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# Delineation of Groundwater Potential Zones Using Remote Sensing and Gis Techniques of Phewa Watershed (Nepal)

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**ABSTRACT**

Groundwater is the primary source of water in the study region, both for domestic and agricultural needs. The main objective of this research is to identify the groundwater potential zones via remote sensing (RS) and Geographic information system (GIS), which is essential in evaluating, preserving, and monitoring various groundwater-related development programs. Man-made pressures include over-exploitation of groundwater and climate changes have led to a strain on groundwater resources. As the use of consumable water increases for human consumption, agriculture, industrial growth, municipal, and pharmaceutical needs to evaluate the groundwater potential and aquifer productivity also increase. Groundwater inspections have been historically done by field survey method, which is inefficient or not practical in terms of time and resources. Arc GIS software is utilized to manipulate datasets. The LULC map of the study area will be developed using Landsat 8 satellite data. A soil map and rainfall map will be created using the data sources from USGS, a Parent soil map will creates using the data from NARC and slope map, lineament density and drainage density from ASTER from earth data. Seven thematic maps will be applied, each with appropriate weight and rank assigned based on its characteristics and connection with groundwater. All the thematic layers combine into a GIS domain, and weight values are put to the attribute table for each polygon. The groundwater potential zone map will be classified into different zones, i.e., very poor, poor, moderate, good, and very good. These results will help hydrogeologists, decision-makers, planners, and local authorities formulate better groundwater resource planning in the Phewa watershed area.

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## Introduction

Water is one of the most important natural commodities on both the surface and the underground [1]. It is the principle and primary source on earth for all creation. Our society's growth is dependent upon the availability and usage of ample water. It is scarce in some areas whereas it is plentiful on another side. Water uses are for various purposes such as agricultural, industrial, residential, recreational, and environmental [2]. Groundwater refers to any water contained in aquifers under the surface of the earth. It is the dynamic and replenishing natural resources that form the ecological system [3]. It is the world's largest freshwater resource, finding essential for human consumption [4]. The water has infiltrated the earth directly from precipitation, recharge from streams and other natural water bodies, and artificial recharge due to human beings' actions [2]. Due to population growth, modern irrigation methods, and commercial usage, there has been a massive rise in groundwater demand [1]. Overexploitation of groundwater resources resulted in a sudden decline in the groundwater table and an excess in groundwater resources' sustainability [5]. Identification of groundwater potential zones could help develop and utilize groundwater and surface water resources to eliminate water scarcity and improve irrigation practices and agricultural income for society's standard living conditions [6].

Nepal has the highest range of altitude on earth, ranging from 60 to 8848m above sea level. The country has broad topographic diversity, with approximately 200km separating the plain region (South) from the high Himalayas (North) [7]. It is well known for its natural beauty, geographical and biological diversity, cultural, and artistic heritage. Nepal is a mountainous country that occupies 83% of the mountain and hill region, and just 17% is covered by plain area. Groundwater is enough available in the plane belt. Around 50% of the water needs for domestic, agricultural, and industrial use are met by groundwater; thus, the supply and quality pressures are rising. There are around 6000 rivers and rivulets consisting of 45000 km with a drainage density of o.3km/km2 in Nepal but ineffective management affects groundwater aquifer recharging and conservation [8]. The local communities use groundwater from springs and hand-dug wells in the hills and mountains area, while boreholes are used in the plain area [9]. Groundwater resources or groundwater conditions in hills and mountain regions are not adequately studied or investigated. Maximum People living in hills and mountains depend on spring for their domestic use, which is also the natural discharge of groundwater. The population ratio has increased rapidly, and the demand for groundwater resources for various purposes, like drinking, agriculture, and so on, automatically increases. Remote sensing and GIS are used to locate the groundwater zone, recharge area, flood zone, and drought area in the broad range by considering geomorphology, slope, lineament density, drainage density, land use, etc. [10]. For sustainable use of resources, the location of the groundwater potential zone is essential. It helps to support decision-makers and policymakers to protect groundwater resources [9].

The influence of climate variations can increase groundwater pumping; the impact of climate variability in the form of drought dramatically affects groundwater resources in the Phewa watershed area. In addressing the possible effect of climate change-related water scarcity, groundwater management should be more strategic, systematic, and constructive. Municipal water supply is insufficient, poor sustainable, and groundwater from the private sector has started to be extracted without any regulations to meet the water requirements. Due to a lack of control and monitoring mechanism, the extraction amount and the places of extraction of groundwater are not identified [8]. So, it makes enormous challenges for proper management and utilization to supply the groundwater.

The principal intention of this research is to generate the thematic layers of the watershed using remote sensing and GIS. It helps to detect and classify appropriate groundwater potential zones through the integration of different layers and analyzing them. It can support delineating suitable surface features and estimating the possible groundwater potential zones that promote sustainable development, cost and time effective techniques, planning and utilization soon through proper management to control for irrigation and drinking purposes.

**Study Area**

Phewa watershed is situated in the Mahabharata range in the western part of Kaski District's Pokhara valley in Nepal's western development region which lies in the latitude of 28º11′ to 28º17′ North and longitude of 83º47′ to 83º58′ east and it has a hilly and mountainous topography with its elevation varying from 784m above sea level, where the highest point is marked at 2517m above sea level [7]. It covers an area of 121.72 square kilometers. The watershed consists of five sub-watersheds, which drain 19 streams and small brooks into Phewa Lake, the second largest and one of Nepal's most prominent lakes and the small river valleys have a sub-tropical climate where the soil is mostly used to produce irrigated rice and maize, hill slopes are sandwiched between valley floors and ridges with a subtropical atmosphere in the lower elevations and temperature climate in the higher elevations [11]. Agriculture, tourism, service, trade, and micro-enterprises are significant economic activities [12]. It belongs to a semi-agricultural watershed in the mid-hill belt of the mountain ecosystem and the forest in the watershed area is mostly dominated by broad-leaved mixed hardwood species [3].

It is famous for its high biodiversity and tourism, but it is also sensitive to natural hazards like landslides, soil erosion, and flash floods. The subtropical climate region experiences intense monsoonal rainfall (June –Sept.) and dry winters (Dec.-March) and this region is also known the highest rainfall area in the country, the recorded highest annual and daily rainfall in the region is about 5500mm, and 315mm, respectively, with the annual mean rainfall of 4500mm and stream flow typically remains low in the winter and highest during the summer monsoon season, moreover, the soils range from silt-loam to loamy-sand [7].

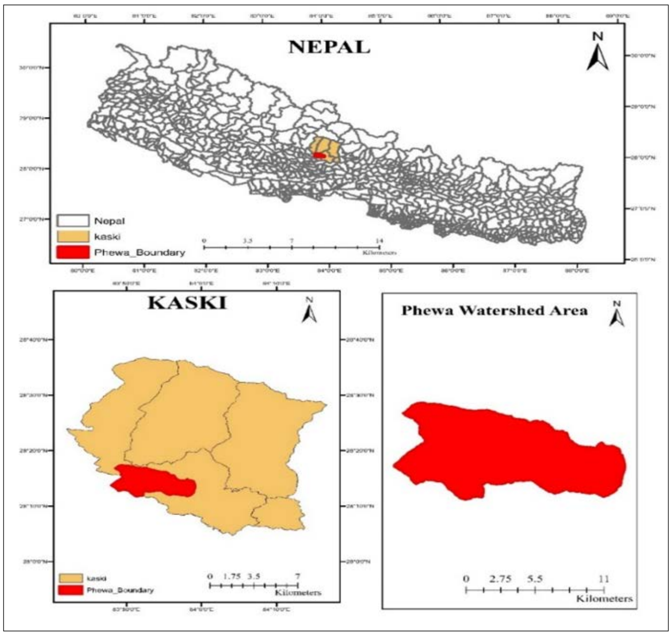



**Figure 1:** Location Map of Study Area

The Phewa watershed climate is humid tropical to subtropical, with a monthly mean temperature ranging between 5-6ºC to 14-20ºC during winter and 18-22ºC to 25-32ºC during summer [13]. During the monsoon season, an average of 88 percent of the total annual precipitation falls [14]. The watershed consists of acidic, moderately fine-textured, and non- stony clay where soil with loamy skeleton texture is found in a hilly area [15]. The dominant bedrock is towards the south at between 15º to 30º, and the northern half of the watershed is characterized by moderate to steep south-facing dip slopes, whereas the upper slopes in the northern part of the watershed are typically steep sloping and gap for channelized flow [16]. This place is weak in the geological setting, and in the northern side, grey to dark grey phyllite is dominant, which is intercalated with white to grey meta sandstone where the southern part consists of fractured, coarse white quartzite containing clear ripple marks with medium to thick depth [13]. The middle slopes serve as a source and transport zone for the geomorphic and hydrological processes that deposit a significant amount of alluvium on the base slopes and in most areas, soil with well-drained, brown clay loam soil with weak to moderately developed sub-angle structure [16].The land covers consist of cultivation or forest, but much of the climax forests have been removed, besides, most non-forested areas are in cultivation, with only a limited percentage of grassland and grazing land and the northern part facing its slope parts towards the south is terraced with rice cultivation. Forest agriculture, water bodies, swarm land and built-up area, covers the watershed area, where built up and agricultural land cover much of the flat and gently sloping landscape, and forests occupy all the remaining land [11]. Forest and biodiversity represent temperature and altitude variation of the catchment area; subtropical forests are in the lower belt and temperature forests in the upper catchment [17].

## Materials and Methods

### Data Used

The data that is collected for this study, its sources, and the purposes are given below:

**Table 1: Data Collected, Sources and its Purpose**

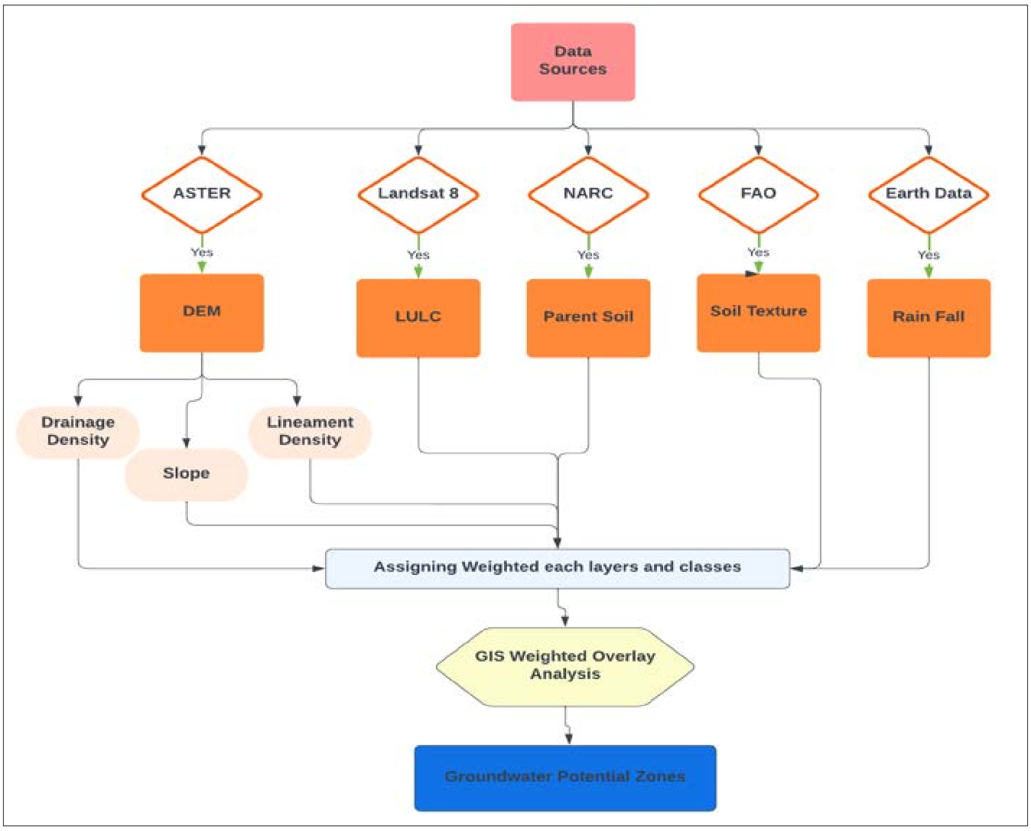
| S.No. | Data Collected | Sources | Functions |
|---|---|---|---|
| 1. | Rainfall | Giovanni.gsff.nasa.gov | Rainfall Map |
| 2. | Parent Soil | National Soil Science Research Centre, Nepal (NARC) | Parent Soil Map |
| 3. | ASTER (Advanced spaceborne Thermal Emission and Reflection Radiometer) | https://search.earthdata.nasa.gov/search/ | Drainage Density, Lineament Density, Slope |
| 4. | Landsat 8 | USGS website https://earthexplorer.usgs.gov/ | LULC Map |
| 5. | Soil Texture | FAO | Soil Texture Map |

GIS Software: Arc GIS 10.8(Arc Map, Arc Catalog, Arc toolbox)

All data are geo-referenced and projected to Geographic coordinate system-World geodetic system1984 (GCSWGS) in UTM (Universal Transverse Mercator) zone 44 North operation in the GIS environment. Certain maps are created, compared and modified from the recent available image in Google Earth. Weights are assigned to the various groupings with in each thematic map based on their characteristics and relationship to groundwater and the thematic layers are merged with the GIS domain, and the issued weight values are compiled in the attribute table for each class.

Different maps such as drainage density, contour, and stream length are created using GIS and remote sensing; subsequently, DEM data is used to create slope, aspect, contour, and flow accumulation maps; and for geo-referencing and geometric correction, image processing of satellite data is used as a result, all the thematic maps are used in overlay analysis, and weights are assigned for each possible groundwater zone [1].

**Flow Chart of the Methodology**




## Results and Discussions

### Slope

The slope is one of the essential terrain parameters expressing the steepness from the ground surface, which provides essential information on the nature of geologic and geodynamic processes operating at that regional scale. The higher degree of slope shows steeper terrain, where the lower degree of slope represents the flat surface [18]. It is developed from the digital elevation model. Flat areas resemble the rainfall and facilitate recharge to groundwater, treat infiltration water compared to the steep slope, where water moves as run of quickly [19]. High weight is given to the flat and gentle slope area, and lower weight is represented in steep and very steep slope areas. Slope affects the drainage density and its differences from place to place and it is directly proportional to the runoff [20]. It is the rate of change of elevation, and it is considered the principal factor of the shallow water flow since it determines the gravity effect on the water movement [6]. Five classes are classified based on their level of importance of groundwater recharge or runoff generation. The lower part and the central part of the study area are covered by the lake, agriculture. Flat and gentle slopes are the primary source of the presence of high groundwater potential zones [21].

**Drainage Density**

Drainage density is the sum of the length of all the streams and rivers in the drainage basin divided by the drainage basin's total area and it is measured by how well or how poorly a watershed is drained by stream channels [22]. It plays a significant role in groundwater availability and contamination and the region with a high drainage density will have limited infiltration and rapid runoff, so the low drainage density value is more favorable for high groundwater potential [23]. The drainage density is inversely proportional to permeability which plays a crucial role in the runoff distribution and infiltration level and high weight is given to low density, and high density is assigned less weight [5]. The high drainage density area has less rainfall, hard rocks, steep slopes, less vegetation, and less infiltration in the study area, whereas, in the low density, it has softer rocks, gentle slopes, lots of vegetation, and more infiltration. More than half of the watershed area is covered with low drainage density, which proves that the infiltration rate is good.

**Lineament Density**

According to numerous research, higher lineament density would enhance the likelihood of occurrence and movement of groundwater [10]. Lineaments which may be seen from satellite imagery, are planer structures on the surface of the earth that indicate an underlying geological structure, such as fractures, cleavages, faults and other discontinuity surfaces which are the best way for the flow and storage of groundwater [24]. The lineament density is categorized in to five classes from low, moderate to high lineament density as shown in the figure.

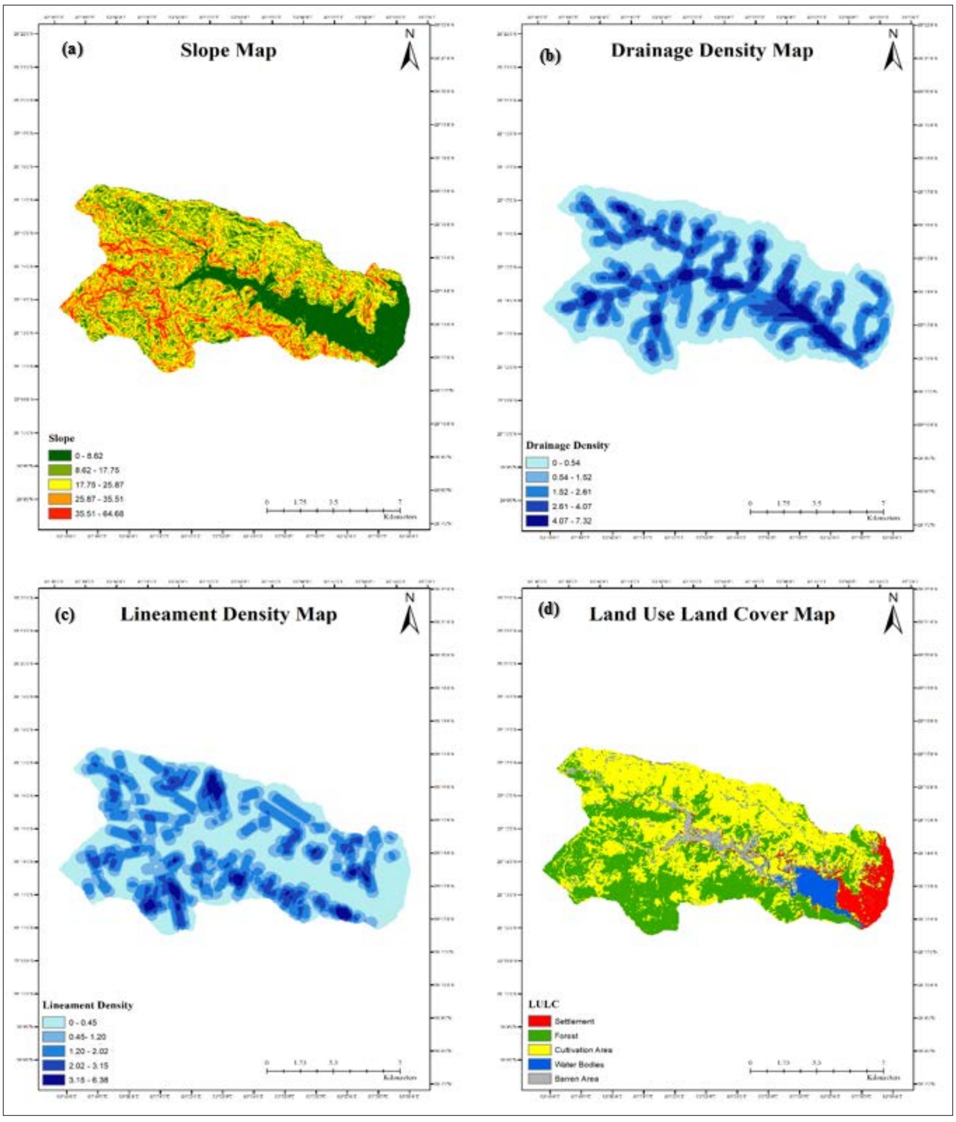



**Figure 2:** (a) Slope Map (b) Drainage Density Map (c) Lineament Density Map (d) Land Use Land Cover Map of the Study Area

**Land use Land Cover**

Land use refers to human activities in the land and land cover refer to the natural vegetation, water bodies, rocks, etc., that result from the land transformation which affects evapotranspiration volume, timing, and recharge of the groundwater system and seen that spatial variation in the amount of groundwater storage occurs due to changes in land use and vegetation cover, so a proper understanding of LULC is necessary to estimate the water resources [6]. LULC tells the critical information about infiltration, soil moisture, groundwater, surface water, sustainable water resource management, etc., in addition to indicating groundwater requirements [25]. Five LULC classes have been identified in the Phewa watershed, namely, Cultivation land, Forest, Water Bodies, Settlement, and Swamp Barren Area. Cultivation land covers a larger area as compared to others. The high weighted is assigned for water bodies, cultivation land, and forest. In contrast, the low weighted is given for settlement and swamp, barren area as we know that precipitation directly infiltrates in the forest, cultivation area, and water bodies but tends to flow directly on the settlement and barren area surface runoff. LULC controls the groundwater recharge and the hydrological processes [26].

**Rainfall**

The average rainfall pattern in watershed differs from 1708.14 mm to 1972.87mm. The main rainfall period of this watershed is from June to September. During the monsoon season, all the streams and springs get flooded. The southeast part of the watershed receives high rainfall, while the northwest part has low rainfall and it is shown that high altitude area receives low rainfall whereas low land altitude receives high rainfall, flat areas can hold the rainfall and facilitate recharge to groundwater compared to steep slope areas where water moves as runoff quickly [6]. The rainfall pattern map is shown in Figure 3(a). The quantity of rainfall plays a vital role in infiltration and the zone which receives low rainfall is not suitable for groundwater zones [1]. The high amount of rainfall is taken as a more weighted value compared to a low amount.

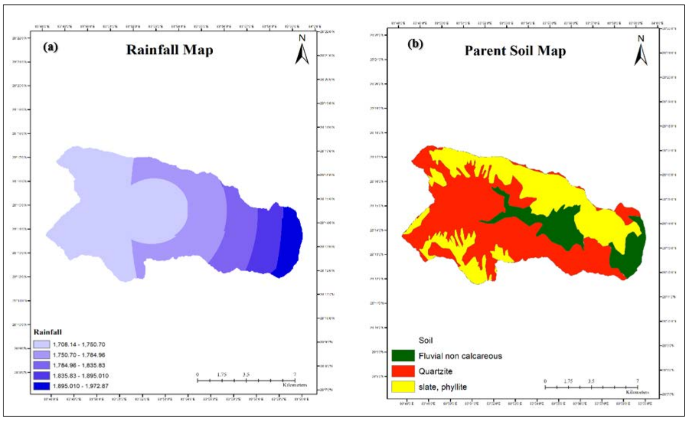



**Figure 3:** (a) Rainfall Map (b) Parent Soil Map

**Parent Soil**

Fluvial soils are deposited by river sedimentation and the textures of these soils are generally coarse sandy with gravel within most of the mountainous regions with good porosity [27]. Depending upon the type of materials carried by the rivers they can be separated into calcareous or non- calcareous where non-calcareous are silty clay with poor drainage and these soils are found in settlement, agriculture and grazing area and classified as a good groundwater potential zones [28]. Quartzite is basically found in the south- western part of the watershed. 'The quartzite formation is prone to deep gully formation, rock fall, rock slides and wedge failures involving rather rough material' [7]. Porosity is low compared to fluvial in the context of groundwater. Phyllite covers basically northern part of the watershed area. It is also susceptible to mass movement and slope failure. Agricultural land lost surface is mostly occurring in Phyllites because most agriculture areas are located in this formation.

**Soil Texture**

"The soil texture and hydraulic properties are the key variables considered for estimating the rate of infiltration. The rate of water infiltration depends directly on the size of the soil grains and the textures of the soil are the important thematic layer for groundwater potential and recharge assessment.

The soil composition, sand, silt, and clay are intrinsic factors for infiltrating the water. The sandy soils have high infiltration rate than clay soils. So soil texture affects the movement, storage, and recharge of the groundwater" [9]. The classification of different soil texture types with their properties along with the soil map is given below.

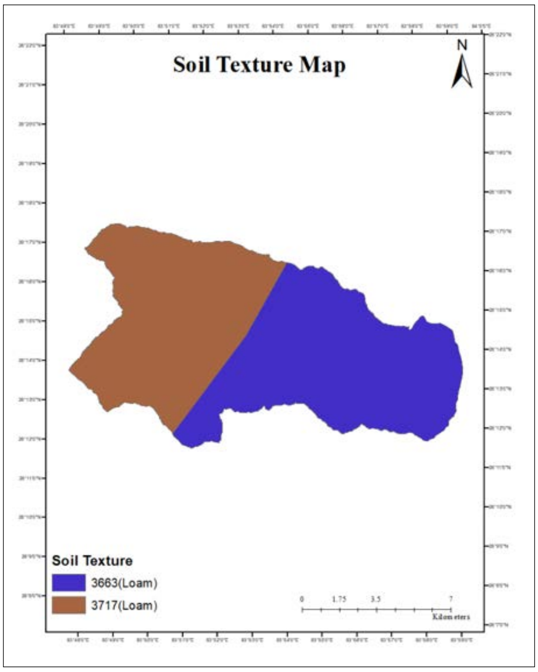



**Figure 4:** Soil Texture Map

**Table 2: Soil Classes, Area, Percentage, and its Properties**

| Soil Class | Texture | Clay % | Silt % | Sand % | Saturated Hydraulic Conductivity mm/hr. | $K_{USLE}$ | GRP HYD | Soil Depth mm | Area Km² | Percentage % |
|---|---|---|---|---|---|---|---|---|---|---|
| 3663 | Loam | 23 | 35 | 42 | 35.65 | 0.2496 | C | 300 | 64.83 | 53.26 |
| 3717 | Loam | 26 | 33 | 41 | 33.91 | 0.252 | C | 300 | 56.88 | 46.73 |

(Source SWAT 2012)

$K_{USLE}$ (Universal Soil Loss equation/ Soil erodibility), GRP HYD (Hydrological Soil Group)

**Rank and Weight Assignment to Thematic Layers (Weighted Overlay Analysis)**
The total influence percentage is defined to be 100, distributed to various thematic layers based on the significance of groundwater occurrence. The weight for each class or scale ranges from 1 to 5 according to the terrain condition, field condition, and the feature of the watershed's geological situation. After integrating all the thematic layers, the final map is created utilizing the aforementioned approaches. The weighted overlay analysis technique determines the groundwater potential zones by superimposing all the thematic maps using ARCGIS 10.8 in the spatial analyst tool. The benefit of WOA is that it is possible to combine human judgment with analysis. "During the weighted overlay analysis, ranks are given for each thematic map parameter, and the weight is assigned according to the influence of the different parameters and the ranks 1,2,3,4 and 5 denote very poor, poor, moderate, high, and very high potential zones, respectively, and the weights and ranks have been chosen based on the judgment of researchers who had carried out similar work on the field of groundwater potential mapping" [6].

Influence and Scale Value of Different Thematic Layers

**Table 3: Rank and Weight for the Different Parameters of Groundwater Potential Zone**

| Parameters | Features/ Classes | Influence (%) | Scale value / Weight |
|---|---|---|---|
| Lineament Density | 0 – 0.45 (Very Low)<br>0.45 – 1.20 (Low)<br>1.20 – 2.02 (Moderate)<br>2.02 – 3.15 (High)<br>3.15 – 6.38 (Very High) | 15 | 1<br>2<br>3<br>4<br>5 |
| Drainage Density | 0 - 0.54 (Very Low)<br>0.54 - 1.52 (Low)<br>1.52 – 2.61 (Moderate)<br>2.61 – 4.07 (High)<br>4.07 – 7.32 (Very High) | 10 | 5<br>4<br>3<br>2<br>1 |
| Slope | 0 -8.62 (Flat)<br>8.62 - 17.75 (Gentle)<br>17.75 - 25.87 (Moderate)<br>25.87 – 35.51 (Steep)<br>35.51 - 64.68 (Very steep) | 20 | 5<br>4<br>3<br>2<br>1 |
| Rainfall | 1708.14-1750.70 (Very Low)<br>1750.70- 1784.96 (Low)<br>1784.96 – 1835.83 (Moderate)<br>1835.83- 1895.010 (High)<br>1895.010 – 1972.87 (Very High) | 10 | 1<br>2<br>3<br>4<br>5 |
| Soil Texture | 3663(Loam)<br>3717(Loam) | 10 | 5<br>3 |
| LULC | Settlement<br>Forest<br>Cultivation Area<br>Water Bodies<br>Barren Area | 15 | 1<br>3<br>4<br>5<br>2 |
| Parent Soil | Fluvial non calcareous<br>Quartzite<br>Slate, Phyllite | 20 | 5<br>1<br>3 |

**Groundwater Potential Zones**
The groundwater potential zone's final map is separated into four zones, as seen in the figure and table below.

Zone-1(Very Poor): - Groundwater in this region is difficult to trap due to the steeper slope runoff with forest, and this zone has very poor potential. There are very few groundwater possibilities in this region.

Zone-2(Poor): - This field involves a steep slope of the hill, and relief from this zone is hard. So, this region has fewer water possibilities. It primarily occupies both woodland and cultivation land.
Zone-3(Moderate): - With low altitude, less slope, it has suitable and sufficient groundwater availability for supply.

Zone-4(Good): -This area is perfect for groundwater existence within the settlement, cultivation land, lake and on the edge of the lake.

Zone-5(Very Good): - This area identifies as the significant sources and suitable for occurrence of groundwater resources.

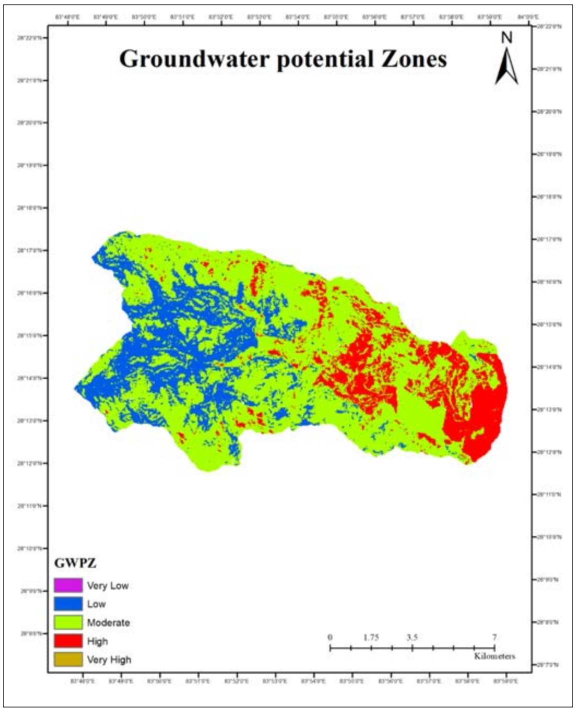



**Figure 5:** Groundwater Potential Zones of the Study Area

**Table 4: Area of Different Groundwater Potential Zones**

| S. No. | Groundwater Potential Zone | Area(km$^2$) | Percentage (%) |
|---|---|---|---|
| 1 | Very Low | 0.0036 | 0.003 |
| 2 | Low | 26.9946 | 22.48 |
| 3 | Moderate | 74.1987 | 61.83 |
| 4 | High | 18.8289 | 15.68 |
| 5 | Very High | 0.0027 | 0.0023 |

## Conclusions

The integrated use of remote sensing and GIS, by engineers, hydrologists, policymakers, and planners to identify the suitable groundwater potential zones in the study area, has proved to minimize cost, time, and labor. The use of this software, coupled with methodologies, has great significance in understanding groundwater's potential. This methodology is crucial for the development operations and recharge's purpose by effective management and the sustainable use of the groundwater resources.

Usage of satellite imagery, topographic maps are followed by an integration process using weighted overlay analysis, six different thematic layers, slope, elevation, drainage density, and rainfall along with the variables for soil, and LULC in order to make the final map which gives the groundwater potential zone map of the study location. The groundwater prospect map reveals that the lower part of the landscape has greater potential for groundwater than the upper region, because of flat land in nature that is better suited to infiltrate more water than the upstream region. These finding give direction and design for future artificial recharge projects in the research region, which will help to guarantee sustainable groundwater management in the future.

The groundwater potential map will help develop, manage and use groundwater supplies efficiently to deliver community water and agricultural purposes. Such research is a good tool for making more plans for fast decision-making in sustainable groundwater management in developing countries like Nepal with poor infrastructures and limited information and data. The results of this study can be utilized and helped to plan new groundwater-based projects and to expand current irrigation and groundwater projects [29].

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