.50	0.49	0.02	0.51	0.02
	0.899-1.423	4842	9	0.52	0.48	0.00	0.52	0.06
Slope	0-2.0	1750045	53	0.64	0.32	0.04	0.68	0.27
	2.0-4.4	1162370	16	0.29	0.59	0.12	0.41	-0.51
	4.4-9.2	248988	6	0.51	0.49	0.00	0.51	0.05
	9.2-17.5	111597	2	0.38	0.49	0.13	0.51	-0.25
	17.5-47.1	71981	0	0.00	0.50	0.50	0.50	-
Altitude	56-101	704476	15	0.45	0.50	0.05	0.50	-0.07
	101-124	913834	21	0.49	0.49	0.02	0.51	0.00
	124-147	746043	18	0.51	0.48	0.01	0.52	0.05
	147-171	605826	14	0.49	0.49	0.02	0.51	0.01
	171-288	390435	9	0.49	0.49	0.02	0.51	0.01
Lineament Density	0 - 0.023785631	23078	45	0.54	0.43	0.03	0.57	0.10
	0.023785631 - 0.071356893	6163	10	0.45	0.49	0.06	0.51	-0.08
	0.071356893 - 0.128076474	6610	11	0.46	0.49	0.05	0.51	-0.05

	0.128076474 - 0.214070678	5143	9	0.49	0.49	0.03	0.51	0.00
	0.214070678 - 0.466564298	2831	2	0.20	0.51	0.30	0.49	-0.91
Geomorphology	Alluvial Plain	1531076	1	0.13	0.48	0.38	0.52	-1.29
	Dam and Reservoir	528854	1	0.39	0.49	0.12	0.51	-0.22
	Flood Plain	8158	0	0.00	0.49	0.51	0.51	-
	Low Dissected Hills and Valleys	1047072	1	0.20	0.50	0.31	0.50	-0.91
	Moderately Dissected Hills and Valleys	21921	0	0.00	0.49	0.51	0.51	-
	Pediment Pediplain Complex	28727610	74	0.53	0.16	0.31	0.84	0.09
	River	598207	0	0.00	0.50	0.50	0.50	-
	Waterbodies Other	83171	0	0.00	0.49	0.51	0.51	-

Table 3 shows the results of the spatial relationship between the existence of groundwater and the impressive factors using the Dempster-Shafer theory (doubt, belief, reasonableness and uncertainty). The groundwater potential map Fig (5-b) was prepared using equation(9), the integrated result indicates that enormous groundwater potential was found for the region having greater values of belief and small values of disbelief for the incidence. The belief values vary from 1.79 to 4.56(Fig 4-a) while Disbelief varies from 3.69 to 4.75 (Fig 4-b). The uncertainty graph(Figure 4.-c) illustrates the lack of information that provides real evidence of the spring incidence. High levels of uncertainty appear in areas with low levels of belief. The plausibility map (Fig 4-d) represents a higher degree where both uncertainty and belief are higher.

Fig. 4 Integrated results of DS model (a) Belief, (b) Disbelief, (c) Uncertainty, and (d) Plausibility.

361 Table 4: Factors of used thematic layers (class) and obtained accumulated weightages through AHP model.

Class	Factor	% Weightage	Rank	Accumulated Weightage
Geomorphology	Alluvial Plain	16	5	80
	Dam and Reservoir		5	80
	Flood Plain		5	80
	Low Dissected Hills and Valleys		2	32
	Moderately Dissected Hills and Valleys		1	16
	Pediment Pediplain Complex		2	32
	Waterbodies-Other		4	64
	Waterbody - River		5	80
Lineament density	Very High	24	5	120
	High		4	96
	Medium		3	72
	Low		2	48
	Very Low		1	24
Lithology	Silt-clay With Kankar & Quartzo-feldspathic Sand	12	3	36
	Quartzite		4	48
	Quartz Sericite Schist		4	48
	Quartz-biotite Schist		4	48

	Pyroxenite	2	24
	Porphyritic Granite	1	12
	Porphyritic Coarse Grained Granite	2	24
	Pegmatite/Acid Intrusives/Quartzofeldspathic Veins	1	12
	Oxidised Silt-clay With Kankar And Micaceous Sand	2	24
	Oxidised Sandy Silt-clay And Quartzo Feldspathic Sand	2	24
	Migmatite	3	36
	Metasediments	4	48
	Metabasites / Metabasics	4	48
	Meta Basalt	3	36
	Medium Grained Pink Granite	3	36
	Medium Grained Leucogranite	3	36
	Grey Sand, Silt And Clay	5	60
	Granite Gneiss	3	36
	Granite	2	24

	Fine Grained LeucoGranite		3	36
	Fine Grained LeucoGranite		3	36
	Dolerite		4	48
	Coarse Grained, Porphyritic Granite		2	24
	Chlorite Schist		1	12
	Augen Gneiss		4	48
	Amphibolite		3	36
	Alluvium		4	48
Slope	0-1	16	5	80
	1-2		4	64
	2-3		3	48
	3-5		2	32
	>5		1	16
Soil	Fine Smectitic Soil	12	4	48
	Shallow Loamy Soil		3	36
	Smectitic Soil		3	36
	Rock Loamy Soil		3	36

	Deep Loamy Soil		2	24
Land Use Land Cover (LULC)	Agriculture	8	3	24
	Barren Land		2	16
	Builtup Area		1	8
	Mines		3	24
	Vegetation		4	32
	Water		5	40
	Wetland		3	24
Drainage Density	Very High	12	1	12
	High		2	24
	Medium		3	36
	Low		4	48
	Very Low		5	60

Groundwater Potential Zones

The groundwater potential maps were prepared using the relative importance of several thematic layers, factors influencing these thematic layers was divided into several categories for estimation of groundwater potential zone. Thematic layers viz.: geomorphology, lineament density, lithology, slope, soil, LULC, drainage density, altitude and Topographic Wetness Index were used under overlay analysis. The map shown in fig 5-a represents groundwater potential zones using AHP model and fig 5-b represents groundwater potential zones using DS model. Both the maps were classified into very high, high, moderate, low and very low groundwater zones.

In AHP model groundwater potential zone map, it is evident that the North -West side of the study area (Fig. 5-a) has high groundwater potential which is classified as very high zone, this zone has an area of 206.19 km². High groundwater zones constitute an area of 919.31 km² and followed by medium zone of 1290.25 km² which cover the majority of the study area. Low zone has an area of 454.69 km² while very low zone 12.15 km².

In the DS model (Fig. 5-b), the south west and south east side of the study has high and very high groundwater potential zones which cover 34% and 17% (Table 5) of the study area respectively. North east side of the study area is classified as poor and very poor groundwater potential zones. The similar trend is also observed in the AHP model. The AHP model supplement the objectivity while the DS model supports subjectivity.

All the channels of watersheds contain a good amount of groundwater relative to the other region of study area. High zone regions are influenced by streams channels. Jaitpur and Panwari blocks of the Mahoba district have high groundwater potential relative to Charkhari and Kabrai blocks.

Fig. 5 Groundwater Potential Zones Maps a) Groundwater potential zones using AHP model, and b) Groundwater Potential zones using DS model

Table 5 Percentage of area under different groundwater potential zones

DS Model		AHP Model	
Groundwater Potential Zones	% Area	Groundwater Potential Zones	% Area
Very Poor	4.19	Very Poor	0.42

Poor	14.80	Poor	15.77
Medium	29.07	Medium	44.76
High	34.4	High	31.89
Very High	17.54	Very High	7.15

Groundwater Quality

The groundwater is contaminated with fluoride in pockets under granite and alkali granite, particularly in the extreme southern region of the study area. Weathering is responsible for leaching of fluoride into the groundwater. It has deteriorated because of geogenic activities. In the northern part of the study area, negligible thickness of overburden (weathered rock and loose soil) are present. Therefore, the concentration of TDS, fluoride and bicarbonate in groundwater increases due to poor fluxing of groundwater. In the central and northern part of the study area concentration of the nitrate in the groundwater has increased due to anthropogenic activities such as unlined septic tanks, unplanned sewerage systems. Additionally, terrain under granite-gneiss contains fixed atmospheric nitrogen which gets added to the soil through bacteria present in plants and soil, natural lighting. Nitrification also occurs due to ammonification of animal waste and plants. Hydro-chemical facies reveal that the nature of groundwater is Na + - Cl - , mixed Ca²⁺ + -Mg²⁺ + -Cl - and Ca²⁺ + -HCO₃ - 3 type the study area. (Ram et al. 2021)

Validation

According to Tehrany et al. (2013), in the ROC curve sensitivity is plotted against true positive and true negative value of groundwater occurrence and the Area Under the Curve (AUC) shows the distribution performance of the models. Here AUC equals to zero indicates a non-informative model while perfect condition represents AUC equals to one. The AUC for the AHP model is 76% while it is 79 % for the DS model, therefore the DS model is more accurate than the AHP model as per ROC curve(Fig. 6). This is because the weight value of TWI and altitude data layers has influenced belief rate, while removing the same results in lower accuracy. The accuracy of the delineated groundwater potential zones in different watersheds under the study area was validated by analysing the bivariate relationship between the groundwater potential zones and the bore well yield data. 16 borewell data were used to validate the results. The validation result indicates that borewells having high discharge (>1500 liter/h) lie in high and very high groundwater potential zones. Whereas discharge of borewells (<1500 liter/hour) lies in moderate and low groundwater zones.

Sensitivity analysis of the thematic layers

In AHP model Sensitivity analysis revealed that the majority of the area has overall weightages varying from 224 to 332 (Fig 7) which is medium and low groundwater zones. The maximum weightage is noted as 456 and minimum as 8. The most influential thematic layer is found to be Lineament density and least was drainage density as well as LULC.

Table 5 Statistical analysis of single parameter sensitivity analysis of AHP model weightages

Parameters	Minimum	Maximum	Mean	Standard deviation
Lineament density	24	120	72.00	37.95

Geomorphology	16	80	58.00	26.96
Slope	16	80	48.00	25.30
Lithology	12	60	35.11	12.86
Soil	12	48	36.00	8.49
Drainage Density	12	60	24.00	18.97
LULC	8	40	24.00	24.00

Fig. 6 ROC Curve outcomes; a) ROC curve of AHP model; and b) ROC curve of DS model

Fig. 7 Frequency distribution of overall weightages

Limitations

The accuracy obtained through both the models is more than 75% and limitation lies with pixel size of a particular class. Because different classes constitute different pixel sizes, therefore belief and importance rate may differ slightly from what was taken in consideration for the delineation of the groundwater potential maps.

Conclusion

The groundwater potential zones (GWPZs) of Mahoba District of Uttar Pradesh, were delineated by an integrated approach using AHP and Dempster Shafer model based on remote sensing and GIS. Several hydrogeological factors of the watersheds, such as geomorphology, drainage density, lineament density, lithology, slope, land use/land cover, soil, altitude and Topographic Wetness Index were used for multi-criteria decision analysis (MCDA) which was again equated in ArcMap using weightages generated through the AHP model and Belief, Disbelief, Uncertainty, and Plausibility through DS model.

In the AHP model lineament density was considered as the most influencing criteria and was given high weight for groundwater potential zone mapping. Normalize weightages for factors considered in the AHP comparison matrix

was calculated as follows: geomorphology (0.38), lineament density (0.19), lithology (0.13), slope (0.10), soil (0.08), LULC (0.06) and drainage density (0.05), overall weightages calculated while assigning ranks for factors of a thematic layer through overlay analysis was performed for the delineation of the groundwater potential zone.

The north-west side of the study area was found to be a very high groundwater zone while the northeast and southeast side of the region was low groundwater zone. The very high groundwater zone constitutes an area of 206.92 km² while the low groundwater zone has an area of only 54.28 km². The study area is dominated by the medium groundwater zone which consists of a total area of 1587.18 km². In the DS model, Belief, Disbelief, Uncertainty, and Plausibility was equated using borewell locations and occurrence of groundwater factors of several thematic layers, the groundwater potential map illustrates that the south west and south east side of the study has high and very high groundwater potential zones, it is also found that streams and canals belong to the very high groundwater zone. The study has been validated using field data pertaining to yield wells. *The receptor operating curve (ROC)* method was used to validate the result, which showed the DS model is more accurate than the AHP model.

Ethical Approval

(Not applicable)

Consent to Participate

All the authors give their consent to participate.

Consent to Publish

All the author gives their consent to publish.

Authors Contribution

Hemant Kumar Pandey has contributed in introduction and methodology section, Vishal Kumar Singh has contributed in numerical analysis and software application while Sudhir Kumar Singh has contributed in result and discussion section of the manuscript.

Availability of Data and Materials

The data will be made available on request.

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