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A CASE STUDY OF GROUNDWATER RECHARGE POTENTIAL IN CHITWAN DISTRICT BY USING MULTI CRITERIA DECISION MAKING APPROACH

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ABSTRACT

Groundwater recharge process is crucial for maintaining the water balance in an area and securing sustainable water supply for drinking, agriculture and industrial purposes and it is also very necessary for the management of both surface and subsurface water resources. The calculation and estimation of groundwater recharge is the way to understand the groundwater reservoir and forecast its potential accessibility. In this study, the effectiveness of the Geographic Information System (GIS)-based Multi Criteria Decision-Making (MCDM) analytic hierarchy process (AHP) as a spatial prediction tool was utilized in exploring the groundwater recharge potential of the Chitwan District. Various aspects of earth surface features such as geology, geomorphology, soil types, land use and land cover, slope, aspect, precipitation, population density, elevation, Lineament density, Drainage density etc. are taken in consideration that influence the groundwater recharge in either direct or indirect way. These thematic layers are prepared and extracted using population data, Landsat 8 image, topographical map, and various other data sources. Weighted analysis and union of data obtained is used for formation of recharge map in this study. A pair-wise matrix analytical method is used to calculate the weightage of layers and are mathematically overlaid for preparation of groundwater recharge potential zone map of Chitwan District. The result reveals that around 78.9 sq. km (3.57%) of total area has been identified as high potential zone for groundwater recharge. The forest areas in central part and south western part of the district have high potential for groundwater recharge. Hilly and mountain terrains in north Mahabharata range are considered as unsuitable zone with very low groundwater recharge potential.

Keywords: Remote Sensing, Analytic Heirarchy Process, Lineament Density, Thematic Layers.

1. INTRODUCTION

In the current global context, the availability of groundwater is steadily decreasing due to excessive extraction compared to the recharge dynamics, and inadequate groundwater management practices. This has led to a worldwide scarcity of fresh groundwater resources. Therefore, it becomes crucial to comprehend the methods and approaches for groundwater recharge and surface water conservation to enhance groundwater levels at the national, regional, and local scales, thereby ensuring sustainable livelihoods (Kaliraj, Chandrasekar, & Magesh, 2014). Some region, have abundant groundwater resources, while others are experiencing significant challenges due to overuse, contamination, or other issues. According to the United Nations (https://www.un.org/waterforlifedecade/scarcity.shtml), by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions which is due to population growth, urbanization, climate change, unsustainable water management practices. According to Wada et al. (2017) groundwater provides around 25% of the world's total freshwater consumption providing drinking water to over 2 billion people and supporting irrigation for approximately 40% of global food production. Similarly, UN (2022) water summit, the world's demand for freshwater is expected to exceed supply by 40% by 2030 highlighting need of sustainable water management practice.

Nepal National Water Plan (WECS, 2005) estimates that about 756 million cubic metres (MCM) of groundwater resources are being used for irrigation purposes and 297 MCM for domestic uses in Nepal. Groundwater impacts the socio-economic health of the urban areas. The urbanization process affects the quality and quantity of groundwater. Due to the population growth, forest is converting into agricultural land, residential area, supermarket etc. People use high amount of chemical fertilizer and pesticides in farming which contaminates the groundwater as well as surface water. Such a change has affect directly or indirectly on the socio-economic conditions as well as eco-environment of the surroundings, one of the fastest growing urbanization location in Nepal. Pandey and Neupane (2017) provides the information of total groundwater abstraction in Chitwan district is around 56 million cubic meters per year, with the majority of this groundwater use (around 85%) for irrigation purposes and remaining 15% used for domestic and industrial purposes. According to Bhandari et al., (2016), the groundwater level in the western district has been declining at average water level fluctuation rate of 2.34 meter per year due to over-extraction, particularly in the dry season. Due to rapid urbanization the catchment is resulting in increase in run-off and decrease in groundwater recharge (Thapa et.al., 2018). Groundwater level is depleting due to the combination of land use /cover (LULC) change and excessive pumping. Hence due to population growth and urbanization the demand of water is increasing day by day. We cannot mitigate the extraction of groundwater but we can balance through recharge of groundwater. We have to increase the recharge in the location which has high capacity to infiltrate and hold groundwater, but still nobody knows the exact location which has high potential to have groundwater recharge. According to the Nepal National Water Plan (WECS, 2005), Inner terai areas such as Chitwan, Dang and Surkhet are also estimated to hold good groundwater potential. So, many studies have been done in national and international level in groundwater recharge potential mapping. In Nepal, several studies have been conducted in Kathmandu Valley, including a study by Lamichhane & Shakya, (2021) that assessed the alteration of groundwater recharge areas due to land use/cover (LULC) change in Kathmandu valley, Nepal. A study by Shrestha (2020) assessed the Groundwater Recharge Potential Mapping in Far Western Middle Mountain of Nepal: A GIS-based Approach. (Kaliraj et al., 2014) assessed the identification of potential groundwater recharge zones in Verigas Upper Basin, Tamil Nadu, and using GIS based analytical hierarchical process (AHP) techniques.

In the study of Chitwan on ground water recharge potential mapping (Neupane & Shrestha, (1970); Bhandari et al., (2016)) considered various parameters such as: land use land cover, soil, slope, rainfall, drainage and geology. The study used data from multiple sources including remote sensing images and geographic information system (GIS) data to map the recharge potential. The authors identified that the recharge potential is higher in areas with sandy soils, low slopes, higher rainfall, forest cover and areas with impermeable soils, high slope and urban or agricultural land use has lower recharge potential.

Our study mainly focuses on identifying and mapping areas with high potential for ground water recharge along with the objectives including generation of thematic layer maps for every factor affecting groundwater recharge potential, identification of layers and its weightage influencing recharge potential and delineation of ground water recharge potential zones. This study mainly focuses on evaluating hydrological characteristics of the study area, determining climate and precipitation patterns, assessing LULC of the study area for the mapping of groundwater recharge potential zone and identifying zone with high recharge potential. (Removed) In the present study, we have used nine layers for weightage purpose and these layers have been assigned with appropriate weightage using AHP analysis. This approach is more reliable in delineation of ground water potential zones as these concept deals with systematic allocation of weights through AHP method and weighted overlay analysis technique in GIS platform.

2. STUDY AREA

Nestled in the heart of Nepal, our study area covers a vast expanse of 2,238.39 sq. km in the central part of country (see Figure 1). With diverse elevations ranging from the southern Terai at 100 meters to the northern district at over 2,000 meters, the landscape is a charming mix of low-lying plains, rolling hills, and majestic ranges. Notably, the UNESCO-designated Chitwan National Park adds to the allure with elevations ranging from 150 to 815 meters. Exploring the geology, the southern part features the Terai Alluvial Plain, a picturesque zone with lush forests and agricultural lands. In contrast, the northern Siwalik Range zone boasts low hills with sedimentary rocks, while the Mahabharata Range to the north showcases metamorphic and igneous rocks. The subtropical climate brings warm summers and mild winters, influenced by the nearby Indian plains and the protective Himalayan range. Average annual temperatures range from approximately 17.8 °C to 30.88 °C, with a mean temperature around 24.4 °C (Bajracharya et.al, 2023) with an annual rainfall of around 2,500 mm, mostly during the monsoon season (https://en.climate-data.org/) embracing the area with a comforting 80% of the total annual rainfall. The Narayani River, Rapti River, Reu River, and Bis Hazari Tal contribute to the liquid beauty of the area. Groundwater, a reliable companion, flows through traditional recharge locations and open lands, including the cherished national park.

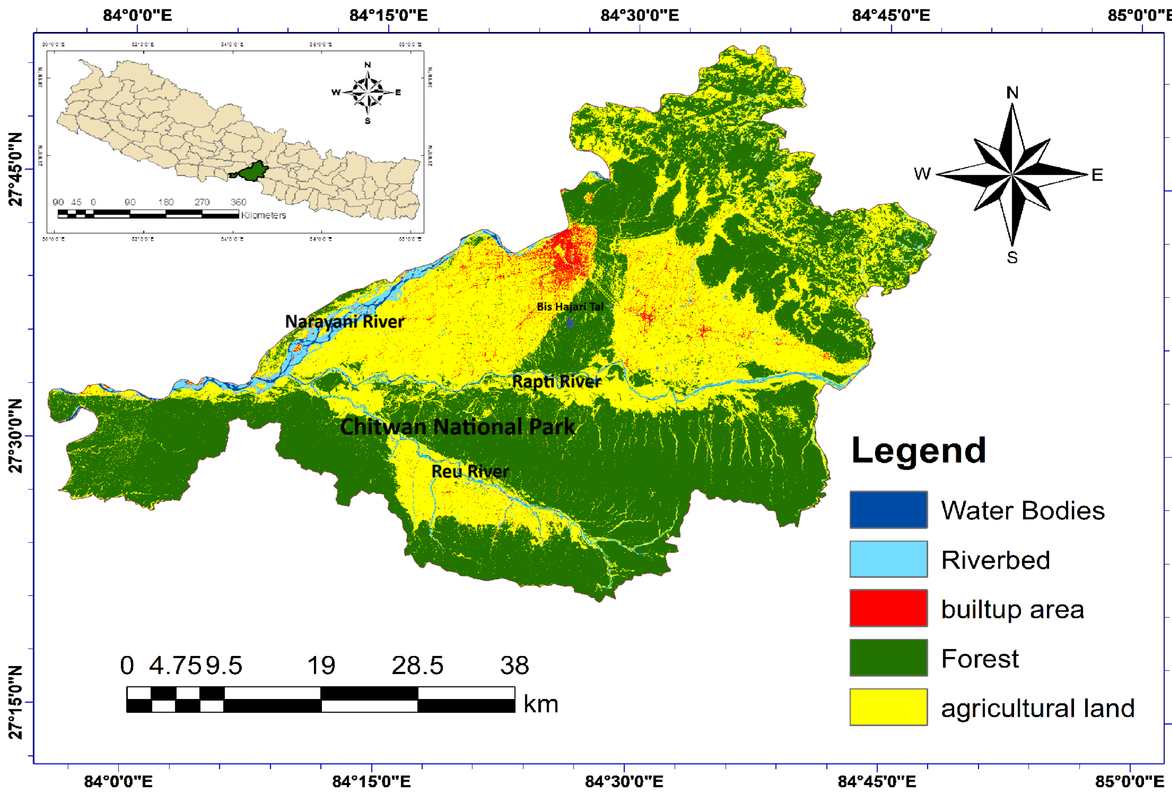

Figure 1 Land Use Land Cover with Water Bodies of Chitwan District

3. Materials and Methods

In the real time data scarce region specially in the groundwater information such type of methodological frame (Figure 2) shows for the delineation of groundwater recharge potential zone which involves selection of factors influencing groundwater recharge potential, collection of thematic data, preparation of various thematic layers map, MCDM analysis for weightage and finally delineation of groundwater recharge potential.

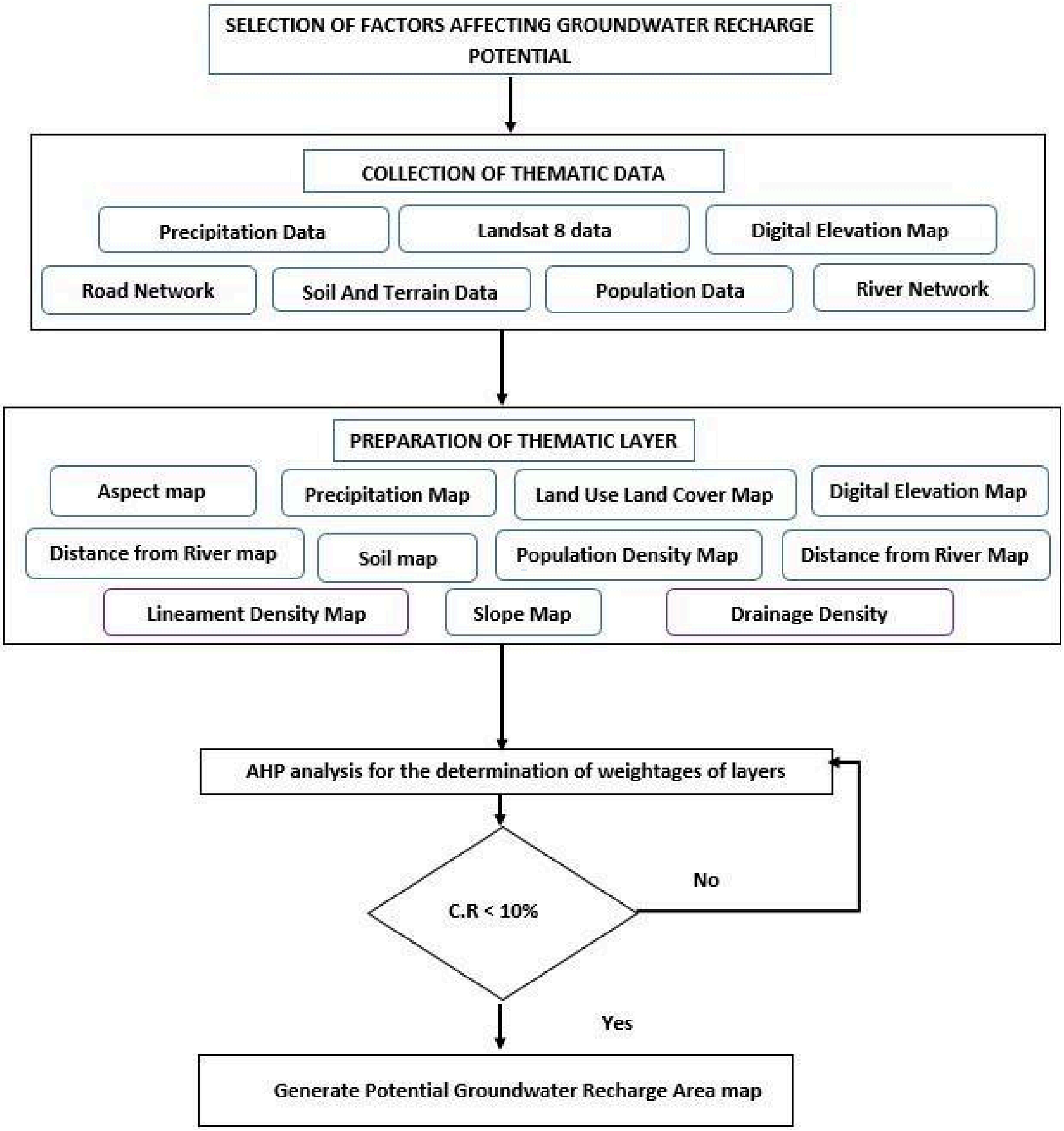

Figure 2 Methodological framework

3.1 Selection of Factors Influencing Groundwater Recharge Potential

Groundwater recharge potential is a critical factor in sustainable water resource management as it determines the recharge potential of various zones in area and various studies have investigated the influencing factors for identifying groundwater recharge potential zones which described various factors to affect groundwater recharge potential including Geology/Lithology, Geomorphology, Soil Texture, Digital Elevation Model, Slope, Rainfall, Drainage Density, Lineament Density, Topographic Wetness Index, Land Use Land Cover, Water Table Depth, Distance From Road, Distance From River, Aspect, Population Density. Considering the reliability and availability of required data Major contributing factors are selected.

3.2 Data Sources

The process of acquiring and analyzing thematic data's includes Landsat 8 images as land use and land cover data from the USGS Earth Explorer platform, soil data from soil and terrain database (SOTER), elevation data from Advanced Land Observing Satellite Phased Array L-Band Synthetic Aperture Radar(ALOS PALSAR) Data using Alaska Satellite Facility(ASF) Data Search Vertex (‘search.asf.Alaska.edu\#\), population data obtained from national statistical agency, Rainfall data obtained from Department of Hydrology and Meteorology (DHM), River network data and Road network data obtained from International Centre for Integrated Mountain Development (ICIMOD IRDS) (‘https: rds.icimod.org’) as described in table no .

Table 1: List of the different data used in this study, including information on spatial resolution and data sources.

Thematic Layers	Resolution	Data and Sources
LULC Layer map	12.5m	Generated from Landsat 8 Image from United States Geological Survey (USGS) earth explorer platform
Soil Map		Soil data from Soil and Terrain database (SOTER)
Digital Elevation Map	12.5m	Elevation data from ALOS PALSAR Data using ASF Data Search Vertex
Slope Map	12.5m	Elevation data from ALOS PALSAR Data using ASF Data Search Vertex
Aspect Map	12.5m	Elevation data from ALOS PALSAR Data using ASF Data Search Vertex
Population Map		Population data from National Statistical Agency
Precipitation Map	12.5m	Rainfall data from Department of Hydrology and Meteorology (DHM)
Distance from River Map	12.5m	River network data obtained from ICIMOD IRDS (‘https: rds.icimod.org’).
Distance from Road Map	12.5m	Road network data obtained from ICIMOD IRDS (‘https: rds.icimod.org’).
Lineament Density Map	12.5m	Generated from ALOS palsar data and Landsat Image
Drainage Density Map	12.5m	River network data obtained from ICIMOD IRDS (‘https: rds.icimod.org’).

3.3 Preparation of thematic maps

By processing various obtained thematic data's for factors affecting groundwater recharge potential using GIS tools various thematic maps were prepared in same resolution. The acquired data was cleaned and preprocessed to ensure its quality and compatibility with GIS software removing duplicates, correcting errors, projecting data to a consistent coordinate system, ensuring data contains attribute information related to chosen theme to prepare thematic map. The attribute data of thematic map is classified to create meaningful categories or classes for analysis.

3.4 Selection of approach

It was observed that the mapping of groundwater recharge potential was predominantly influenced by several factors, which was discovered to not contribute equally to groundwater recharge. As various factors have various weightage for influencing groundwater recharge potential thus a proper calculation of weightage for factors is important which is to be done by Multi Criteria Decision Method (MCDM) including techniques like Weighted Sum Models, Dominance-Based Approaches, Outranking Methods, Fuzzy Set Theory, Data Envelopment Analysis (DEA), Utility Theory. Saaty, (1988) Analytic Hierarchy Process (AHP) is a widely used utility-based multi-criteria decision-making technique which involves decomposing the decision problem into a hierarchy of multiple criteria and sub-criteria in the decision-making process attributed to its flexibility, transparency, consistency, and ease of use which has been applied in various fields, including groundwater management. Several research articles have demonstrated the effectiveness of AHP in groundwater recharge potential analysis. Shrestha,et al., (2020) used AHP to assess the suitability of different sites for artificial groundwater recharge in Iran. The study found that AHP can help in the selection of appropriate recharge sites and improve the efficiency of recharge operations.. Palaka & Jai Sankar, (2015) investigated the Kosigi Mandala in Kurnool District, India, to evaluate the recharge potential using AHP Method. The study found that AHP can provide a reliable and efficient method for identifying potential recharge sites in the regions. Numerous research articles have demonstrated its effectiveness in this field attributed to its flexibility, transparency, consistency, and ease of use thus selection of AHP method is performed in our project for analysis as AHP allows for the incorporation of multiple criteria and sub-criteria in the decision-making process. This approach involves assessing the geometric mean (Eq. 1) and assigning normalized weights (Eq.2) to various parameters to facilitate the decision-making process. The interrelatedness of different parameters with groundwater recharge was integrated to form a cluster of relationships (Yu, Liu, Meng, Wu, & Rishe, 2002).

Geometric mean = *Eq. (1)*

Normalized weight = *Eq. (2)*

The normalized weighted map serves as an indicator of potential groundwater recharge zones that have been classified into five categories ranging from very high to unsuitable zones. The class with the highest weight is regarded as a very high suitable zone for groundwater recharge, while the least weighted class is considered less or unsuitable for groundwater recharge. All parameters were assigned a suitable weight and integrated with the geometric mean of the corresponding layer to obtain the normalized weighted output. The assigned weights and the normalized weights of individual parameters are critical in determining the potential zones for groundwater recharge.

3.5 Data standardization

To utilize each thematic layer in the study, each grid of the thematic layers is assigned a unique value. The standardization process is then applied to convert these values into dimensionless values that can be compared across layers. The standardization process involves using equations (3 and 4) below, which ensure that larger values indicate better conditions and smaller values indicate worse conditions for each grid in the thematic layers (Pei-Yue, Hui, & Jian-Hua, 2010)

Standardization used for larger the better: y_i = Eq. (3)

Standardization used for larger the better: y_i = *Eq. (4)*

Where, y_i is the standardized value of the thematic grid and i is the index of thematic grid and x_i, $x_{i,max}$, $x_{i,min}$ are the original, maximum and minimum values of the thematic grids respectively.

3.6 Calculation of the Ground Water Potential Recharge Area (GWPRA) index

To obtain a single score for potential recharge area, all the thematic layers were integrated in GIS using Eq. 5 (Malczewski, 1999). The high potential recharge zone was determined by computing the sum of the product of each weight and its corresponding grid value (Jhariya, et.al., (2016). The assigned values in each layer grid, as well as the weight factor of each layer, were used to calculate the theoretical potential recharge areas. The higher the value of the grid, the higher the potential for recharge, and vice versa.

$$GWPRA = \Sigma \qquad \text{Eq. (5)}$$

Where xi represents the normalized weight of the i^{th} class of the thematic layer, w_j is the weight derived from AHP of the j^{th} thematic layer, m is the total number of thematic layers, and n is the total number of classes in the thematic layer.

4.0 RESULTS AND DISCUSSION

4.1 Selection of Factors Influencing Groundwater Recharge Potential

Table 2: Selection of layers

Literature Review	G	GM	Ste	DEM	S	R	DD	LD	TWI	LULC	WTD	DFRo	DFRi	A	PD
Region and Duguma (2022)	✔	✔	✔	✔	✔	✔	✔	✔		✔					
Bhattarai and Ghimire (2023)	✔		✔	✔	✔	✔	✔		✔	✔			✔	✔	
Shrestha (2020)	✔				✔	✔	✔	✔		✔					
(Kaliraj et al., 2014)	✔	✔			✔	✔	✔	✔		✔					
Eko and Rustanto (2020)	✔		✔	✔	✔	✔	✔			✔					
Palaka and Jai Sankar (2015)		✔					✔	✔		✔					
(Allafta, Opp, & Patra, 2021)	✔	✔			✔		✔	✔		✔			✔		
(Bhave, Katpatal, & Pophare, 2019)	✔	✔			✔			✔		✔					
Lakshmi and Reddy (2018)	✔	✔				✔	✔			✔					
(Allafta et al., 2021)	✔	✔	✔	✔	✔	✔	✔			✔	✔				
(Arulbalaji, Padmalal, & Sreelash, 2019)	✔	✔	✔		✔	✔	✔	✔	✔	✔					
(Lamichhane & Shakya, 2019a)	✔			✔	✔	✔				✔		✔	✔	✔	✔
Our Selection	✔			✔	✔	✔				✔		✔	✔	✔	✔

G- Geology/Lithology, GM- Geomorphology, STe- Soil Texture, DEM- Digital Elevation Model, S- Slope, R- Rainfall, DD- Drainage Density, LD- Lineament Density, TWI- Topographic Wetness Index, LULC- Land Use Land Cover, WTD- Water Table Depth, DFRo- Distance From Road, DFRi- Distance From River, A- Aspect, PD- Population Density

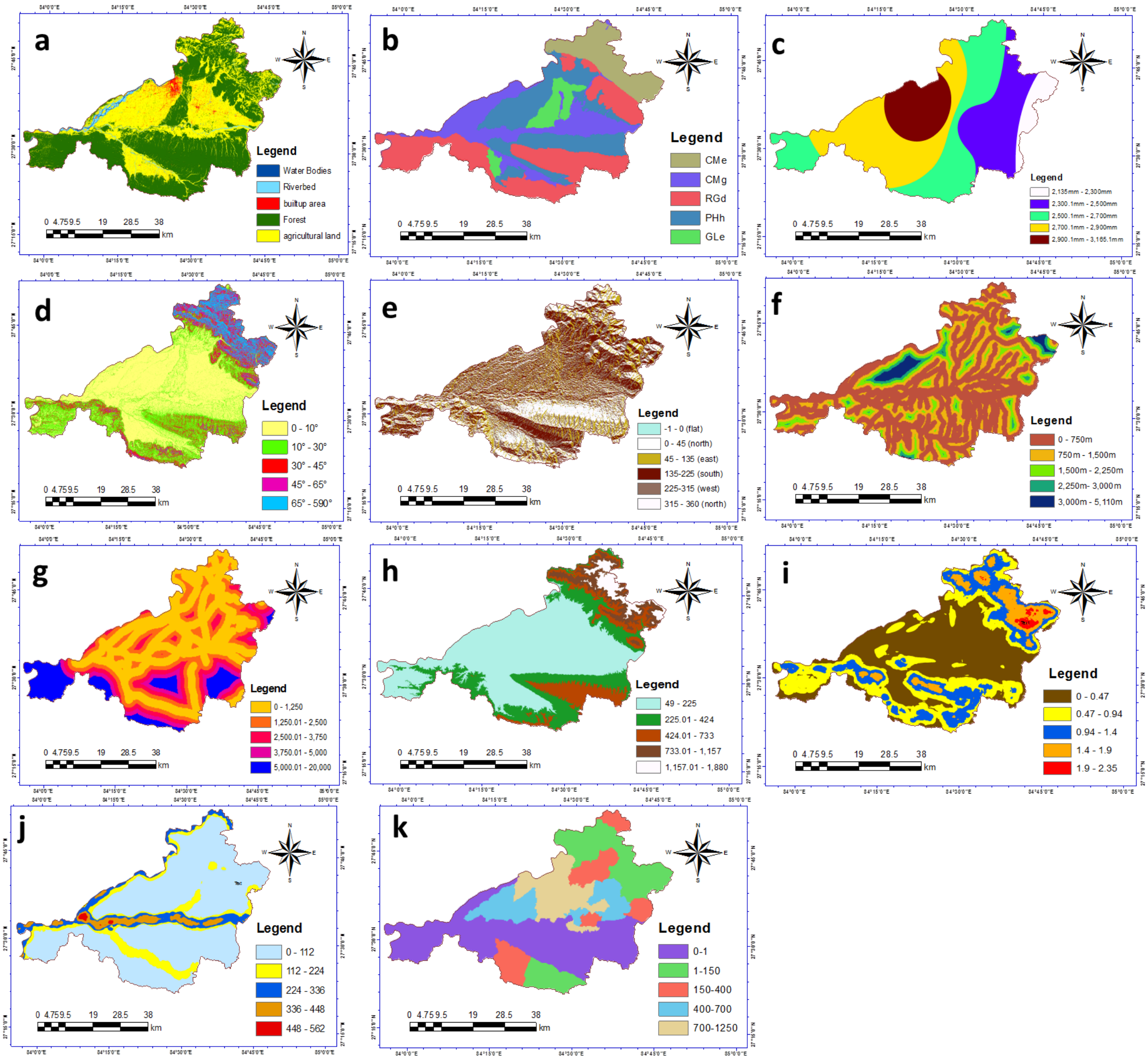

Figure 3: Map of a) Land use land cover b) Geological/Soil type c) Precipitation d) Slope e) Aspect f) Distance from river g) Distance from road h) Digital elevation model i) Lineament density j) Drainage density k) Population density

The various of studies (Region and Duguma (2022); Bhattarai and Ghimire (2023); Shrestha (2020); Kaliraj et al. (2014); Palaka and Jai Sankar (2015); Allafta et al. (2021) ,Bhave et al. (2019); Lakshmi and Reddy (2018); Çelik (2019); Lamichhane and Shakya (2019)) were consider the various of parameter as per the data availability and lined to the groundwater recharge dynamics as listed as the Table 2. Sources, length, reliability, and accuracy of data and the available tools for the analysis are the key indicator for the analysis. Considering all the factors selected by various researches for influencing groundwater recharge potential we selected the major factors including LULC, Type of soils, Elevation, Slope, Aspect, Distance from river, Distance from road, Population Density, Rainfall / Precipitation contributing for groundwater recharge potential.

4.1.1 Analysis of LULC map

The Land Use/Land Cover (LULC) map, a GIS-based representation, delineates the diverse extent, distribution, and composition of land uses and covers within a specific area. This map plays a pivotal role in evaluating runoff, infiltration, and groundwater recharge capabilities in watersheds or sub-basins, offering essential soil information such as soil moisture content, groundwater, surface water, and a preview of groundwater potential. The LULC map, covering an expanse of 2,238.39 square kilometers, was meticulously crafted using Landsat 8 imagery sourced from USGS Earth Explorer and processed with ArcGIS at a resolution of 30m x 30m. Figure 3(a) vividly illustrates the land use and land cover patterns, enumerating various land classes (Lamichhane & Shakya, 2020). Notably, forests, encompassing Sal, Pine, and Tropical Deciduous varieties, emerge as the predominant land use, covering almost 55.71% of the region (1,236.37 square kilometers) and contributing significantly to the high recharge potential. Agricultural lands, comprising cultivated areas, grasslands, pastures, and various croplands, constitute the second most dominant factor, occupying 39.3% of the total area (872.210 square kilometers) and playing a crucial role in recharge potential. Built-up areas, including urban and developed zones, make up 1.72% of the total area (38.29 square kilometers), with densely populated regions such as Bharatpur, Ratnanagar, and Khairahani exhibiting high population density but low recharge capacity. River beds, covering 2.57% of the total area (57.14 square kilometers), and water bodies, encompassing lakes, ponds, and rivers like Narayani River and Rapti River, constitute 0.70% of the total area (15.49 square kilometers) with a lower recharge potential.

4.1.2 Analysis of soil map

The soil map of Nepal, sourced from the Soil and Terrain (SOTER) Database in ISRIC World Soil Information, provides valuable insights into the soil characteristics of the region. Soil texture, a key determinant, influences various soil properties such as moisture content, infiltration rate, hydraulic conductivity, permeability, grain size, and specific composition, all of which collectively impact recharge potential. The proportions of sand, silt, and clay in the soil play a crucial role in determining the rate at which water infiltrates the soil and contributes to groundwater recharge. Notably, porous media, such as sand and gravel, exhibit higher recharge potential compared to less or nonporous media, as emphasized by Rukundo and Dogan (2019). Figure 3(b) illustrates the diverse soil types present in the area, with five dominant types identified as Eutric combisols (CMe), Gleyic combisols (CMg), Dystric Regosols (RGd), Haplic phaeozems (PHh), and Eutric Gleysols (Gle). Table number provides a comprehensive overview of the distribution of these soil types and their respective contributions to groundwater recharge potential. Dystric Regosols (RGd) emerge as the dominant soil type in Chitwan district, covering approximately 32.77% (734.5 sq. km) of the total area. These soils exhibit low water-holding capacity and poor infiltration rates, thereby limiting groundwater recharge potential. Following closely are Haplic phaeozems (PHh) with 25.55% (572.6 sq. km) of total area coverage, characterized by a moderate to high groundwater recharge potential. Gleyic Cambisols (CMg), constituting approximately 21.77% (487.97 sq. km) of the total area, have the potential to become waterlogged and exhibit limited recharge potential. Eutric Cambisols (CMe), occupying about 13.65% (305.93 sq. km) of the total area, demonstrate a moderate to high groundwater recharge potential. Eutric Gleysols (Gle), covering 6.25% (140 sq. km) of the total area, exhibit a moderate groundwater recharge potential. This detailed analysis provides valuable information about the soil composition in Chitwan district, enabling a deeper understanding of groundwater recharge potential across different soil types.

4.1.3 Analysis of Precipitation map

Rainfall is super important for refilling underground water, and our research looked at how it affects groundwater in our area. We made a Precipitation map using yearly rainfall data from weather stations. This map shows how rainfall seeps into the ground and refills the underground water storage (aquifer). More intense and frequent rainfall usually means more water refilling underground. In Figure 3(c), we see the distribution of rainfall intensity across the area, ranging from 2135 mm to 3165.1 mm. We divided the rainfall into five classes (Lamichhane et.al., 2020), like categories, such as 2135.6mm - 2341.5mm covering 7.6% of the total area, 2341.6mm - 2547.4mm covering 25.6%, 2547.5mm - 2753.3mm covering 32.66%, 2753.4mm - 2959.2mm covering 24.86%, and 2959.3mm - 3165.1mm covering 9.25%. Our map shows where the rainfall is intense or not. The areas with high intensity have a good chance of refilling underground water, while low-intensity areas might not recharge as much. Understanding this helps us know where groundwater can be replenished more effectively.

4.1.4 Analysis of Slope map

Slope is about how steep or flat the ground is. It's essential for understanding how water moves on the surface and gets into the ground. Gentle slopes let water soak in more, while steep slopes make water rush over the surface, reducing how much goes into the ground. Our Slope map Figure 3 (d), made from Digital Elevation Map data, shows that around 76.79% of the area has gentle slopes (0° to 30°), which are great for groundwater recharge. Steeper slopes, greater than 45°, cover about 14.29% of the area, and on these, water flows quickly, reducing chances for infiltration and recharge.

Different parts of Chitwan, like the Chure range, Siwalik hills, and Mahabharata range, have steep slopes and, as a result, lower groundwater recharge potential. However, the flat plains in the district have higher potential for groundwater recharge. Understanding slope helps us know where water is likely to soak into the ground, benefiting groundwater recharge in certain areas.

4.1.5 Analysis of Aspect map

Aspect is like the way a slope faces, from flat (0 degrees) to north (90 degrees), east (180 degrees), south (270 degrees), and west (360 degrees). It's crucial because it affects how much sunlight a slope gets, making east and south-facing areas drier with less recharge potential. We used a Digital Elevation Map (DEM) to create an Aspect map, showing slope orientations. Figure 3(e) displays the map with five orientations: flat, north, east, south, and west. South-facing slopes get more sunlight, leading to less water soaking in, while north and west orientations have higher recharge potential. North orientation, especially, reduces evaporation losses because it gets less sunlight. So, areas facing north or west have more recharge potential, and flat zones are better for water infiltration than other orientations.

4.1.6 Analysis of Distance from river map

The map in Figure 3(f) illustrates the river network and distances from the river, created using the Euclidean distance concept. We measured the distance from the river at intervals of 750 meters in each range. Generally, areas near the river have higher recharge potential compared to those farther away. This is because closer areas benefit from more water availability and soils with better water storage and infiltration rates. As you move away from the river, there's a decrease in recharge potential, and the vice versa holds true.

4.1.7 Analysis of Distance from Road map

In Figure 3(g), the road network and distance from the road map reveal insights into the district, employing the Euclidean distance concept at intervals of 1250 meters. Areas near roads are often utilized for construction and settlements. Roads and other non-porous surfaces contribute to higher surface runoff, causing issues like erosion and sedimentation, and reducing water available for groundwater recharge. Consequently, regions close to roads may exhibit lower groundwater recharge potential due to factors such as soil compaction, increased runoff, chemical contamination, and vegetation loss. However, moving away from roads reveals vacant lands that facilitate infiltration. Therefore, there's a rise in recharge potential with increased distance from roads and a decrease in potential as you get closer.

4.1.8 Analysis of Digital Elevation Map

In Figure 3(h), the Digital Elevation Map (DEM) is created from ALOS PALSAR Data using ASF Data Search Vertex. This map provides a digital representation of the elevation or relief of the district's terrain, measured in meters or feet above sea level. The map indicates the highest elevation in the Mahabharata Range at 1880 meters and the lowest elevation at 49 meters. Higher elevations are linked to steeper slopes and deeper valleys, which have a lower recharge rate. Conversely, flat/plain areas create opportunities for ponding, enhancing the potential for recharge, as discussed by Bashir et al. (2008).

4.1.9 Analysis of Lineament Density map

In Figure 3(i), the Lineament Density map is created by analyzing Hill shade map derived from the DEM Map processed from ALAS Palsar data using ASF Data Search Vertex. Lineaments, which are linear features like faults, fractures, ridges, or valleys, contribute to this map. Lineament density is a measure of the presence of these features, with high density indicating interconnected conduits that enhance water flow and permeability, resulting in high recharge potential. Conversely, low lineament density suggests lower recharge potential.

The lineament density classes in the study area, as depicted in Figure 3(i) and detailed in the accompanying table, range from 0 to 2.35 km/km². Notably, 44.5% of the total area (998 sq.km) falls within the low-density range of 0-0.47 km/km², carrying a weightage of about 4.2% in the overall lineament density layer. On the other hand, the high-density range (1.9-2.35 km/km²) covers 1.1% of the total area (24.36 sq.km), contributing significantly with a weightage of about 42% in the lineament density layer.

4.1.10 Analysis of Drainage Density map

The Drainage Density map, showcased in Figure 3(j), illustrates the total length of streams or channels per unit area in the study region, derived from the river network diagram obtained from ICIMOD. A higher drainage density suggests a well-developed and interconnected network of streams and channels. In areas with elevated drainage density, surface runoff becomes dominant, limiting groundwater recharge, as water swiftly moves through channels without sufficient time for infiltration. Examining Figure 3(j) and the accompanying table, the drainage density classes range from 0 to 2.35 km/km². Approximately 44.5% of the total area (998 sq.km) falls within the low-density range of 0-0.47 km/km², representing a minimal weightage of about 4.2% in the overall drainage density layer. Conversely, the high-density range (1.9-2.35 km/km²) covers 1.1% of the total area (24.36 sq.km), contributing significantly with a weightage of about 42% in the drainage density layer.

4.1.12 Analysis of Population density

The Population Density map, depicted in Figure 3(k), illustrates the distribution of population across district, utilizing population data to highlight densely and sparsely populated areas. Densely populated regions, such as Bharatpur Municipality (with a population of 2,03,066), Ratnanagar Municipality (56,000), Khairahani Municipality (48,000), and Kalika Municipality (36,000), exhibit a higher concentration of impermeable surfaces like roads and buildings. This urbanization reduces water infiltration into the soil, resulting in lower groundwater recharge potential. Conversely, Chitwan National Park, with lower population density, contributes to higher recharge potential. The map classifies population density into five categories: 0, 0-150, 150-450, 450-700, and 700-1234 individuals per square kilometer. As population density increases, there is a rise in land demand for housing, commercial, and industrial purposes, leading to changes in land use patterns like deforestation and urbanization. These changes can diminish rainfall infiltration into the soil, affecting the aquifer and causing a reduction in recharge potential.

4.2 Normalized matrix and consistency ratio

The study involves the validation of AHP model by obtaining the normalized matrix to convert the raw comparison values into a set of weights that reflect the relative importance of each criterion or alternative in relation to others and calculating the consistency ratio which serves as a measure of the reliability of the judgments made by the decision-maker during the pairwise comparisons (Saaty, 2004).

Table 3: Selection of layers

Indexes	LULC	ST	PPT	Slope	Asp	DFRi	DFRo	PD	Elev	LD	DD	W(%)
LULC	**1.00**	0.50	0.33	4.00	3.00	2.00	7.00	3.00	3.00	0.33	0.50	8.95
ST	2.00	**1.00**	0.50	3.00	5.00	3.00	7.00	7.00	6.00	0.50	1.00	13.51
PPT	3.00	2.00	**1.00**	5.00	7.00	3.00	9.00	9.00	7.00	1.00	2.00	20.78
Slope	0.25	0.33	0.20	**1.00**	2.00	0.50	5.00	7.00	3.00	0.20	0.33	5.57
Asp	0.33	0.20	0.14	0.50	**1.00**	0.25	3.00	3.00	2.00	0.14	0.20	3.30
RD	0.50	0.33	0.33	2.00	4.00	**1.00**	3.00	7.00	5.00	0.33	0.33	7.57
DFRo	0.14	0.14	0.11	0.20	0.33	0.33	**1.00**	3.00	0.50	0.11	0.14	1.99
PD	0.33	0.14	0.11	0.14	0.33	0.14	0.33	**1.00**	0.50	0.11	0.14	1.57
Elev	0.33	0.17	0.14	0.33	0.50	0.20	2.00	2.00	**1.00**	0.14	0.17	2.46
LD	3.00	2.00	1.00	5.00	7.00	3.00	9.00	9.00	7.00	**1.00**	2.00	20.78
DD	2.00	1.00	0.50	3.00	5.00	3.00	7.00	7.00	6.00	0.50	**1.00**	13.51

LULC- Land Use Land Cover, ST – Soil Type, PPT - Precipitation, ASP – Aspect, DFRi - Distance From River, DFRo - Distance From Road, PD – Population Density, Ele – Elevation, LD - Lineament Density, DD - Drainage Density, W - Weightage, % - Percentage

A lower consistency ratio indicates more consistent judgments, which enhances the credibility and reliability of the decision process whereas high consistency ratio suggests inconsistency in the pairwise comparisons. The consistency ratio (CR) provides a threshold (10%) for acceptability. If the calculated CR exceeds this threshold, it indicates a potential issue with the consistency of judgments, and adjustments may be necessary. Table 3 presents the normalization and calculated consistency ratio to be 3.3% which is very low to the threshold of 10% enhancing the credibility and reliability of the decision process thus the obtained weightage for layers is accepted and processed.

4.3 Analysis of layers

The study involved preparing various layers and analyzing their impact on groundwater recharge, quantifying their relative importance through the Analytical Hierarchy Process (AHP) analysis, and ranking them based on expert judgment. Table 3 & 4 presents the calculated weightage of factors contributing to groundwater recharge potential, with precipitation receiving the highest weightage of 21.63%, while population density has the lowest at 2.01%. The Land Use/Land Cover (LULC) layer, with an AHP weightage of 14.22%, identifies forests as the major contributor, holding 47.87% weightage within the LULC layer, while water bodies contribute the least at 4.23%. The Type of Soil layer, with a weightage of 21.02%, designates Eutric Cambisols (CMe) as the most influential type, contributing 44.49%, while Dystric Regosols (RGd) has the least impact with 6.32%. The Precipitation layer, constituting 30.56% weightage, highlights that areas with maximum precipitation (2959.3mm-3165.1mm) contribute 45.3%, while those with minimum precipitation (2135.6mm-2341.5mm) contribute 5.1%. The Slope layer, with an 8.6% weightage, shows that areas with minimum slope (0-10) have the highest weightage of 42.06%, whereas those with the maximum slope (above 65) have the least at 4.16%. The Aspect layer, carrying a 5% weightage, reveals that flat areas have the highest weightage at 42.75%, while south-facing aspects have the lowest at 4.77%. The Distance from Road layer, with a weightage of 2.9%, indicates that areas farthest from roads (above 5000m) contribute 49.18%, while those closest (0-1250m) contribute 4.99%. The Population Density layer, with a 2.2% weightage, shows that areas with lower population density (0-1) contribute 43.31%, while those with higher density (above 700) contribute 4.38%. Finally, the Elevation layer, with an AHP weightage of 2.9%, illustrates that lower elevation ranges (49-225m) have the highest weightage at 41.85%, while the highest elevation range (1157-1880) has the least at 4.35%.

The research conducted an in-depth analysis of various recharge driving factors influencing groundwater recharge potential in district by using the Analytical Hierarchy Process (AHP) analysis, the study quantified the relative importance of different layers, ranking them accordingly. Precipitation emerged as the most influential factor with a weightage of 21.63%, while population density had the least impact at 2.01%. The Land Use/Land Cover (LULC) layer highlighted the dominance of forests, especially Eutric Cambisols, in recharge potential. The Type of Soil layer emphasized the significance of CMe soil type. Other layers, including slope, aspect, distance from road, population density, and elevation, were also analyzed, providing insights into their respective contributions to groundwater recharge potential. The study's comprehensive findings contribute to a nuanced understanding of district's hydrological dynamics and can inform sustainable water resource management practices in the region.

Table 4: Weightage first and second layer and ranks

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Rank	Area (Sq.km)	% of area
Type Of Soil	13.51	Cme	44.49	9	305.93	13.65
		Cmg	7.21	3	487.97	21.77
		Gle	11.18	5	140	6.25

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Rank	Area (Sq.km)	% of area
		PHh	30.8	7	572.6	25.55
		RGd	6.32	1	734.5	32.77
Land use	8.95	Water Bodies	4.23	3	15.49	0.7
		Riverbed	10.92	5	57.14	2.58
		Forest	47.87	9	38.28	1.72
		Agricultural Land	28.77	7	1236.37	55.7
		Built-up Areas	8.21	1	872.21	39.3
Precipitation (mm)	20.78	2135.6-2341.5	5.1	1	170.9	7.6
		2341.6-2547.4	7.75	3	575.34	25.6
		2547.5-2753.3	15.31	5	733.75	32.66
		2753.4-2959.2	26.54	7	558.44	24.86
		2959.3-3165.1	45.3	9	207.8	9.25
Slope (degree)	5.57	0-10	42.06	9	1136.01	50.75
		10.1-30	28.32	7	582.95	26.04
		30-45	17.44	5	199.215	8.9
		45-65	8.02	3	151.47	6.76
		65 above	4.16	1	168.632	7.53
Aspect	3.3	Flat	42.75	9	34.24	1.54
		North	29.5	7	638.255	28.68
		East	9.65	3	384.85	17.29
		South	4.77	1	619.018	27.82
		West	13.34	5	548.33	24.64
Distance from river (meter)	7.57	0-750	41.35	9	1308.02	58.3
		750-1500	28.99	7	591.46	26.37
		1500-2250	17.15	5	213.19	9.5
		2250-3000	7.61	3	73.41	3.27
		3000 above	4.9	1	56.52	2.52
Distance from road (meter)	1.99	0-1250	4.99	1	1047.04	46.69
		1250-2500	7.24	3	487.31	21.73
		2500-3750	14.74	5	254.64	11.35
		3750-5000	23.85	7	97.29	4.33
		5000 above	49.18	9	356.15	15.88
Population Density (per km^2)	1.57	0-10	43.31	9	889.48	39.66
		10-150	29.83	7	469.33	20.93
		150-450	15.43	5	305.10	13.6
		450-700	7.06	3	275.48	12.28
		700 above	4.38	1	302.85	13.5
Elevation (m)	2.46	49-225	41.85	9	1029.68	43.22
		225-424	28.61	7	718.00	30.14
		424-733	16.74	5	374.98	15.74
		733-1157	8.4	3	125.37	5.26
		1157-1880	4.35	1	134.23	5.63

Layers	Weightage of Layer (%)	Classification of layers	Weightage of classification (%)	Rank	Area (Sq.km)	% of area
Lineament density (km/km^2)	20.78	0-0.47	4.16	1	997.49	44.50
		0.47-0.94	8.02	3	646.09	28.82
		0.94-1.4	17.44	5	402.65	17.96
		1.4-1.9	28.32	7	171.10	7.63
		1.9-2.35	42.06	9	24.36	1.08
Drainage density (km/km^2)	13.51	0-2500	43.31	9	1372.86	61.36
		2500-5000	29.83	7	601.69	26.89
		5000-7500	15.43	5	189.87	8.49
		7500-10000	7.06	3	58.38	2.61
		10000 above	4.38	1	14.63	0.65

4.3 Ground water Recharge Potential map Analysis

The Groundwater Recharge Potential Map was created by analyzing 11 layers using the AHP method and GIS tools. This map visually represents the area's groundwater recharge capacity in five classes: very low, low, moderate, high, and very high. In the map, the Very low recharge potential zone (1-3) covers approximately 1.73% of the total area (38.8 Sq.km), while the Very high recharge potential zone (6-9) constitutes 3.52% of the total area (78.9 Sq.km).

The predominant recharge potential is in the moderate zone (3-6), encompassing about 94.75% of the total area (2120.76 Sq.km), with low recharge (3-4) covering 12.25%, moderate recharge (4-5) covering 39.45%, and high recharge (5-6) covering 43.03% of the total area (as per Table 5 & 6). Notably, areas with forests and alluvial soil deposits exhibit the highest recharge potential, while steeper mountain slopes have lower recharge potential.

Table 5: Groundwater recharge potential values ranges (Lamichhane & Shakya, 2019b).

Recharge potential value	Very low	Low	Moderate	High	Very high
	1.0 – 3.0	3.1 - 4.0	4.1 - 5.0	5.1 - 6.0	6.1 - 9.0

The comprehensive analysis of the Groundwater Recharge Potential Map offers a valuable insight into the hydrological intricacies and the map provides a holistic view of the groundwater dynamics. The predominant moderate recharge potential zone suggests a balance between factors influencing groundwater recharge, reflecting the region's complex interplay of natural and anthropogenic elements.

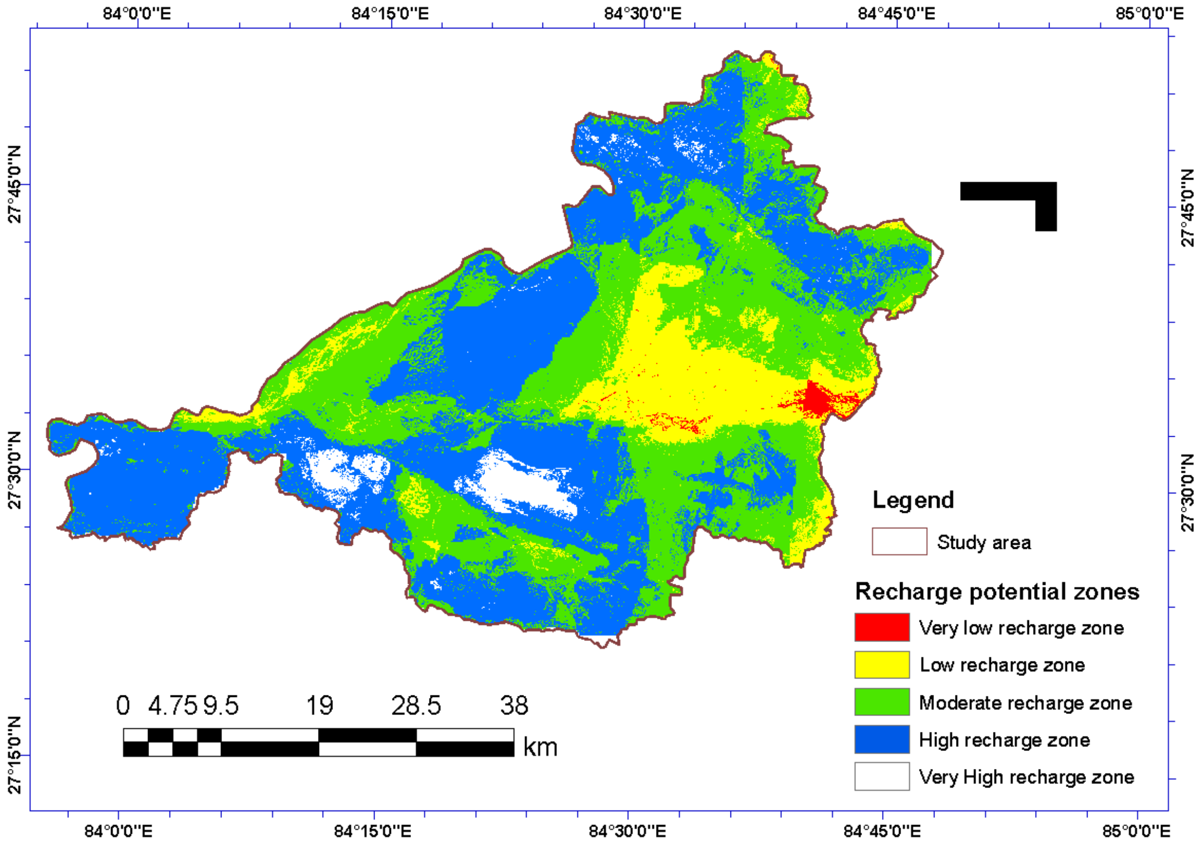

Figure 4: Groundwater recharge potential map

The influence of forests and alluvial soils on recharge potential aligns with established hydrological principles, while the impact of steeper mountain slopes underscores the role of terrain in limiting recharge. The weighted analysis, particularly emphasizing precipitation, land use, and soil type, highlights the key drivers of groundwater recharge. This nuanced understanding is vital for sustainable water resource management and underscores the need for context-specific interventions to preserve and enhance groundwater recharge in Chitwan.

Table 6: Calculation of area coverage of layers of groundwater recharge potential map

Recharge potential	Area (Sq.km)	Percentage of Area
Very low recharge zone	38.8	1.73
Low recharge zone	274.28	12.25
Moderate recharge zone	883.1	39.45
High recharge zone	963.41	43.03
Very high recharge zone	78.9	3.52
Total	2238.45	100

5.0 Conclusions

The application of integrated geospatial technology and AHP has proven to be a better tool for the identification of potential groundwater charges zone. Our study clearly separates the potential zones for ground water recharge by analysing the influencing factors like LULC, Slope, Aspect, Distance from river, Distance from road, Population density, DEM, Type of soil, Precipitation, Lineament density and Drainage density based on various citation review. The results reveals that around 78.9 sq. km (3.52%) of total area has been identified as high potential zone for groundwater recharge, which is almost the forest portion of National Park area. The low recharge potential zone occupies around 38.8 sq. km (1.73%) of the total area, which is the northern steep slope terrain of our study area. The plain and gentle slope in the middle and lower part of area contribute for high ground water recharge. Haplic Phaeozems (PHh) and Eutric Cambisols (CMe) are considered as suitable soils for ground water recharge, which is mostly found around Ichhyakamana rural municipality and Bharatpur urban municipality areas. The precipitation is high around Bharatpur and Chitwan National Park areas, which contribute for high ground water recharge. Areas that are closer to a river tends to have higher recharge potential than those that are farther away. The areas of National Park and Madi urban municipality are closer to the river, contribute to high ground recharge. The Bharatpur metropolitan areas is highly populated and densely urbanized and hence the ground surface of this area is mostly impervious. Due to impervious surface, the surface runoff is high which contribute to low ground water recharge in this area.

The identification of potential recharge zones can help in the efficient allocation of resources and effective management of groundwater. The evaluation of groundwater recharge potential zones in a particular area can assist in the development of appropriate management strategies for groundwater resources, including the regulation of groundwater withdrawals, recharge enhancement, and the protection of recharge zones and important step towards sustainable management of groundwater resources ensuring the long-term availability of this vital resource. High groundwater recharge potential zone includes high precipitated, permeable soil and rock formation and forest area in the district thus these locations have high natural recharge of groundwater so this zone is the suitable location for artificial recharge station in order to enhance recharge through means like infiltration basins and recharge wells. Our study technique is comprehensive multi-parametric and cost effective and it is the valuable practical tool for the analysis of the different factors influencing the groundwater recharge and separation of ground water recharge potential zones.

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