Journal of Engineering Research and Reports

Volume 24, Issue 3, Page 42-61, 2023; Article no.JERR.96236
ISSN: 2582-2926

Delineation of Ground Water Potential Zoning Using GIS and Remote Sensing by AHP of Sunsari District (Koshi Basin) Area of Nepal

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2023/v24i3807

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/96236

Original Research Article

Received: 02/12/2022
Accepted: 05/02/2023
Published: 10/02/2023

ABSTRACT

This study assesses the groundwater potential in Sunsari district of Nepal by using a multi-criteria decision analysis tool along with remote sensing and geographic information system (GIS).The study has taken precipitation, Land use/cover (LULC), slope, geology, drainage density, lineament density, soil, and canal density as key influencing factors for determining the groundwater potential of the study area. The Analytical Hierarchical Process (AHP) technique was adopted in deriving the relative weights of these criteria and sub-criteria based on a review of the literature according to their relative importance in recharging the groundwater. The final thematic map of groundwater potential zones was prepared based on a groundwater potential index computed by aggregating the selected thematic layer with appropriate weights. The groundwater potential zones are classified into three zones based on the score of the groundwater potential index. The generated groundwater potential zones were further validated with ground truth data using a confusion matrix

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with a kappa coefficient and analysis of the receiver operating curve (ROC). The validation indicated fair predictability of groundwater potential zone with the AHP and GIS model. The areas under "Poor", "Moderate" and "Good" are 13.6%, 36.0%, and 50.4% of the study area, respectively. The areas under the "Good" potential category are concentrated in the lower southern and western parts of the study area, while the east central part with highly dense built-up area falls under the "Poor" potential category. Also, the area just north of the central part is under the "Moderate" zone. There is a good coherence of precipitation and LULC with groundwater potential zones and less coherence of other factors.

Keywords: Groundwater potential zones; GIS/RS; weighted overlay; Thematic map AHP

1. INTRODUCTION

Groundwater is the most important sources of the water in earth that takes place below the surface on which millions of people depends on it for fresh water for daily life globally [1]. Groundwater varies spatially in quantity as well as quality and is more fresh water resources as it does not exposed to the open environment directly unlike surface water [2]. In terms of socioeconomic development ground water plays a significant role and contributes immensely to underdeveloped and developing land locked country like Nepal however sufficient surface water resources are available but difficult to trap for use. Hence, needs huge initial investment to harness such resources. Groundwater is used for irrigation and drinking water supply especially in plain region. In most cases the uncontrolled ground water use has led to the depletion of water table each year .The demand of fresh water is increasing due to population increase in plain regions through migration of people from hilly areas to the city for greener pastures in plane area for seek of employment [3]. Agriculture water demand has also been increased, influencing the use of and caused to use of groundwater in large amount quantities that made the discharge and recharge of groundwater resources unbalanced [4]. This can cause the shortage of water globally in the near future. Today drinking water supply has become a serious issues and challenges [5]. So therefore the groundwater potential mapping has become an essential work for the water resource department on sectoral and regional basis.

Ground water potential zoning has been carried out on field basis which is time consuming and expensive [2]. But now a days remote sensing and GIS techniques have become a good tool for zoning which work on the integration and development of thematic layers that show the potential prospect of ground water of in the region quantitatively, which varies from place to place depending on the hydrology, climate, topography, geology, ecology, slope, soil type of the watershed area. Therefore, these factors are to be used for groundwater potential zoning (GWPZs) [6].There are various methods and techniques available for this study of zoning in recent days that are available in recent literature [7]. Among which the Analytical Hierarchy process (AHP) is most common and user friendly for the study. AHP minimizes the mathematical problems and complexity in decision making so it is widely used for GWPZs [8].

The primary aim of this study was to identify and delineate the groundwater potential of Sunsari district province-1 Nepal. To meet this goal, the study attempted:

- To identify the parameters influencing the groundwater potential in the study area.
- To delineate the region for different groundwater potential zones and explore the suitability of AHP as a decision tool.

1.1 Description of the Study area

Sunsari is a district area in Province 1 of Nepal's eastern region. It is in the terai's outer reaches which covers 1257 square kilometers. It shares borders with Morang district on the east, Saptari and Udayapur district (Koshi River) on the west, Dhankuta (Bheddetar) on the north, and India (Bihar) on the south. It is also connected to the hilly regions of Nepal's eastern region. The study area is shown in Fig. 1.

The headquarters of Sunsari district is Inaruwa Municipality. The study area consists of two sub-metropolitan, four urban metropolitan, and six rural municipalities. Sunsari lies in the southeastern part of Nepal along the Siwalik foothills and is one of the rapidly developing districts of Nepal. It is characterized by populous and fast-growing cities like Dharan Sub metropolitan city, Itahari sub-metropolitan,

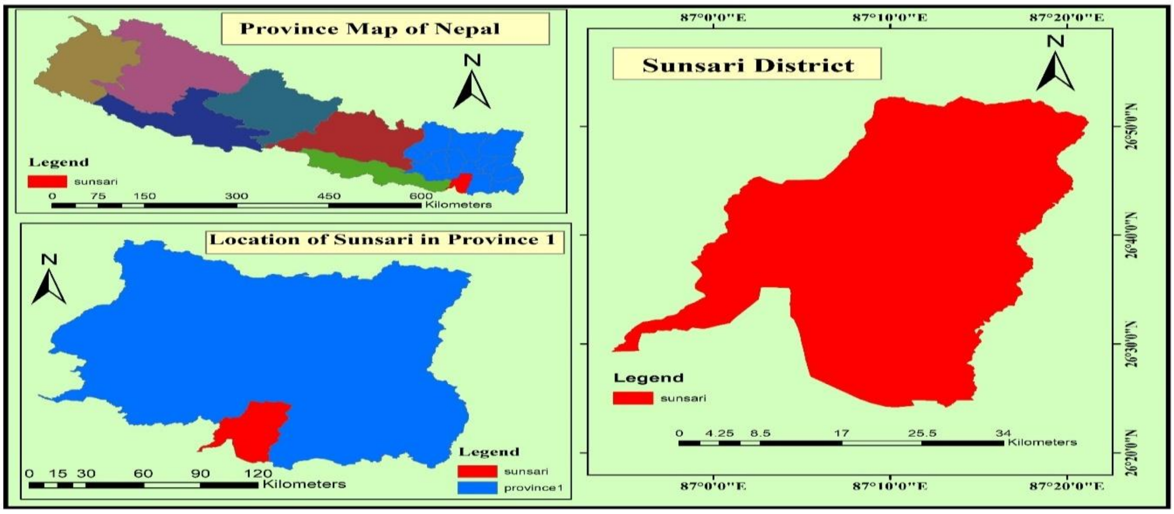

Fig. 1. Location Map of the study area

Duhabi municipality, and Inaruwa municipality city along with an industrial corridor. The study area is a part of the largest Saptakoshi River basin of Nepal [9,10].

2. MATERIALS AND METHODS

Necessary input data were collected from the primary and secondary sources. Thematic layers needed for the study were prepared using the Arc GIS tool, weights of the influencing criteria were decided along with the rating of sub-criteria using AHP and finally, the thematic layers were overlaid in Arc GIS to produce the groundwater potential map. The methodology used for the research work is shown in the Fig. 2.

2.1 Data Collection, Resolution and Processing

SRTM DEM of 30 m resolution was downloaded from earthexplorer.usgs.gov and clipped for the study area using GIS. The DEM was processed in DEM to obtain thematic layers of slope map, drainage map, drainage density map, aspect map, and lineament density map.

Further LULC map, soil map, and geology map were obtained from secondary sources like ICIMOD and FAO and processed in GIS. The Canal Density map was prepared by digitizing canal alignment in Google Earth Pro software. Hydrological rainfall data of different gauge stations in the study area were obtained from DHM and well location and depth data were also collected from Groundwater Resource Development Board.

2.2 Identification of Influential Criteria

The most creative task in making a decision is to choose the factors that are important for that decision [11]. The study's influential criteria have everything to do with groundwater potential. Although the goals and attributes can aid in the selection of a set of evaluation criteria, there are no universal procedures for determining a set of criteria. It is self-evident that the collection of criteria is problem-specific and dependent on the particular system being researched.

The set of evaluation criteria for the decision problem in any study may be set through a detailed examination of the relevant literature, analytical study, and opinions. To justify the relation, references from different kinds of literature were taken. We have taken eight influencing criteria i.e. rainfall, slope, LULC, geology, soil, canal density, drainage density, and lineament density [12].

2.3 Estimation of Weights to Influencing Factors

Table 2 shows the procedure of assigning weightage for each parameter and class within the parameter based on its importance. The value 9 in the table shows higher importance, while 1/9 shows the least important while 1 shows the equal weight of a parameter or a class. Based on these weightage criteria each parameter in the study has been classified. The Table 2 shows the weightage assigned for selected nine parameters for the study.

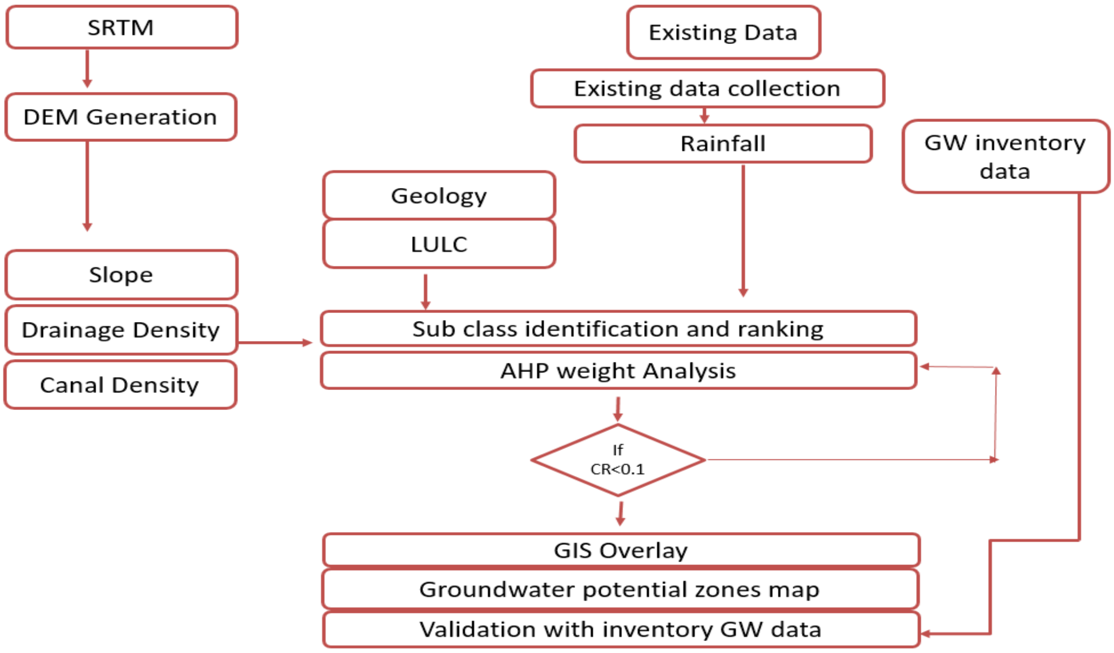

Fig. 2. Flowchart designed for the study

(Mission, LULC: Land use/cover, CR: Consistency ratio, GIS: Geographic Information System)

Table 1. Data acquisition and resolution of data

No	Thematic Layers	Source	Spatial Resolution
1	DEM	SRTM (earthexplorer.usgs.gov)	30 m
2	Slope	SRTM DEM (earthexplorer.usgs.gov)	30 m
3	Drainage density	SRTM DEM (earthexplorer.usgs.gov)	30 m
4	Land use/cover	ESRI Land cover 2020	10 m
5	Lineament Density	SRTM DEM (earthexplorer.usgs.gov)	30 m
6	Rainfall	DHM Daily data from 1983-2018 AD	Interpolated and resampled to 30 m
7	Geology	ICIMOD https://rds.icimod.org/	Digitized and reclassified into 30-m resolution raster data at approximately1:35,000,000 scales
8	Soil	FAO	
9	Canal Density	Digitization from Google Earth	Resampled to 30 m

Once the influencing criteria are decided, AHP as a tool of multi-criteria decision approach was adopted. A fundamental scale is used in making the comparison. It consists of verbal judgments ranging from equal to an extreme (equal, moderately more, strongly more, very strongly more, and extremely more) corresponding to the verbal judgments are the numerical judgments (1, 3, 5, 7, 9) and compromises between these values [11].

2.4 Weights of Criteria

The goal of this study was set to produce groundwater potential zones and influencing criteria were set. For preparing a pairwise comparison matrix, Saaty's scaled weights were given to each variable as shown in Table 3.

Now, n by n reciprocal matrix which was derived from pair comparison. Each column of the reciprocal matrix was summed. Each element of the matrix was divided with the sum of its column to get normalized relative weight. The sum of each column is 1. By averaging across the rows the normalized principal Eigen vector was calculated as given in Table 4.

2.5 Estimated Weights to Criteria and Sub Criteria

After determining the behavior and contribution of various thematic features to groundwater occurrence and control in the study area, appropriate weights were assigned to the various themes and individual features of various themes.

Table 2. Saaty's relative scale of comparison

Verbal Judgment	AHP numeric value
Extremely Important	9
Very Strong to extremely Important	8
Very strongly Important	7
Strongly to Very strongly Important	6
Strongly Important	5
Moderately to strongly important	4
Moderately Important	3
Equally to moderately Important	2
Equally Important	1

Table 3. Relative comparison of criteria in AHP model

i	j	A	B	A or B	(1-9)
1	2	Rain	Slope	A	2
1	3		LULC	A	3
1	4		Geology	A	5
1	5		Canal Density	A	5
1	6		Lineament Density	A	6
1	7		Soil	A	8
1	8		Drainage Density	A	9
2	3	Slope	LULC	A	2
2	4		Geology	A	5
2	5		Canal Density	A	4
2	6		Lineament Density	A	5
2	7		Soil	A	7
2	8		Drainage Density	A	9
3	4	LULC	Geology	A	3
3	5		Canal Density	A	5
3	6		Lineament Density	A	6
3	7		Soil	A	8
3	8		Drainage Density	A	9
4	5	Geology	Canal Density	A	2
4	6		Lineament Density	A	3
4	7		Soil	A	5
4	8		Drainage Density	A	6
5	6	Canal Density	Lineament Density	A	5
5	7		Soil	A	3
5	8		Drainage Density	A	4
6	7	Lineament Density	Soil	A	5
6	8		Drainage Density	A	4
7	8	Soil	Drainage Density	A	2

Table 4. Pairwise comparison of criteria

Matrix		Rain 1	Slope 2	LULC 3	Geology 4	Canal Density 5	Lineament Density 6	Soil 7	Drainage Density 8	0 9	0 10	normalized principal Eigenvector
Rain	1	1	2	3	5	5	6	8	9	-	-	31.97%
Slope	2	1/2	1	2	5	4	5	7	9	-	-	23.65%
LULC	3	1/3	1/2	1	3	5	6	8	9	-	-	19.17%
Geology	4	1/5	1/5	1/3	1	2	3	5	6	-	-	8.86%
Canal Density	5	1/5	1/4	1/5	1/2	1	5	3	4	-	-	7.47%
Lineament Density	6	1/6	1/5	1/6	1/3	1/5	1	5	4	-	-	4.70%
Soil	7	1/8	1/7	1/8	1/5	1/3	1/5	1	2	-	-	2.38%
Drainage Density	8	1/9	1/9	1/9	1/6	1/4	1/4	1/2	1	-	-	1.79%

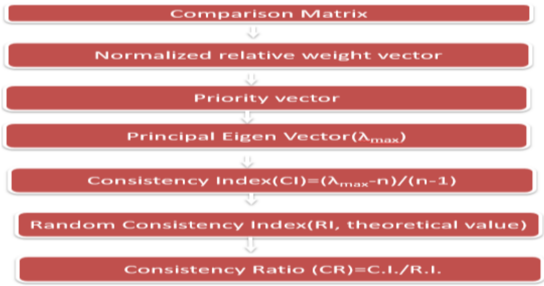

Fig. 3. Methodology followed in preparing priority vector and deciding criteria weight

Table 5. Weights of criteria and sub-criteria based on AHP

Criteria	Sub-criteria	Rank	Weight	CR	Weight (%)
Rainfall	1961.4 -2014.21	1	0.02	0.01	32
	2014.21-2052.59	2	0.097		
	2052.59-2090	3	0.16		
	2090-2143.73	4	0.26		
	2143.73-2206.09	5	0.42		
Slope	0-2.65	5	0.52	0.04	24
	2.65-10.1	4	0.29		
	10.1-21.23	3	0.1		
	21.23-31.32	2	0.056		
	31.23-67.68	1	0.037		
LULC	Water Body	5	0.37	0.07	19
	Tree	3	0.11		
	Grass	2	0.079		
	Crops	4	0.29		
	Built up area/flooded vegetation/bare ground /shrub	1	0.018/0.063/0.025/0.052		
Drainage density	0-0.55	5	0.53	0.04	2
	0.55-1.1	4	0.21		
	1.1-1.66	3	0.15		
	1.66-2.21	2	0.073		
	2.21-2.77	1	0.037		
Geology	Seti/Takure/syangja formation	1	0.097/0.065/0.031	0.05	9
	Upper Siwalik	2	0.044		
	Lower Siwalik	3	0.21		
	Middle Siwalik	4	0.15		
	Recent	5	0.4		
Soil	RGd (Sandy Loam)	5	0.38	0	2
	PHc (loam)	3	0.21		
	Gle (clay Loam)	2	0.071		
	CMg(clay loam) and FLc (loam)	1	0.071		
	CMe(Clay light)	4	0.21		
Canal Density	Very Low	1	0.058	0.03	7
	Low	2	0.081		
	Moderate	3	0.14		
	High	4	0.22		
	Very High	5	0.49		
Lineament	Very Low	1	0.067	0.01	5
	Low	2	0.09		
	Moderate	3	0.15		
	High	4	0.26		
	Very High	5	0.43		

These were created based on previous research and the Analytic Hierarchy Process (AHP) [11]. Table 5 shows Saaty's Analytical Hierarchical Process rating scale was used to assign weights to various aspects and themes of all the thematic layers for groundwater potential zones.

3. RESULT AND DISCUSSION

3.1 Spatial Distribution of Influencing Criteria

3.1.1 Digital Elevation Model (DEM)

In this study, DEM of 30m spatial resolution was downloaded from USGS. It was used to analyze drainage, drainage density, and slope of the study area. The elevation ranges widely range from 52 m to 1791 m above sea level as the topography of the study area varies from plain areas of Terai to the Mahabharat range in the north.

3.1.2 Precipitation

The precipitation data for three stations Chatara, Dharan, and Tarahara were taken from the year 1983 to 2018 AD. The average annual rainfall recorded by these stations, when plotted and spatially interpolated, ranges from minimum rainfall of 1961 mm to 2206mm. The annual average rainfall (1983-2018 AD) of three stations is tabulated in Table 6.

The bar chart representation also shows that Dharan Bazar has the highest annual average rainfall (1983-2018 AD) of three stations.

Monsoon rainfall is the main source of recharge in the study area. The rainfall is categorized into five classes i.e. Low (1961.44-2014.21 mm), Moderate (2014.21-2052.59 mm), High (2052.59-2090.027 mm), very high (2090.07-2143.73 mm), and maximum (2143.73-2206.09 mm) that occupied 10.17%, 20.89%, 43.57%, 14.99%, and 10.36% of study area respectively as shown in Table 7.

Higher Rainfall was found in the northern and northwestern parts which would significantly contribute to groundwater recharge while the lower eastern part has lower rainfall. Higher rainfall has contributed to recharge but the very steep slope allowed surface water to flow downward. Pairwise comparison is done to derive the rating of sub-criteria with a consistency ratio of 0.02 which is less than 0.1.

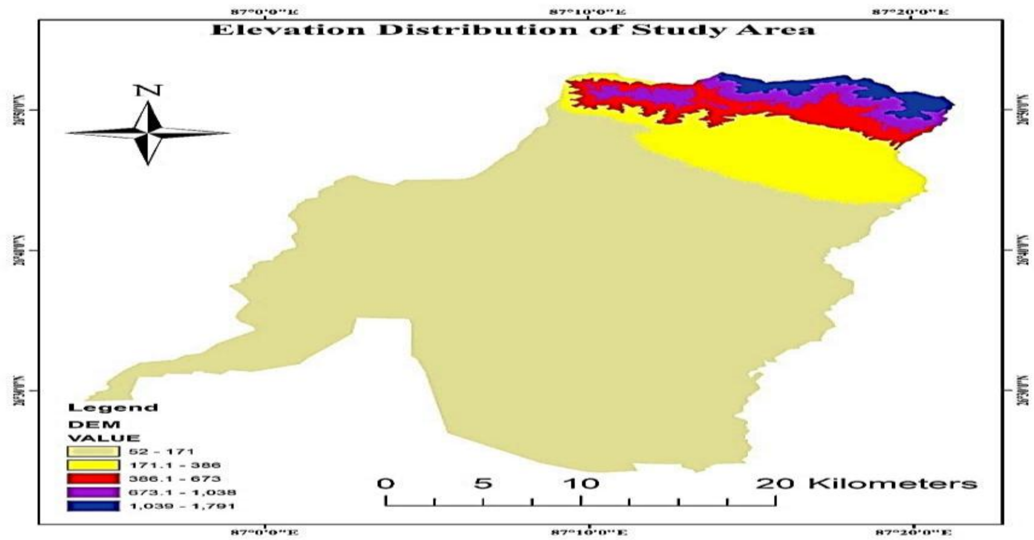

Fig. 4. Digital elevation model (DEM) of study area

Table 6. Rainfall data for the study area

Station ID	Name	LAT	Long	Precipitation (mm)
1311	Dharan Bazar	26.81	87.28	2206.11
1316	Chatara	26.81	87.16	2116.82
1320	Tarahara	26.7	87.26	1961.43

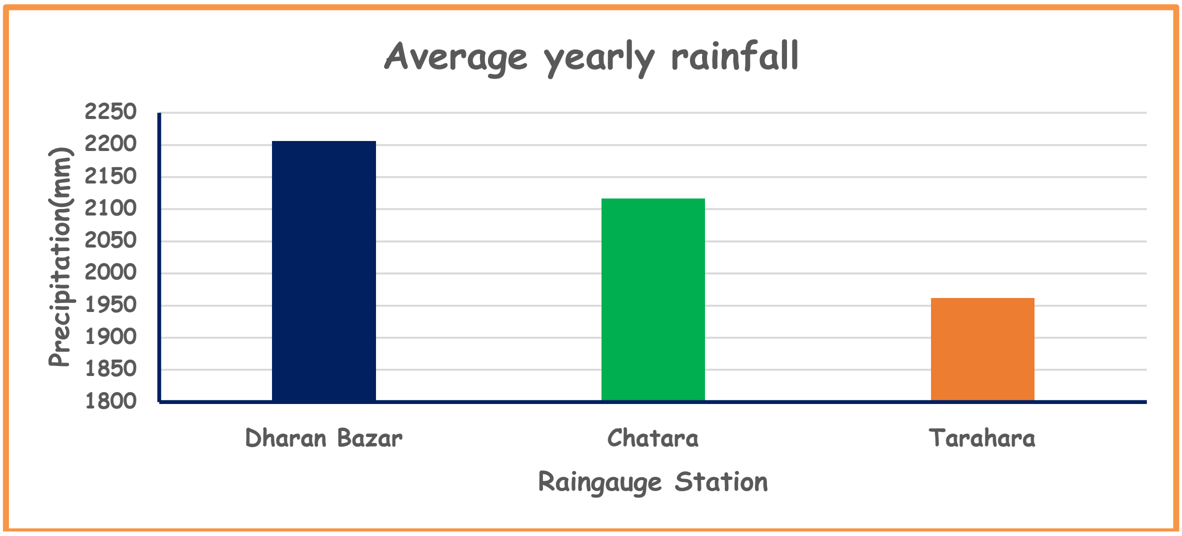

Fig. 5. Average yearly rainfall of stations within Sunsari district

Table 7. Distribution of precipitation in the study area

SN	Precipitation (mm)	Area (sq. km)	% Area
1	1961.44-2014.21	121.11	10.17
2	2014.21-2052.59	248.75	20.89
3	2052.59-2090.027	518.78	43.57
4	2090.07-2143.73	178.58	14.99
5	2143.73-2206.09	123.44	10.36
Total		1190.66	100

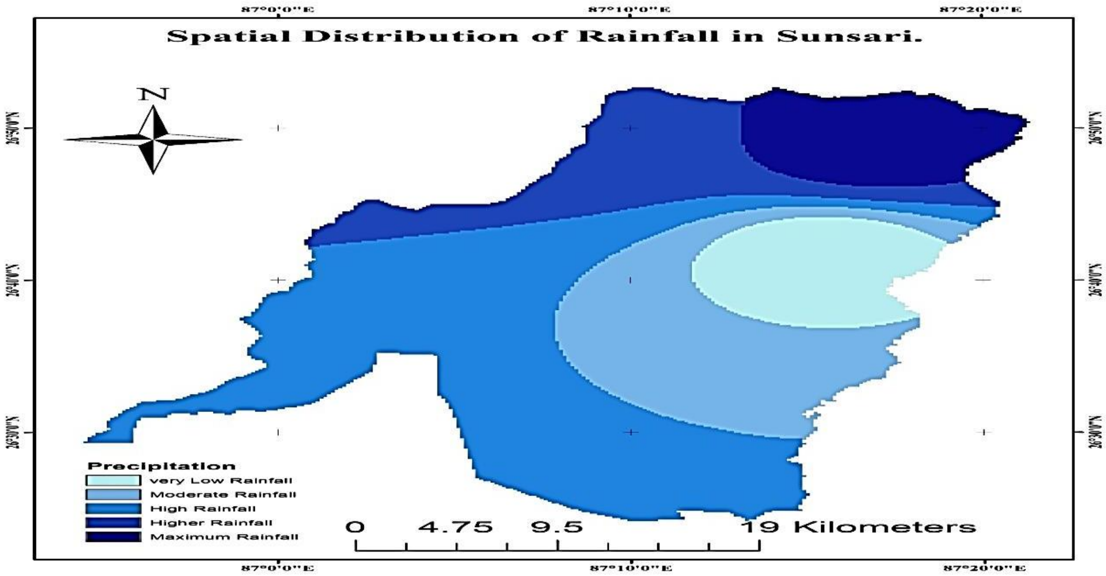

Fig. 6. Rainfall distribution map of study area

3.1.3 Slope map

Slope Map was prepared using elevation data of DEM in terms of degree. The maximum study area is covered by a flat area and very little with a high slope. The slope of the study area has been classified as near level (0-0.265), gentle (2.65-10.08), moderate slope (10.08-21.23), steep slope (21.23-31.32), and very steep slope (31.32-67.68) percentage.

Table 8. Area distribution of slope

Slope Class	Slope (%)	Area(km^2)	% Area
Very Steep Slope	31.32-67.68	25.43	2.14
Steep Slope	21.23-31.32	42.04	3.53
Moderate Slope	10.08-21.23	39.93	3.35
Gentle Slope	2.65-10.08	306.38	25.73
Near Level	0-2.65	776.91	65.25
Grand Total		1190.69	100.00

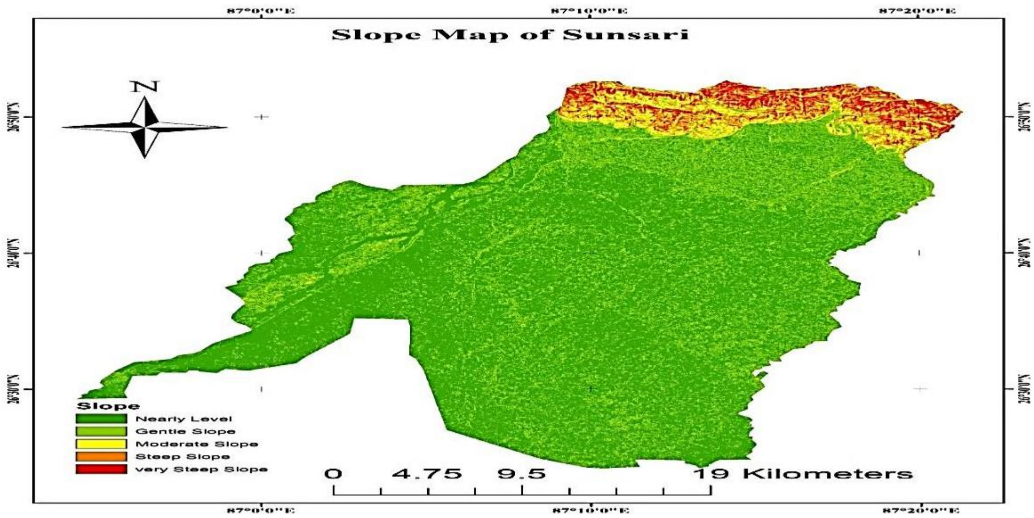

Fig. 7. Slope map of study area Sunsari district

The slope distribution map showed that most of the southern part of the study area falls under near level to a gentle slope that has significantly contributed to groundwater potential in that area. Steep slopes are associated with feeble recharge potential because the water flows rapidly downward, so it does not allow sufficient time for rainwater to percolate [2].

Derivation of rank for the sub-criteria is shown in the annexed table. The higher the rank, the higher is the contribution to groundwater recharge and hence GWPZ.

3.1.4 Land Use/Cover (LULC)

Land use land cover of study areas showed different types of land cover and settlements of 8 classes as shown below. Land Use classification showed the largest percentage of area is covered by agricultural land (48.48%) in the southern region with irrigation facility and forest (22%) in the northern part while the built-up area covers about 17% of the study area. The western border has a large water body and is sandy on the banks of the Koshi River.

The Consistency ratio check was done on Sub criteria of LULC that Showed a CR of $0.07<0.1$ which is considered a valid decision which is shown in the annexed table.

Pore spaces in the soil catch and hold water in the roots, providing a conduit for water to percolate into the surface by loosening the rock and soil on agricultural grounds. Built-up and barren lands, on the other hand, reduce infiltration by reducing permeable surface area and increasing runoff potential [13].

The study area has a large area of cropland owing to good water potential in that region and the built-up area is expected to have poor groundwater potential.

3.1.5 Geological variation

Geology map of study areas showed the different class of geology that contributes to recharging differently and corresponding weights will be assigned. The study area has 89.83 percent of recent geology which has alluvium, boulder, gravel, sand, silt, and clay. This geology is favorable to groundwater recharge and hence groundwater potential.

Table 9. Percentage area covered by land use/cover classes

Class	Area Covered(Sq. Km.)	% Area	Sub class rating	CR
Water Body	32.37	2.718753	5	0.07
Crop	577.41	48.4899	4	
Tree	269.72	22.65038	3	
Grass	1.85	0.155248	2	
Bare Ground	41.99	3.526046	1	
Built Area	197.97	16.62474	1	
Flooded Vegetation	1.18	0.0987	1	
Shrub	68.31	5.736242	1	
Grand Total	1190.79	100		

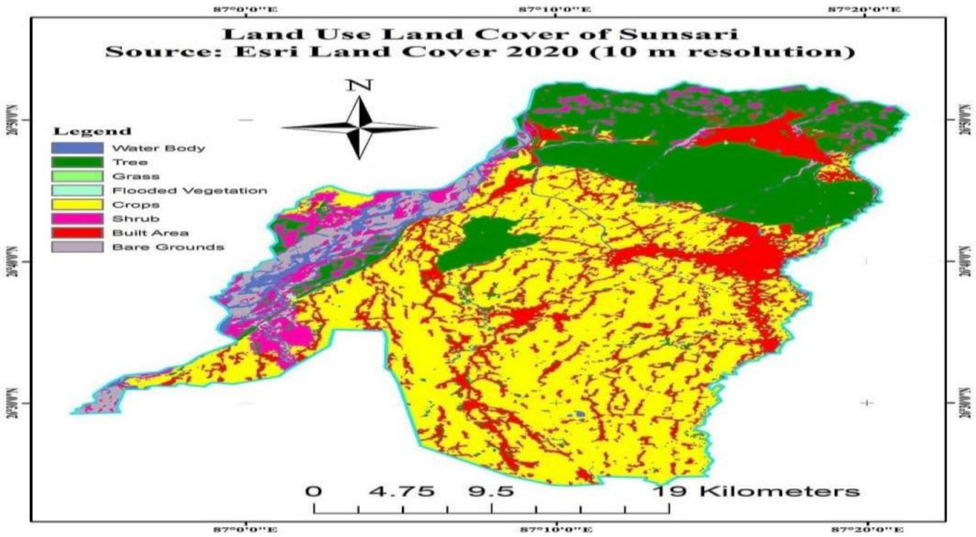

Fig. 8. Land use/cover map of study area Sunsari district

Table 10. Geology of study area

SN	CLASS	Area (sq. km)	% Area
1	Recent	1063.91	89.83
2	Lower Siwalik	66.03	5.58
3	Middle Siwalik	24.84	2.10
4	Seti Formation	16.98	1.43
5	Takure Formation	9.61	0.81
6	Upper Siwalik	1.56	0.13
7	Syangja Formation	1.39	0.12
Total		1184.32	100.00

Lower, middle and upper Siwalik constitute 5.58%, 2.10%, and 0.13% of the study area. Similarly, Takure formation and syanja formation occupies 0.81% and 0.12% of the study area.

3.1.6 Soil types

The rate of infiltration depends on the grain size of the soil. The soil map is derived from the ICIMOD and clipped for the study area that shows FAO soil classification. The soil map was classified based on dominant soil types which are further reclassified as per USDA texture as per Harmonized World Soil Database and suitable ranking and weights were derived.

3.1.7 Lineament density

A lineament may represent a fault, fracture, and master joint, a long and linear geological formation, topographic linearity, valleys or straight course of streams, boundaries between the different lithological units, vegetation cover, or artificial objects such as road, bridge, etc. The map showed high to very high lineament density in the northern regions due to rugged topography and expected to contribute more to the groundwater potential of the area through fault and fractures.

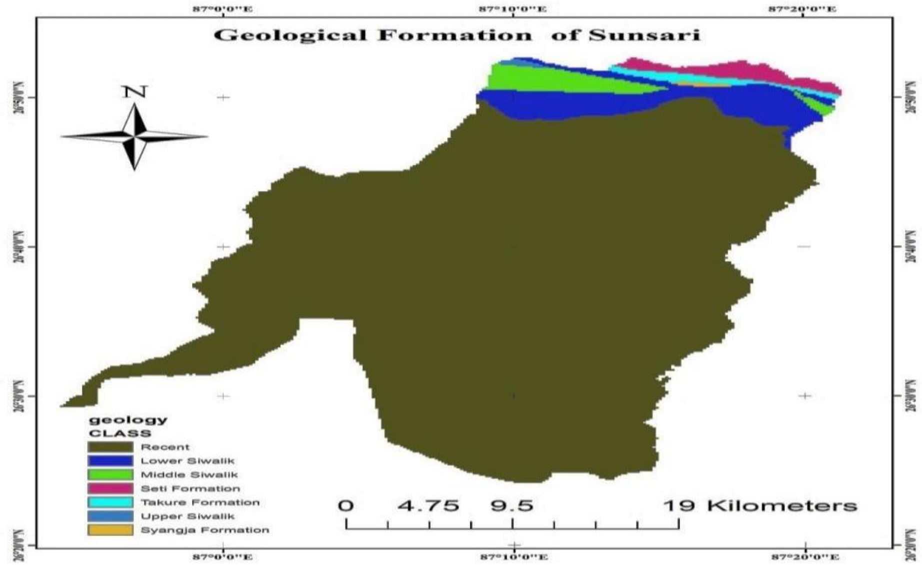

Fig. 9. Geological formation of study area Sunsari district

Table 11. Area distribution of soil class

Class	Area(km^2)	% Area
CMe	37.43	3.19
CMg/FLc	219.78	18.70
GLe	637.38	54.24
PHc	204.00	17.36
RGd	76.46	6.51
Grand Total	1175.06	100.00

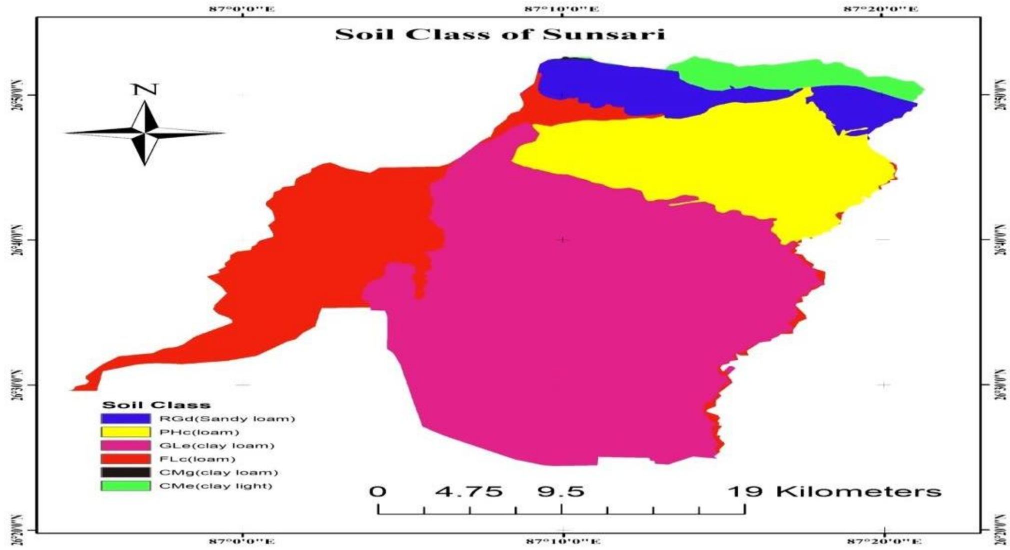

Fig. 10. Soil map of study area Sunsari district

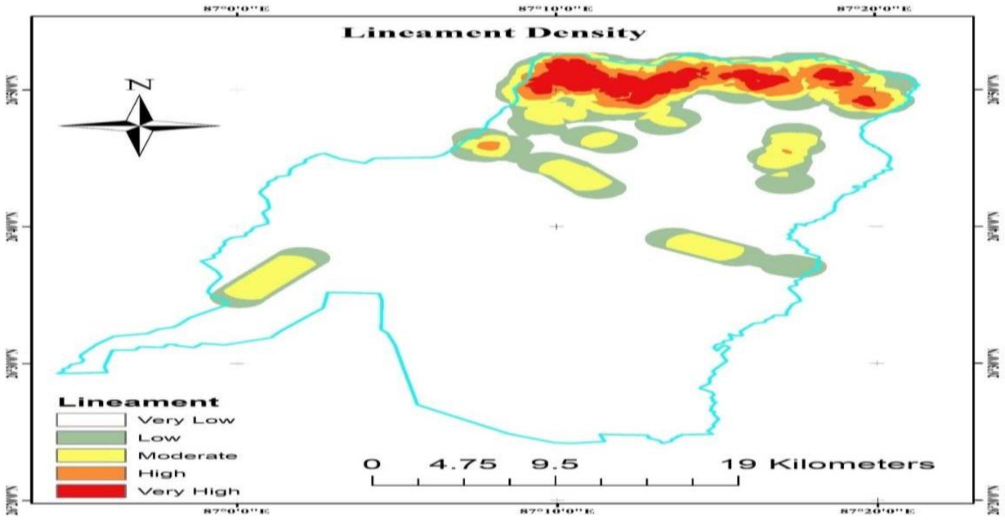

Fig. 11. Lineament density of study area

Table 12. Area distribution of canal density

Canal density	Area(km^2)	% Area
Very low	630.52	52.95
Low	289.23	24.29
Moderate	137.56	11.55
High	97.53	8.19
Very High	35.99	3.02
Grand Total	1190.83	100.00

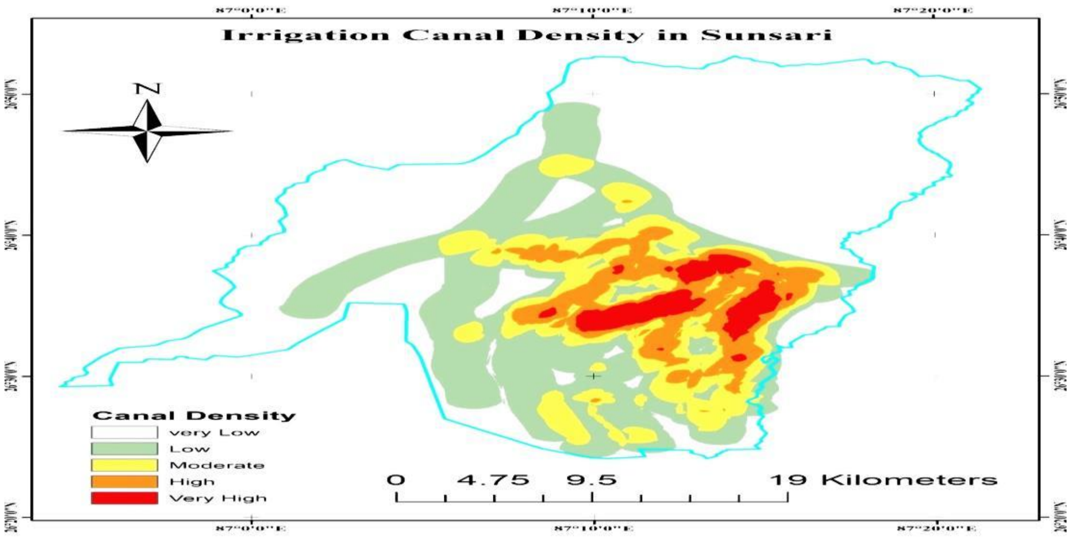

Fig. 12. Canal density map of study area Sunsari district

3.1.8 Canal density

Unlike previous literature, canal density is also included as one of the influencing criteria as a large area of sunsari district falls in the command area of Sunsari Morang Irrigation Project. All canal alignments were digitized using Google earth pro and Arc GIS and line density was computed to derive canal density map.

Most of the area north of the east-west highway has very low to no irrigation canal. Only Southern cropping land has irrigation facilities. It is found that 24.29% area is occupied by moderate density, high canal density area occupies 8.19 % and Very high occupies 3.02 % of the study area while 24.29 % and 52.95% area has low and very low canal density respectively.

The area with high and very high canal density is supposed to have higher groundwater potential.

3.1.9 Drainage density

Drainage density can be defined as the ratio of the total length of the stream and river in the drainage basin and the total area of the drainage basin. It is the measure of how a drainage basin is drained by a stream channel. The area with low drainage density has a higher probability of groundwater recharge and higher potential for groundwater.

The study area seemed to have a very low drainage density as 67.02% of the study area has a very low drainage density. The study area has 19.03% of low, 9.11% of moderate, 4.06% of high, and 0.78% of very high drainage density.

3.2 Groundwater Potential Zones

All input thematic layers were reclassified as per their priority rating which was derived using a multi-criteria decision approach using pairwise comparison and then exported to the equal cell size of 30m by 30m. The weighted overlay analysis was done to produce the final groundwater potential zone map.

The study merged effects of different factors account for occurrence and movement of groundwater, namely Rain, Slope, LULC, Geology, Canal density, Lineament density, soil and drainage density with score weights of 32.97%, 23.65%, 19.17%, 8.86%, 7.47%, 4.70%, 2.38%, and 1.79% respectively.

Table 13. Area distribution of drainage density

Drainage density	Sum of Area(km^2)	% area
Very high	9.25	0.78
High	48.33	4.06
Moderate	108.51	9.11
Low	226.67	19.03
Very low	798.06	67.02
Grand Total	1190.83	100.00

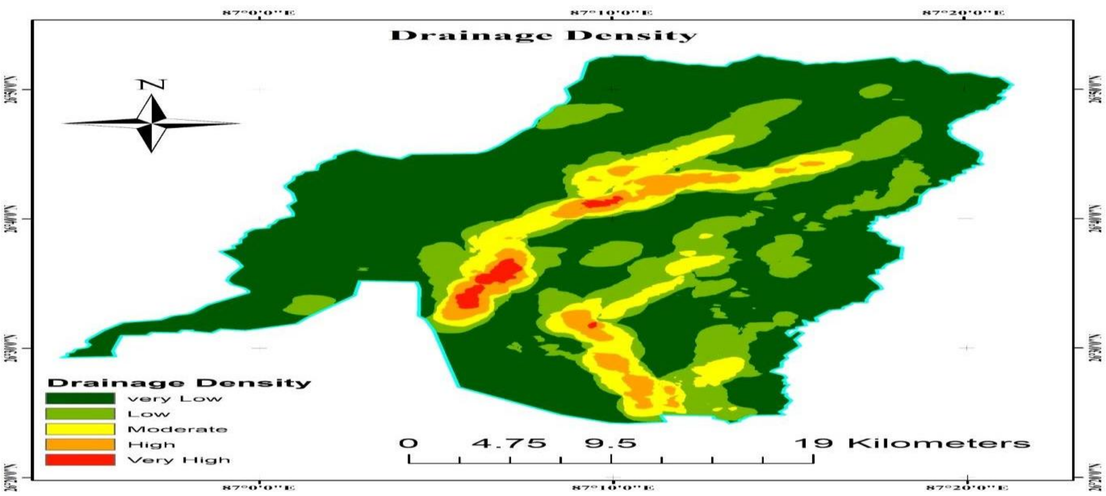

Fig. 13. Drainage density map of study area of Sunsari district

Table 14. Distribution of classes of produced groundwater potential zones

GWPZ	GWP Index	Normalized Index	Area (square KM)	% Area
Poor	197 – 292.19	0 – 0.36	159.00	13.61
Moderate	292.19 - 339.27	0.36 – 0.55	420.08	35.95
Good	339.27 - 458	0.55 – 1.0	589.43	50.44

The final groundwater potential zone map is subdivided into "Poor" (13.61% area), "Moderate" (35.95 % of the area), and "Good" (50.44% of the area). The area distribution of Final Groundwater potential classes is as shown in the table. The corresponding groundwater potential index for poor, moderate, and good ranges from 197 minimum to 458 maximum. After normalization of the index using the formula:

$$z = \frac{x_i - x(min)}{x(\max) - x(\min)} \dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

We get a normalized range for groundwater potential index as 0 -0.36 for Poor, 0moderate, and 0.55 – 1.0 for good groundwater potential zones [14].

The result showed Good GWPZ concentration in the lower southern part and western part characterized by intensive agricultural land, recent geology, and nearly flat slope shows good water potential while eastern central part heavily built-up area showed poor zones. Also, the area just north of the central part is seen to be in a moderate zone due to the temporal forest area and vegetation. The very northern border of the ridge being highly steep all the precipitation and seems to flow down owing to the poor zone while the Bhavar range shows moderate groundwater due to its high infiltration capacity but groundwater seems to roll to plain are due to rolling gradient in this region.

The predicted groundwater potential map showed that the urban municipalities like Itahari, Inaruwa, and industrial corridor fall under poor GWPZ because of lower rainfall and high built-up area while Dharan municipality is in moderate to good potential zone due to recharging potential of Bhavar (Siwalik Zones). Similarly, fluvial sandy zones in the bank of the Koshi river on the western border side of Sunsari are recognized as a good potential zone.

The effect of canal density in the area of the highly built-up area has been neutralized with land use weight. The area with cropping land use where moderate to high canal density was found showed moderate to good groundwater potential. This can be further validated in the field where irrigation channels lying in the settlement and industrial areas like Khanar and Sonapur are not in function as cropping land use has hanged to the built-up area.

The fast-growing Tarahara region that lies in the just northern outskirts of Itahari municipality shows Poor to moderate groundwater potential while the forest area that lies between Tarahara and Dharan shows good groundwater potential zones owing to favorable recharge parameters.

3.3 Validation of Groundwater Potential Zones

The spatial map of inventory groundwater data was prepared and categorized into 3classes: Poor (3.8m-5.5m), Moderate (3.1m -3.7m), and good (2.2m -3m). Now, 60 location points were generated so that they represented all classes of groundwater data in Arc GIS to extract the values from the spatial map as shown.

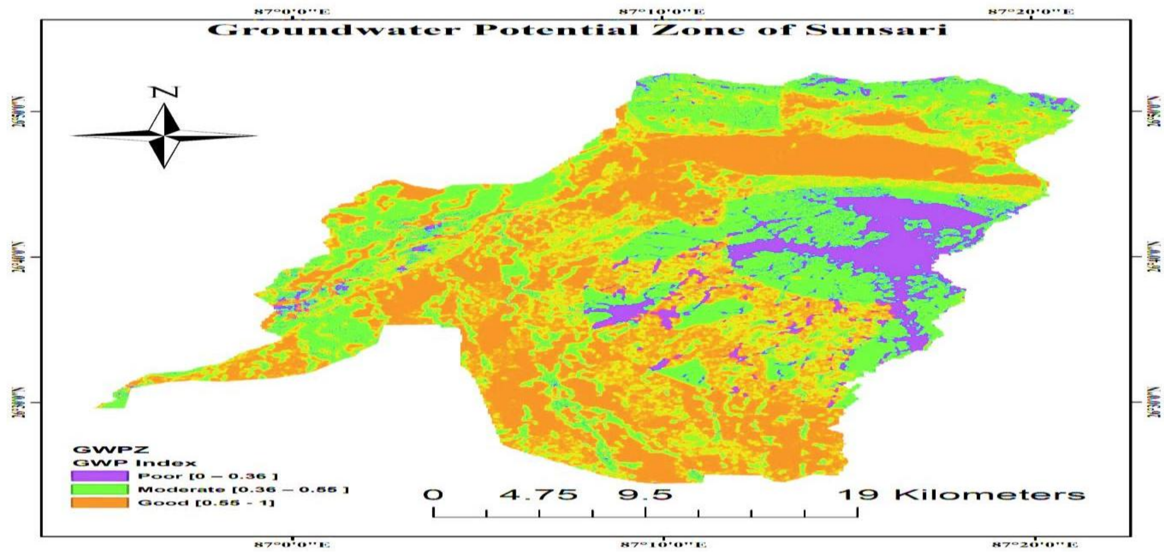

Fig. 14. Simulated groundwater potential zones

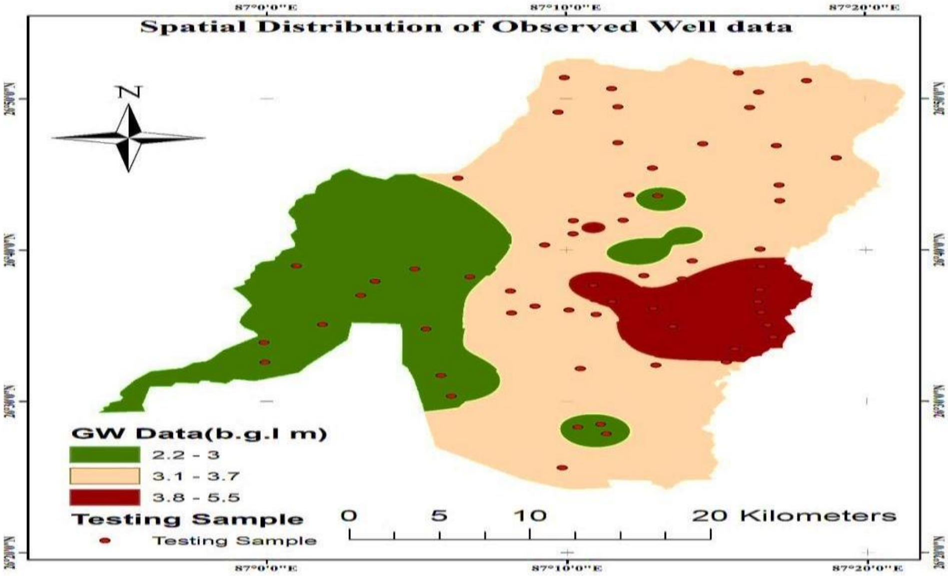

Fig. 15. Inventory groundwater spatial map with sample test points

Quantitatively or statistically the result of this particular study was validated by 3 approaches [2,13,1].

1. Classification accuracy or cross tab
2. Scatter plot
3. Receiver operating curve (ROC) and Area under the curve(AUC)

These sample test points were used to extract the raster value of the groundwater potential map and categorized as Poor, moderate, and good.

Validation done with the different approach were as shown below.

3.3.1 Cross-tabulation: Confusion matrix

When the cross-tabulation analysis was done in IBM SPSS software, 7, 22, and 13 observation (true points) of Poor, Moderate and Good class lied in the respective class of produced GWPZ map.

The cross tab analysis gave the kappa coefficient of 0.6 and overall accuracy of 70%.

Table 15. Cross-tabulation

			WELL PIXEL			
			1	2	3	Total
GWPZ	1	Count	7	5	0	12
		% within WELL PIXEL	63.6%	14.7%	0.0%	20.0%
	2	Count	3	22	2	27
		% within WELL PIXEL	27.3%	64.7%	13.3%	45.0%
	3	Count	1	7	13	21
		% within WELL PIXEL	9.1%	20.6%	86.7%	35.0%
Total		Count	11	34	15	60
		% within WELL PIXEL	100.0%	100.0%	100.0%	100.0%

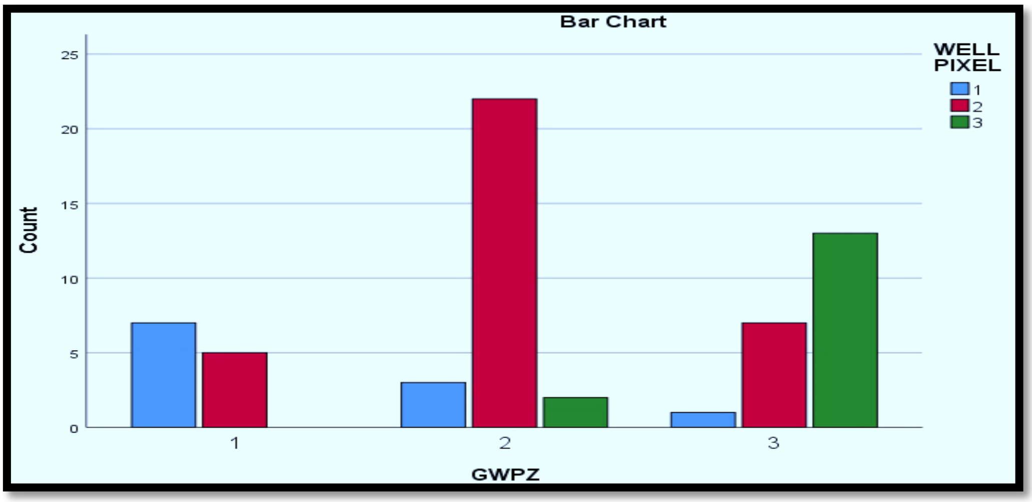

Fig. 16. Bar chart for validation (GWPZ: Groundwater potential Zones)

$$\text{Overall Accuracy} = \frac{No\ of.\ correct\ Prediction}{Total\ \ no\ of\ Sample} = \frac{42}{60} = 0.7 = 70\%$$

$$\text{Kappa coefficient (K)} = \frac{TS \times TCS - \sum(column\ total\ \times row\ total)}{TS^2 - \sum(column\ total\ \times row\ total)}$$

$$= 0.603$$

3.3.2 Scatter plot

The Weightage value (rater value) of the final groundwater potential map is plotted against groundwater depth below ground level from the spatially interpolated map of inventory groundwater well data to create the scatter plot. The scatter plot showed groundwater potential has negative relation with groundwater fluctuation with r^2 value of 0.4.

3.3.3 ROC and AUC

Receiver operating analysis was done to validate the prediction efficiency of the model in the statistical tool SPSS that gave the following results.

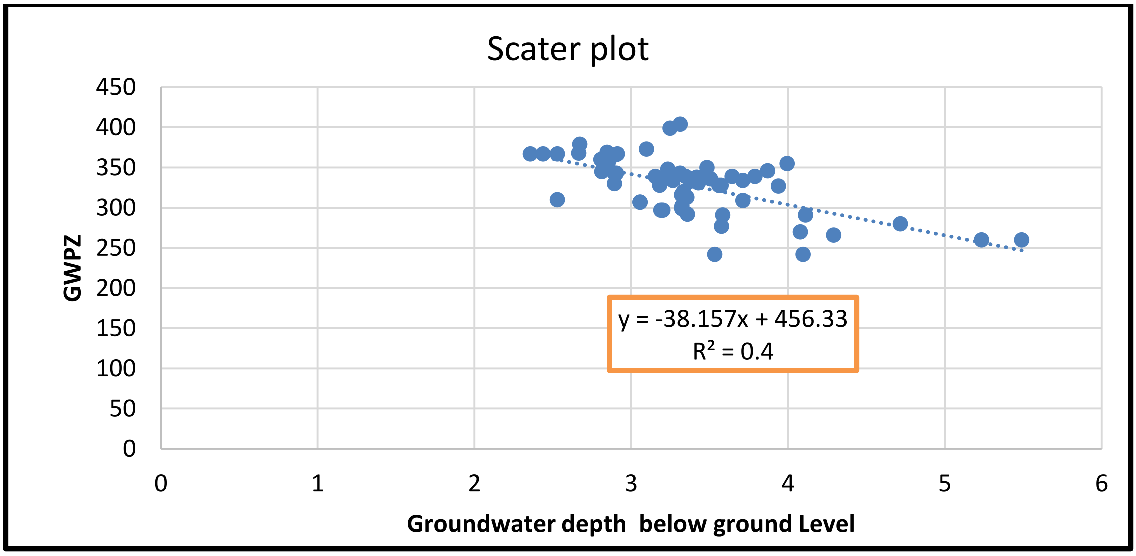

Fig. 17. Scatter plot groundwater depth data (bgl) vs groundwater potential index

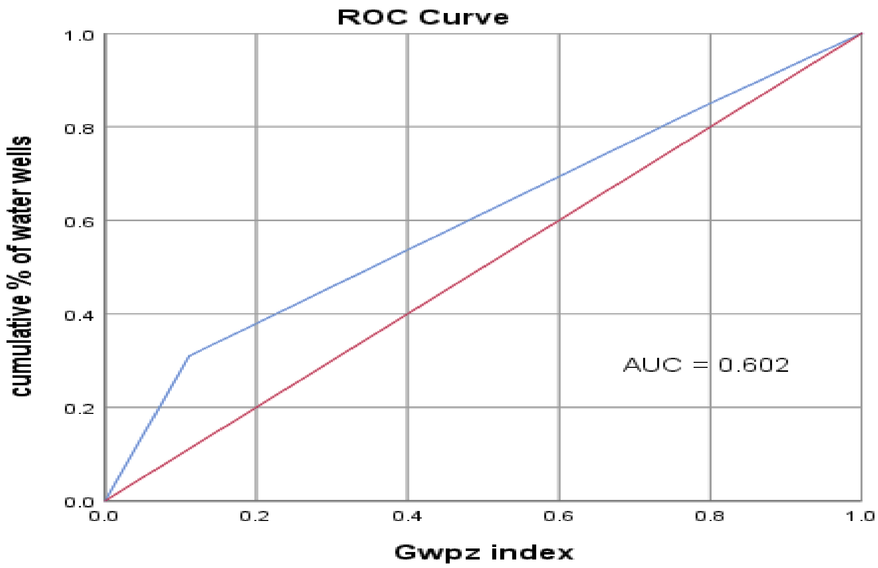

Fig. 18. Receiver operating curve and area under curve

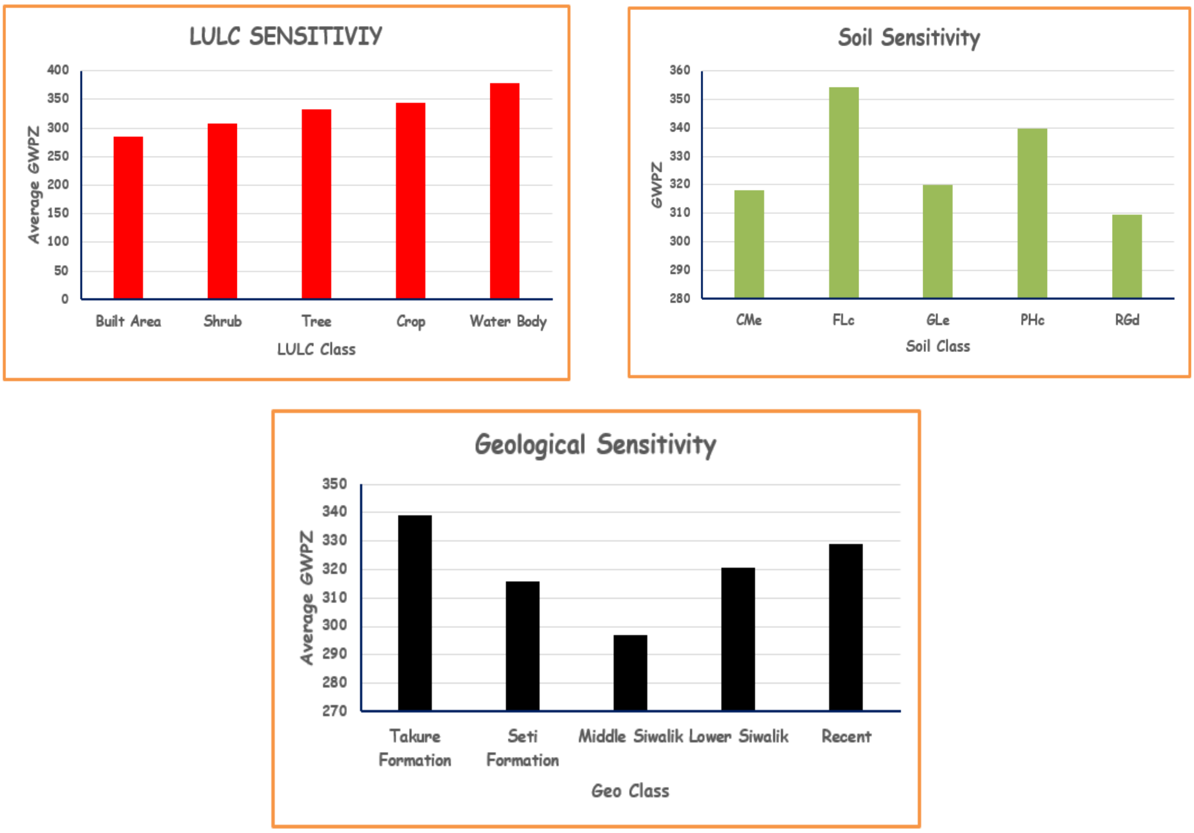

Fig. 19. Relation of categorical Classes with GWPZ

The analysis showed that the area under the ROC curve was found to be 0.602 which is greater than 0.5(Null hypothesis) that shows the AHP tool is capable of predicting the GW.

3.4 Sensitivity of Groundwater Potential to Influencing Parameters

The relation of each influencing criteria with simulated groundwater potential index is checked

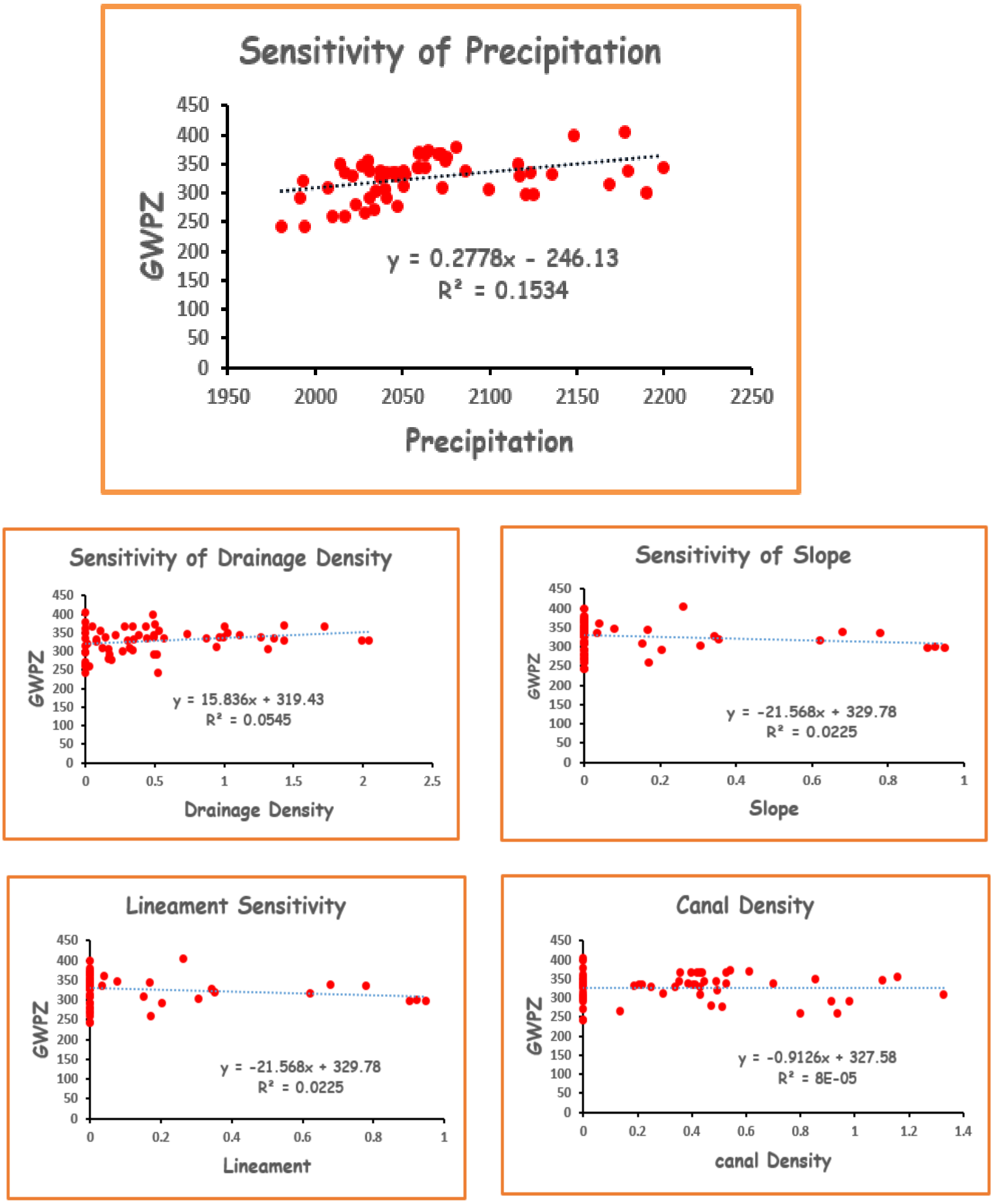

Fig. 20. Scatterplot of criteria with GWZ

with scatter plot for criteria like rainfall, densities, and slope and with bar chart for categorical data like LULC, Geological class, and Soil classes.

For the criteria with categorical classes, the average value of the GWPZ index value represented by respective classes of each criterion like LULC, geo classes, and soil classes was plotted as a bar chart.

For the scatterplot, 60 points representing every part of the study area were chosen and respective values of precipitation, slope and densities map were extracted. These values were plotted against the GWPZ index values of the simulated map.

The Sensitivity analysis showed that LULC, Precipitation, and slope factor are more sensitive and GWPZ determining factors in this study. The effect of other factors like drainage density, lineament, and geology seems to have been neutralized with the above dominating criteria as shown by the relation of each criterion with the GWPZ index of the final produced map.

4. CONCLUSION

Delineation of the groundwater potential zone in Sunsari District using AHP and geospatial techniques with the help of existing and remotely sensed geospatial data was found to be very effective in terms of reducing time, costs, efficiency, and manpower, allowing proper groundwater resource management and development. Rain, Slope, LULC, Geology, Canal density, Lineament density, soil, and drainage density, with score weights of 32.97 percent, 23.65 percent, 19.17 percent, 8.86 percent, 7.47 percent, 4.70 percent, 2.38 percent, and 1.79 percent, respectively, were combined to account for the occurrence and movement of groundwater.

The final groundwater potential zone map revealed that the study area has “Poor” groundwater potential (13.61 percent of the area), “Moderate” groundwater potential (35.95 percent of the area), and “Good” groundwater potential (50.44 percent of the area). We get a normalized range for groundwater potential index as 0 -0.36 for Poor, 0.36 -0.55 for moderate, and 0.55 – 1.0 for good groundwater potential zones.

The effect of canal density in the highly developed area was negated by land use weight, whereas the agricultural area had moderate to good groundwater potential. The built-up area has fallen into the poor zone, whereas agriculture has remained in the moderate to good zone, demonstrating good coherence with the GWP index. Except for severely built-up areas, much of the plain region with a mild slope, recent geology, sandy loam soil, and extensive cropland showed good potential. The Siwalik range revealed a moderate to good potential zone. Due to the recharging ability of the Bhavar zone, Dharan, despite being severely built-up, showed moderate potential. The north extreme steep area, on the other hand, showed little potential.

The final predicted GWPZ map was validated with ground truth data using a confusion matrix with a kappa coefficient of 0.603 and overall accuracy of 70%, as well as a scatterplot of GWPZ index and observed spatial groundwater well depths (b.g.l) with r^2 of 0.394 and receiver operating curve (ROC) with the area under the curve (AUC) of 0.602, demonstrating fair predictability of the AHP integrated model of predicting GWPZ.

The groundwater potential map is delineated to show areas with a higher potential for groundwater development as well as areas with a lower potential for groundwater development within the geographic location of the study area in a simple way so that it can be readily understood by anyone without an advanced scientific background; however, developing such precise potential maps requires intense knowledge. The findings could be used as a starting point for identifying potential groundwater resource exploration or exploitation areas. The analysis of groundwater potential in specific places is critical, but further research is required to ensure its reliability. Furthermore, investigations on the quality and suitability for various activities including drinking, agriculture, and industry can be conducted. As a result, future research should include a quantitative analysis of groundwater recharge.

Thus this research also paved the trail for further research and study of precise groundwater potential mapping including bore log lithological data and also combining geophysical methods of groundwater explorations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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