The Third Pole: Journal of Geography
Vol. 22: 73-96, 2022
DOI: https://doi.org/10.3126/ttp.v22i01.52574

PROBABILISTIC DETERMINATION OF GROUNDWATER USING SEMI-QUALITATIVE MCDA-BASED ANALYTIC HIERARCHY PROCESS APROACH IN SUNSARI DISTRICT, NEPAL

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Abstract

Groundwater served as the major source of water for existing biophysical species in an ecosystem. In recent years, depletion of the level of groundwater becomes an emerging serious environmental issue due to the anti-reciprocal man and human activities such as global climate change. This study aims to examine the groundwater potential areas using the semi-qualitative research design, based on Analytic Hierarchy Process. The focused is based on the Geographic Information System for the analysis of determining factors, such as distance from the stream and river, precipitation, pond frequency, normalized difference water index, land-use/land cover, drainage density, slope gradient, soil, and topographic wetness index. The Receiver Operating Characteristics were used to check the accuracy of the final calculated map of the groundwater potential zone. The 5 points Likert scale ranges very poor (1) to very high (5) used to analyse the groundwater potential zones. The result shows that 0.81 percent area is very poor for the potentiality of groundwater in the study area. Other scale contained 8.13 for poor, moderate (19.94%), high (39.72%) and very high potential zones (31.41%). The Receiver Operating Characteristics result showed that under the curve success rate is 0.64% and the prediction rate is 0.76%. This result shows a reliable degree of predictability of groundwater near the spatial distribution of marshes, lakes, and water bodies in the study area. The finding shows that the very high potentiality of groundwater areas are determining by the factors of precipitation, pond frequency, distance from river and stream, drainage density, land-use/land cover, soil, and slope in the study area. The result of this empirical analysis can be applied to analyze sustainable and effective water resources management activities.

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Keywords: Groundwater, Analytic Hierarchy Process, Multi-Criteria Decision Analysis, GIS, Groundwater Potential mapping.

Introduction

Groundwater recharge refers to a residual flow of water accumulated into the saturated zones due to evaporation, evapotranspiration, and runoff losses of precipitation, which sometimes occurs via diffuse infiltration, climate change, land use land cover (LULC), geology, and slope all affect groundwater recharge (Dragoni & Sukhija, 2008). In recent years, the effect of global climate change including anthropogenic factors such as population increase and LULC change, civil engineering works, mining, and groundwater extraction has strongly caused a crisis in water resources (Preene & Brassington, 2003; Wada et al., 2016; Lamichhane & Shakya, 2019). Hence, groundwater is essential for maintaining ecosystems and allowing for human adaptability to climate change and fluctuation (Giordano, 2009; Taylor et al., 2013). For instance, the world's fastest-growing population areas have significant groundwater recharge and sustainability concerns, particularly in arid and semi-arid countries that depend on resources for household, industrial and agricultural requirements (Mensah et al., 2022). Therefore, effective groundwater management is hindered by climate change, anthropogenic activities showing poor water quality, and low water levels (Wada et al., 2016).

The past and present conditions of LULC change in the forms of conversion of previous recharge areas to constructed built-up areas leading to a decrease in groundwater recharge in Nepal (Lamichhane & Shakya, 2019). For decades, groundwater irrigation practices have been crucial to increasing production in Nepal because mostly Nepalese farmers are depends upon the monsoon for livelihood and food security (Malla & Karki, 2016). In this regard, groundwater mapping is a fundamental step for effective management of water resources, and their sustainability in the ecosystem in the Tarai region of Nepal, where the dynamic pattern and process of LULC caused various types of environmental consequences for a decade (Ghimire, 2017). Hence, this study aims to map the potentiality of groundwater by correlating different determining factors.

Nowadays, Geographic Information System (GIS) and Remote Sensing (RS) technology significantly transformed the methodological paradigm to generate groundwater potential mapping (Adeyeye et al., 2019; Ghimire et al., 2019; Lamichhane & Shakya, 2019). Along with the GIS and RS approaches, other various types of statistical approaches have been incorporated for groundwater potential mapping such as machine learning approaches have been adopted by Al-Fugara et al., 2020; Zzaman et al., 2022. In addition, statistical approaches such as logistic regression, bi-variate statistical index and Analytical Hierarchy Process (AHP) were adopted by Moghaddam et al., 2015. The artificial intelligence approach was also applied by (Hanoon et al., 2021).

In this context, Analytical Hierarchy Process (AHP) is a semi-qualitative Multi-Criteria Decision Analysis (MCDA) approach that has been widely applied for groundwater mapping (Moghaddam et al., 2015; Arulbalaji et al., 2019; Owolabi et al., 2020). In the AHP model, weight value was assigned to determining factors that are quite subjective and knowledge about the conditioning factors and value ascertain depends on the study area and ability of the expert (Sharma & Mahajan, 2019; Dikshit et al., 2020). Remaining other Statistical-based approaches including artificial intelligence, machine learning, and statistics depend upon the collective effort of the determining factors (Mandal and Mandal, 2018; Dikshit et al., 2020). Lamichhane and Shakya (2019) argued that the AHP model coupled with GIS has successfully generated the groundwater potential zones in Nepal showing a significant and precise level of accuracy. Hence, the AHP-based MCDA technique was selected for groundwater potential zonation in the Sunsari district of eastern Nepal.

Methods and Materials

Study area

The Sunsari district lies in Province No. 1 of Nepal. The spheroid projection system shows that the district is located in 86° 54' to 87° 41' E and 26° 20' to 26° 52' N (Fig.1). It covered an area 1257 km^2. The elevation ranges 63 m to 1797 m from sea level. It is composed by the Tarai (plain), Chure (Siwalikhills) and Mahabharat range, which consists of upper, middle and lower Siwalik sedimentary sequences. The lower Siwalik exposes fine-grained sandstone with inter-beds of mudstone, shale, siltstone, middle Siwalik characterized by medium to coarse-grained sandstone, pebbly sandstone with inter-beds of siltstone and mudstone, and the upper Siwalik made up with boulder, cobble, and conglomerate with mud, silts, and sand lenses (Dhital, 2015a). The Tarai plain is made up with Pleistocene to Holocene sediments, which can be classified into three parts, viz. upper Tarai or Bhawar zone, middle Tarai or Marshy Land, and lower Tarai or Gangetic Alluvium (Dhital, 2015b). Tectonically, these two different sedimentary sequences such as Siwalik and Tarai separated by the Main Frontal Thrust (MFT) while the Main Boundary Thrust (MBT) separates the Siwalik sedimentary from the lesser Himalayan sequences in the north section (Hasegawa et al., 2009).

The climate condition of the study area constituted the temperatures and precipitations summarized as the hot wet summer and cool dry in the winter season of each year. The Department of Hydrology and Meteorology (DHM) of Nepal recorded the maximum temperature of 33.2^{0}C was recorded in May and the minimum temperature of 9^{0}C in January. Annual precipitation was recorded 1549.8 mm. This district has 1147186 total populations in 274651 households. The population is composed by the 48.6 percent male) and 51.4 percent females. It is a fifth largest populace district (3% of the total population) of Nepal in 2021.

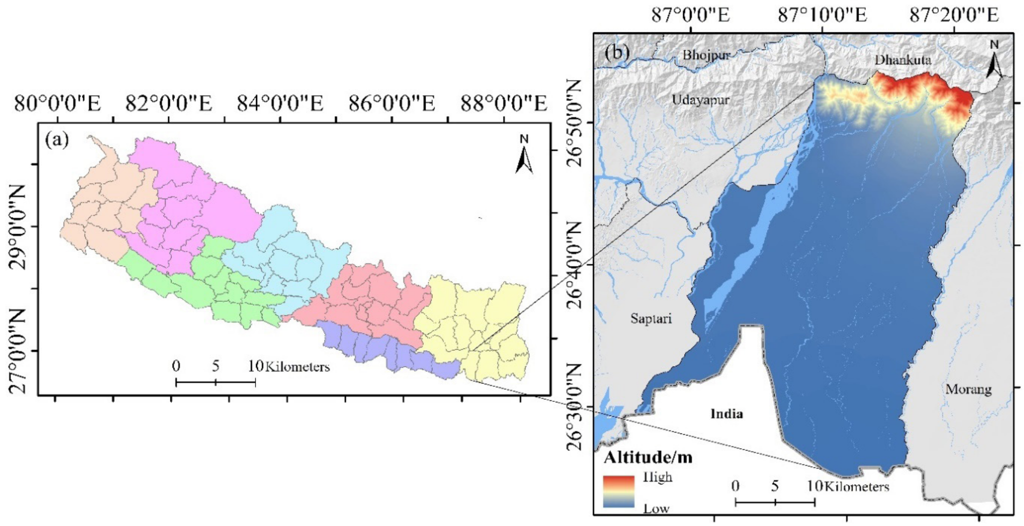


Figure 1: The location map of the study area : (a) Nepal with provincial structure, (b) Sunsari district with altitude

Dataset and sources

Datasets of groundwater potential areas were prepared by the analysis of nine controlling factors, such as hydrological, environmental, and topographical factors (Table 1). These factors are: Land Use Land Cover (LULC) and Normalized Differences Water Index (NDWI) have prepared from the downloaded of Landsat 8 OLI/TIRS C1 Level-2 with 30 m spatial resolution (https://earthexplorer.usgs.gov). The Topographic Wetness Index (TWI) and topographical slope have extracted from the Digital Elevation Model (DEM) using topographical contour (1:25,000) map of 20 m interval. The density map was prepared by the extraction of hydro line (1:25,000) distance from the river and river drainage developed by Survey Department of Nepal. The soil map was prepared from downloaded soil data of the SOTER databases (https://www.isric.org/explore/soter). The CHIRPS v02 precipitation map was prepared from downloaded monthly rainfall 0.050x0.050 databases for the year of 2000-2020 (https://www.chc.ucsb.edu/data/chirps). Yigez et al. (2022) have investigated the reliability of CHIRPS v02 rainfall production in soil loss and sediment export modeling in the Koshi River Basin, Nepal. The pond density map was prepared by extracting the location of ponds, lakes and swamps from Google Earth satellite images using the direct visual image interpretation method. Finally, all these controlling factor maps were processed in GIS modeling at 30 m spatial resolution. The summary of data sources are depicted in Table 1.

Table 1: Description of Dataset/source/purpose

Dataset	Sources/purpose
Landsat Image	Landsat 8 OLI/TIRS C1 Level -2 with 30 m resolution downloaded from (https://earthexplorer.usgs.gov/), used to extract the LULC, and NDWI maps
Stream/river	Topographical contour (1:25,000) with 20 m interval developed by the Survey Department, Nepal, used to generate the distance from the stream and drainage density maps
DEM	Topographical contour (1:25,000) with 20 m interval developed by the Survey Department, Nepal, used to generate the topographical slope gradient, and TWI maps
Soil texture	Downloaded from (https://www.isric.org/explore/soter), used to prepare the soil map
CHIRPS v02 Precipitation	Monthly precipitation (2000-2020) downloaded from www.chc.ucsb.edu/data used to prepare the precipitation map
Lake, Ponds, and Swamp area	Extracted from the satellite Image available in the Google Earth, used in to extract the pond frequencies map

Note: OLI/TIRS= Operational Land Imager and Thermal Infrared Sensor, LULC= Land Use Land Cover, TWI = Topographic Wetness Index, NDWI= Normalized Differences Water Index, DEM = Digital Elevation Model, CHIRPS = Climate Hazards Group Infrared Precipitation with Station data

In addition, various equations, modeling and maps are used for data analysis, which are mentioned in the relevant text, such as drainage density, normalized differences of water index, topographical wetness index etc.

Result and Discussion

Selection of thematic determinant factors

The presence of groundwater and its sustainability are strongly influenced by several factors including biophysical and natural factors (Ghimire et al., 2019; Lamichhane & Shakya, 2019). This paper used the following major determining factors: distance from stream (m) and river, precipitation (m), pond frequency (m/km^2), normalized difference water index (NDWI), land-use/land cover (LULC), drainage density (m/km^2), degree of slope gradient, soil, and topographic wetness index (TWI) and illustrated in Figure 2. However, the impact of these factors on the groundwater are varying from one place to other due to geologic, geomorphic, and biophysical characteristics of the study area. These controlling factors were also used by Ghimire et al. (2019), Lamichhane and Shakya (2019) in their empirical studies of groundwater in Nepal. These selected factors have shortly illustrated in the following figure.

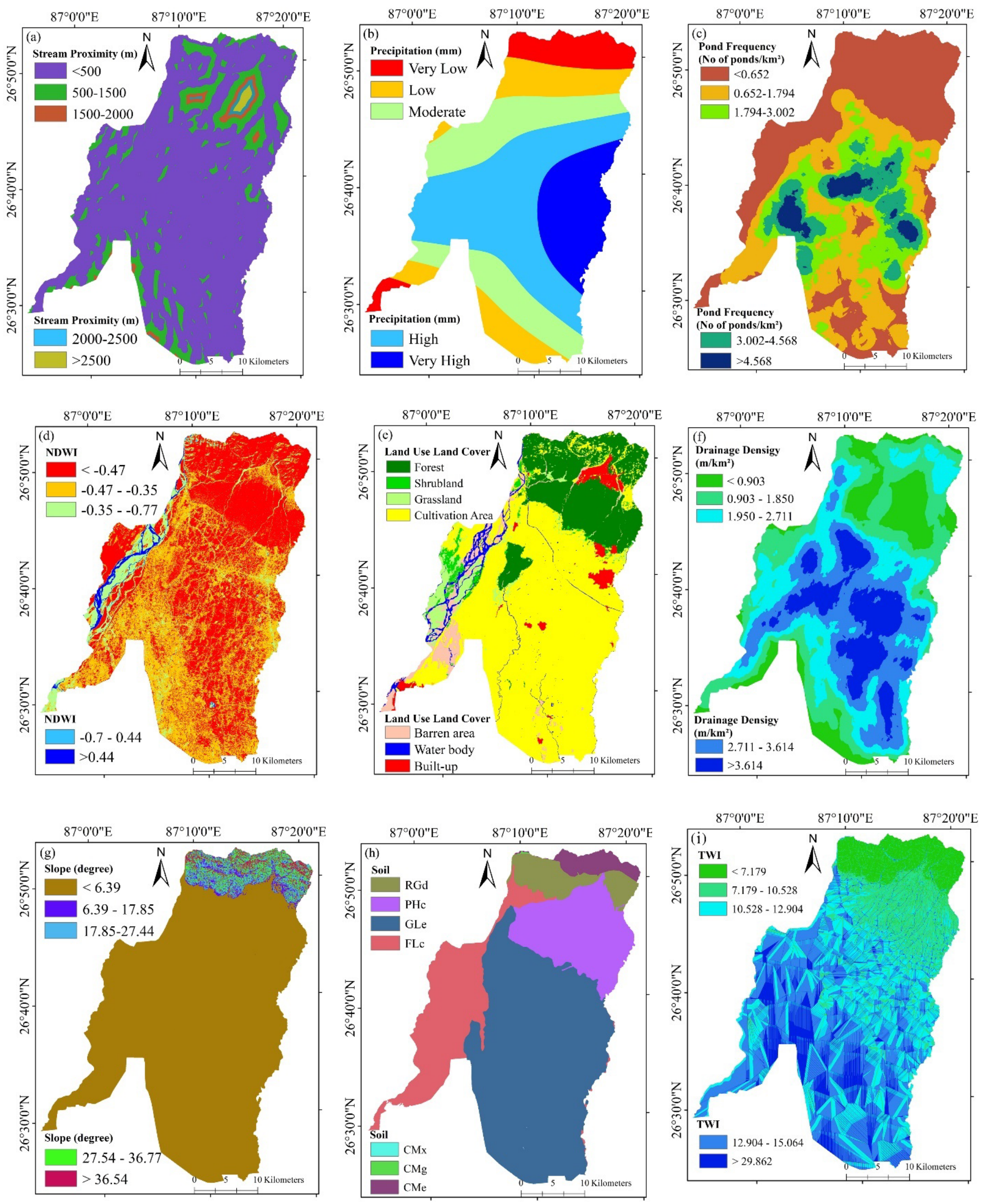


Figure 2. Factor maps for determining the groundwater potential zone: (a) distance from stream (m); (b) precipitation (mm); (c) pond frequency (no of pond/km^2); (d) normalized differences water index (NDWI); (e) land-use/land cover; (f) drainage density (m/km2); (g) slope (degree), (h) soil, (i) topographic wetness index (TWI)

Distance from stream and river

This paper also analyse distance from stream and river. The hydro flow line indicates the spatial presences of groundwater in relation to stream, river and pounds. The distance to the stream and river is considered a subjective determining factor. Distances can be classified into five groups from very low to very high based on the interval classification method (Figure 2a). Class-intervals are characterized as very low (<500 m), low (500-1500 m), medium (1500-2000 m), high (2000-2500 m) and very high >2500 m). The calculated value of the distance from streams and rivers shows that the closer the distance, the greater the potential of groundwater and as the distance increases, the presence of groundwater in the study area decreases.

Precipitation

The rainfall intensity has a significantly influence to the groundwater potentiality in the study area where than 80% of annual rainfall occurred in the months of July to September. The mid-eastern part of the study area receives more precipitation as compered other parts of the study area (Figure 2b). The occurrence of precipitation data can be classified into five different categories, such as very low (<25776.74 mm), low (25776.74-26497.72 mm), moderate (26497.72 -27090.53 mm), high (27090.53-27763.44 mm) and very high (>27763.44 mm). The calculated value of the assumed that higher the intensity of precipitation, more likely to be potential of ground water recharge vice versa.

Pond frequencies

Pond frequencies are considered as the important controlling factor to groundwater potentiality in the study area. The study area having the higher number of ponds, lakes, and swamps with a remarkable volume of water. This paper used raster map to calculate pond frequencies (Figure 2c). The pound frequencies can be classified into five classes based on natural break method, such as very low (<0.652), low (0.652-1.794), moderate (1.794-3.002), high (3.002-4.568), and very high (4.568).

Topographic slope gradient

Slope gradient controls the groundwater storage, regularized the rate of runoff and water percolation into the subsurface of the study area. The topographic conditions and slope gradients are playing a significant role to ascertain the rate of groundwater recharge processes. In this paper, the slope gradient calculated using five classes natural break method (Figure 2g), such as, very gentle (<6.39°), gentle (6.39°-17.85°), moderate (17.85°-27.44°), moderately steep (27.44°-36.77°) and very steep (>36.77°). This study revealed that southern part (Tarai) has a gentle slope angle as compared to the northern Siwalik and Mahabharata ranges.

Soil

The characteristics of soils are also considered as the determining factors for the groundwater potentiality in the study area. This study reveals that the study area is composed by the different types of soil (Figure 2h). The soils of the study area can be categorized into RGd (Dystric Regosols), PHc, GLe (Eutric Gleysols), FLe (Eutric Fluvisols), CMx (Chromic Cambisols), CMg (Gleyic Cambisols), and CMe (Eutric Cambisols).

Drainage density

The drainage density refers to the stream per unit area in a given area and the concept was developed by Horton in 1932 and Strahler in 1952. The drainage density is also considered as the determiner of groundwater recharge. This study reveals that higher drainage density observed in the plain (Tarai) as compared to the Siwalik and Mahabharata ranges. The drainage deensity can be calculated by the following formula:

$$D_b = L/A$$

Where, D_b refers to drainage density, 'L' means total length of the streams and 'A' represents the total area of basin.

The drainage density map was divided into five different classes based on natural break methods (Figure 2f), which are low (<0.903 m/km^2), very low (0.903-1.850 m/km^2), moderate (1.850-2.711m/km^2), moderately high (2.711-3.614 m/km^2), and very high (>3.614 m/km^2)

Normalized Differences Water Index (NDWI)

The normalized differences water index technique is used to detect the infiltration rate and recharging of groundwater in the study area. On the basis of natural break method a NDWI map was prepared (Figure 2d). The index can be classified into five categories, such as very low (< -0.47), low (< -0.47 to -0.35), moderate (-0.35 to -0.77), high (-0.77 to -0.44), and very high (>0.44). The normalized difference water index can be calculated by the following formula:

$$\text{NDWI} = \frac{(GREEN - NIR)}{(GREEN + NIR)}$$

Where, '*NDWI*' means normalized difference water index, for Landsat 8 data, Green is band 3, and Near Infrared (NIR) is band 5. The formula can also be expressed as follows:

$$\text{NDWI} = \frac{(Band3 - Band5)}{(Band3 + Band5)}$$

Topographic Wetness Index (TWI)

The topographic wetness index can be used to determine the terrain profiles of the study area. It is also considered as the determiner of water accumulation and distribution of water in a particular area as well as the presences of groundwater. The higher calculated TWI index value indicates more likely to be groundwater and lower value indicates vice versa. In this study, the TWI map was classified into different five classes (Figure 2i) such as very low (<7.179), low (7.179-10.528), moderate (10.528-12.904), moderately high (12.904-15.064), and very high (>15.064) based on natural break method. The TWI index can be calculated by the following formula:

$$\text{TWI} = \text{In}\frac{\text{a}}{\tan\beta}$$

Where, where, '*a*' is the cumulative local upslope area draining through a point (per unit contour length) and '*tanβ*' is slope angle at the point.

Land Use Land Cover (LULC)

The land use land cover features are also determines the rate and volume of surface runoff and infiltration of groundwater. It is playing a crucial role to the potential groundwater mapping in the study area. This study has classified , land use land cover map into seven classes such as cultivation area (63.4%), forest (20.1%), shrub (1.8%), grass (4.21), barren (5.04%), urban built up (2.74%) and water body (2.62%) based on identified features (Figure 2e). This study revealed that the presence of forest, cultivation area, and shrub lands are more significant for recharging of groundwater as compared to other lands.

Pairwise Matrix Composition, Assignment and Normalization of Weight

This study is also formulated a matrix structure, assignment and normalization of weight indices in a pair. It is calculated using mathematical techniques and the sum of the normalized weights of each factor. It is also called AHP. AHP was first introduced by Satti in 1980 for decision making. It deals with dependent and independent variables for natural resource management and risk mapping. This helps to reduce the inconsistency weightages of the pairs of normalization vectors of each factor. In this regard, several procedures have been applied to obtain results, such as the selection of appropriate determinant factors and their weight value, delineating the presence, roles and responsibilities of conditional groundwater, production of a digital cartographic-based database of selected factors, and normalization. Each parameter is assigned weights for different sub-categories. A value assigned to each thematic factor is confirmed through the weight comparison matrix and the AHP model obtains the weight of each theme.

In the AHP model, the scale of relative importance denotes as 1 is equal importance, 2is weak, 3 is moderate importance, 4 is moderate plus, 5 is strong importance, 6 is strong plus, 7 is very strong importance, 8 is very, very strong importance and 9 is extreme importance (Saaty, 1980). The pairwise matrix of each determinant factor is confirmed based on the scale of relative importance. Finally, the consistency ratio related to the pairwise matrix of each parameter to normalize their weight has checked and the result appears that AHP processes are accepted. In the last processes, an entire thematic layer has correlated to each other in terms of assigned weight value by applying statistical techniques known as weight sum overlay in the GIS environment to get the final layers showing groundwater potential area. The groundwater potential area has been calculated with the digital cartographic-based statistical methods, in which different parameters or determinant factors have been enrolled to get the objectives.

Calculation of consistency ratio

The consistency ratio consists of the pairwise ranking of in situ parameters through the analytical hierarchy processes calculated for results with either accepted or rejected. It is calculated by the following formula:

$$CR = \frac{CI}{RI}$$

Where, 'R1' represents the random consistency index value that relies on the order of the matrix and 'R1' indicates the consistency index obtained from the following formula:

$$CI = \frac{\lambda\text{max - } n}{n-1}$$

Where, 'λ_{max}' is the principle eigenvalue, n is the number of factors, 'λ_{max}' sum of the products between each element of the priority factors, and column total. The random consistency Index (RI) given by (Saaty, 1980) is presented as below.

Table 2: Analytical Hierarchy Process (AHP) based index ratio for different values n values contributed by Saaty, 1980

Factors(n)	1	2	3	4	5	6	7	8	9	10
Random Consistency(R1)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3: different nine thematic determinant factors and their pairwise comparison matrix for AHP analysis

Thematic Factors	Pp	Pf	Ds	Dd	LULC	S	SI	TWI	NDWI
Precipitation (Pp)	1.00	5.00	4.00	4.00	2.00	2.00	2.00	2.00	2.00
Pond Frequencies (Pf)	0.20	1.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00
Distances from Stream (Ds)	0.25	0.33	1.00	2.00	2.00	2.00	2.00	2.00	2.00
Drainage Density (Dd)	0.25	0.50	0.50	1.00	2.00	2.00	2.00	2.00	2.00
land-use/land cover (LULC)	0.50	0.50	0.50	0.50	1.00	2.00	2.00	2.00	2.00
Slope (S)	0.50	0.50	0.50	0.50	0.50	1.00	2.00	2.00	2.00
Soil (Sl)	0.50	0.50	0.50	0.50	0.50	0.50	1.00	2.00	2.00
TWI	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	2.00
NDWI	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00
Total Column	4.20	9.33	11.00	11.50	11.00	12.50	14.00	15.50	17.00

Source: Calculated by author

CI = (9.98 - 9)/(9-1)

= 0.12

CR = 0.12/1.45

= 0.084

According to the formula for consistency index (CI), the value of λ_{max} is 9.98, number of determinant factors is nine, and Saaty's consistency ratio index value for (n=9) is 1.45. Hence, the consistency index value is 0.084. It resulted that the consistency ratio of given weight to each different thematic factors are less than (<0.10) indicating reasonable and acceptable consistency in pairwise comparison matrix. However, weight assignment to each determinant factors primarily depends on the individual expertise of the researcher and it may vary from a different place to place in terms of condition.

Calculation of groundwater potential zone

Groundwater determining factors and their classes along with their normalized weight values were fitted to equation 3 to generate the groundwater potential zones in the study area, which was successfully applied by some previous researchers (Das & Mukhopadhyay, 2020; Ahmadi et al., 2021; Melese & Belay, 2022).

$$\text{GWPZ} = Precipitation_{\text{W}} Precipitation_{\text{Wi}} + Slope_{\text{W}} Slope_{\text{Wi}} + Pond\ frequencies_{\text{W}} Pond\ frequencies_{\text{Wi}} + Soil_{\text{W}} Soil_{\text{Wi}} + NDWI_{\text{W}} NDWI_{\text{Wi}} + Dist\_from\_stream_{\text{W}} Dist\_from\_stream_{\text{Wi}} + LULC_{\text{W}} LULC_{\text{Wi}} + Drainage\_density_{\text{W}} Drainage\_density_{\text{Wi}} + TWI_{\text{W}} TWI_{\text{Wi}}$$

Where, '*GWPZ*' is the groundwater potential zonation, '*W*' refers to normalized weight of each thematic layer, and '*Wi*' presents normalized weight of the features. Precipitation, pond frequency, normalized differences water index (NDWI), distance from the stream, land-use/land cover (LULC), drainage density, slope, and soil represent the groundwater determining factors.

Accuracy assessment

The Receiver Operating Characteristics (ROC) curve has been applied to validate the accuracy of results showing groundwater potential zones, which method has been widely adapted for the predictability degree and groundwater mapping in terms of sensitivity and specificity (Andualem and Demeke, 2019). The ROC curve is an effective way to illustrate how well deterministic and probabilistic detection and forecast systems perform (Swets, 1988). Then, the final output mapping of the groundwater potential zone also correlated with the spatial distribution of ponds, lakes, swamps, and other water bodies. It is calculated by following formula:

$$\text{X} = 1 - Specificity = 1 - \left[\frac{TN}{TN + FP}\right]$$

$$\text{Y} = Sensitivity \left[\frac{TN}{TP + FN}\right]$$

Where, the '*TP*' refers to true positive, represents results correctly indicates the presence of the condition. The '*TN*' refers to true negative and represents results that indicate the absence of the condition. The '*FP'* indicates the result wrongly, presence of the condition, and the '*FN'* refers to false negative shows wrongly indicating the absence of condition.

As mentioned in the methodology and material section, eight different determining factors have been selected for the calculation of the potential presence of groundwater in the Sunsari district, and these factors were classified in different sub-categories as the grouped data based on the natural break.

The calculated value of determining factors

This study reveals the AHP-based multi-criteria decision analysis, the potential zone of the groundwater has generated using the night different determinant factors based on the weight of each thematic layer of determinant factors (Table 3). The result indicated that hydrology-related factors have a significant role to determine the potential of the groundwater viz. precipitation, pond frequencies, and distance from the stream, and drainage density, which discussed in previously undertaken studies (Ghimire et al., 2019; Lamichhane & Shakya, 2019). Similarly, homogenous nature of contributing factors, i.e. land-use/ land cover (LULC) and slope gradient carried an intermediate significance in the study area. The soil texture, topographic wetness index, and normalized differences water index have a less significant weight values in comparison to above-mentioned other thematic factors. The NDWI, soil factors have been revealed as a less significant contributing role to the potentiality of groundwater in comparison to other factors since NDWI indicates the land surface water condition (Du et al., 2014), used in the mapping of the dynamic of surface water presence. The final groundwater potential map has categorized into different five classes; such as very poor potential, poor potential, moderate potential, high potential, and very high potential based on the natural break method (Table 4). About 0.81% and 8.13% of the total area have contains to very poor potential, and poor potential zones. The moderate potential zones accounts as the 19.94% of the total area while high potential and very high potential zones cover the 39.72% and 31.41% of total area, respectively.

Spatially, steep slopes, fragile geology of Siwalik and Mahabharata range, steep ward streams merged into narrow V-shaped valley conditioned a less significant role to recharge the groundwater and its potentialities. However, moderate groundwater potentialities appeared in the wide and plain of width streams in Siwalik hill areas. The foothill areas such as Dharan, Baguwa, Patnali, Chatara, and Panbari are consisting to moderate potentialities of the groundwater due to presence of poorly sorted boulder, cobbles, pebbles, and sand derived from the Siwalik and Mahabharat range, abrupt of river and stream channel due to monsoon induced flooding. These areas just remained as the zone groundwater recharge for Tarai (Dhital, 2015b, 2015a). The high and very high potentialities of the groundwater revealed in the middle Tarai (marshy land), and lower Tarai (Gangetic alluvium) areas, where upper section of lower Tarai and most section of marshy land areas such as Duhabi, Sonapur, Khanar, Laukahi, Bokraha, Khanar, Itahari, Madhuban, and Dumraha have a very high potentialities of the groundwater. The middle and lower Tarai exposes combined zone made up with the Gangetic alluvium and deposits and meandering of tributaries. This area is almost flat and gradient is less than 0.1%. while sediments are sand, silt, and clay with some pebbles (Dhital, 2015b).

The AHP-based groundwater potential mapping enrolling topographic, environmental and hydrologic determinant factors is inevitable preliminary and prerequisite task for well planning based resources exploitations and further sustainable development of water resources conservation. In this regard, this research significantly contributed to recognize the spatial based-groundwater potential zonation, which will landmark for subsequent research and development projects under the changing environment. However, this semi-statistical approach has a limitation, in which selection and assigning weight to the thematic determinant factor relies on researcher's expertise and knowledge. Hence, sometimes nature-based interaction (cause and effect) of triggering factors may divert research to wrong research directions. We used the dataset having 30m of resolution for this analysis, which also help to be scarce of adequate results of small-spatial units. A good quality of dataset is more important to improve the precision of results since the quality of input variables and their collective efforts helps to produce a better result in statistical analysis. In this research, we have a lack of more significant dataset related to spatial distribution well and its deep, acquirer thickness due to its unavailability.

Table 3: Normalized weights of each nine determinant thematic factors

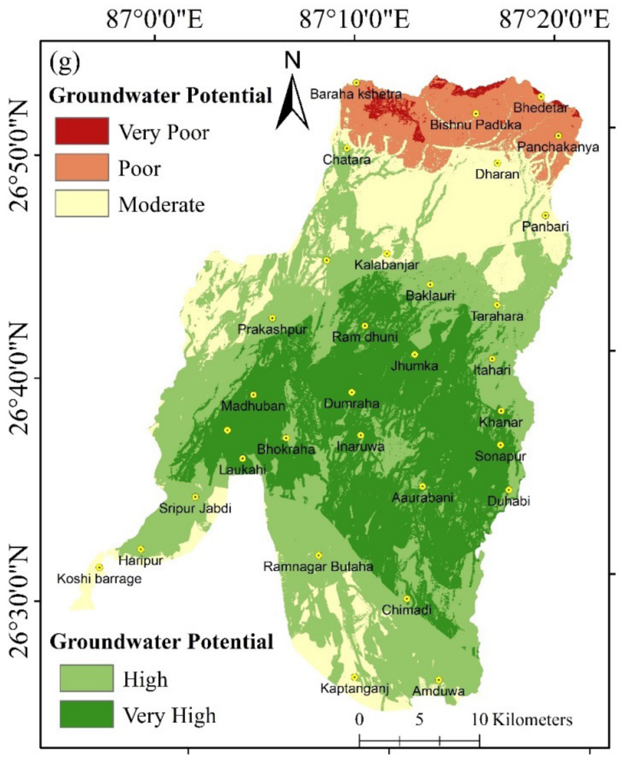
Thematic Factors	Thematic Factors									Normalized Weight (W)
	Pp	Pf	Ds	Dd	LULC	S	Sl	TWI	NDWI	
Pp	0.238	0.536	0.364	0.348	0.182	0.160	0.143	0.129	0.118	2.217/9=0.25
Pf	0.048	0.107	0.273	0.174	0.182	0.160	0.143	0.129	0.118	0.15
Ds	0.060	0.036	0.091	0.174	0.182	0.160	0.143	0.129	0.118	0.12
Dd	0.060	0.054	0.045	0.087	0.182	0.160	0.143	0.129	0.118	0.11
LULC	0.119	0.054	0.045	0.043	0.091	0.160	0.143	0.129	0.118	0.10
S	0.119	0.054	0.045	0.043	0.045	0.080	0.143	0.129	0.118	0.09
Sl	0.119	0.054	0.045	0.043	0.045	0.040	0.071	0.129	0.118	0.07
TWI	0.119	0.054	0.045	0.043	0.045	0.040	0.036	0.065	0.118	0.06
NDWI	0.119	0.054	0.045	0.043	0.045	0.040	0.029	0.029	0.059	0.05
Total	1.000	1.000	1.000	1.000	1.000	1.000	0.994	0.997	1.000	1.00

Table 4: Spatial coverage of groundwater potential zones

Degree of potentiality	Area (km^2)	% of area
Very Poor Potential	9.63	0.81
Poor Potential	96.84	8.13
Moderate Potential	237.60	19.94
High Potential	473.42	39.72
Very High Potential	439.97	31.41

Source: Calculated by author

Figure 3: Potential groundwater zones in the Sunsari District



Result validation

The degree or quality of potentiality mapping of the groundwater derived through the analytical hierarchy process (AHP) have investigated using the ROC curve analysis, in which different types of water body features, viz. swamp, lake, pond, and inundated areas were considered as the sample to test the success rate and prediction rate. Out of total waterbodies 1726 features, (517) 30%, (1209) 70% features were randomly selected for the purpose of testing and training of result analysis. The ROC curve based-area under curve (AUC) describe the degree of the modelling forecast system indicating system's ability to predict the correctly the occurrences or non-occurrences of predefined events (Devkota et al., 2013). The ROC curve have performed the under the curve of success rate and prediction rate were 0.69% and 0.76%, respectively, which indicates that potential mapping of the ground water have a significantly and reasonably good accuracy (Figure 4). This result also has consistent with the spatial distribution of pond, swamp, and water bodies in the study area.

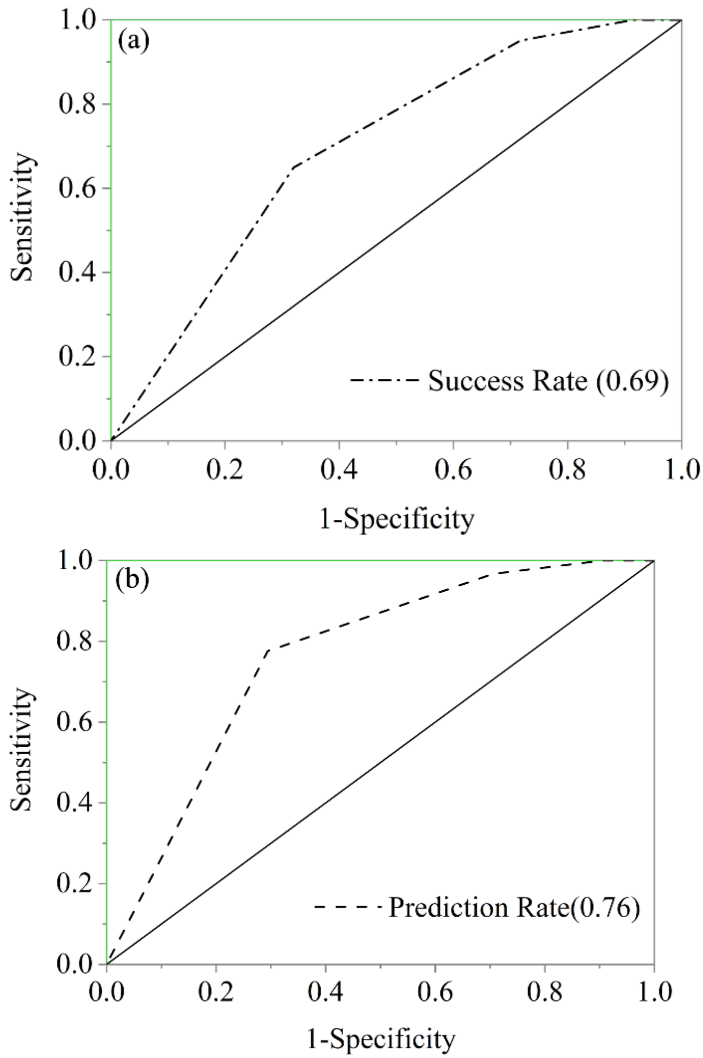


Figure 4: The receiver operating characteristics (ROC) curve showing area under the curve (AUC) for groundwater potential zone mapping: (a) success rate (b) prediction rate

Conclusion

This paper attempts to the probabilistic determinants of groundwater in Sunsari district of eastern Nepal. The potentiality of groundwater analyses by the AHP-based multi-criteria decision examination techniques. For this purpose, nine determinants factors were identified, such as precipitation, pond frequencies, drainage density, distance from stream, slope, soil texture, land-use/land cover, normalized differences water index, topographic wetness index. These factors are considered as determining factors of groundwater potentiality. The receiver operating characteristics (ROC) curve was used to test the prediction accuracy. The final groundwater potential map result indicates very poor potential (0.81%), poor potential (8.13%), moderate potential (19.94%), high potential (39.72%), and very high potential zone (31.41%). The thematic factors are also significantly weighted to determine the potentiality of groundwater. The results of ROC and AUC curves success rates and prediction rates indicate that a good accuracy for prediction of ground water potential zone with 0.69% and 0.76%. This paper concludes that, there is a strong applicability of AHP-based semi-statistical approach to determine the potentiality of the groundwater in the study area. This empirical finding shows that these determining factors are correlating to each-other. Thus, this finding can be replicated to the sustainable water resources management as well as further research.

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