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Site Suitability Analysis for Urban Development: A Case of Ranikhet, Uttrakhand

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ABSTRACT
Identifying potential sites for urban development in hilly regions is a crucial aspect of planning. Conducting site suitability analysis is essential for determining appropriate locations for various developmental projects, particularly in the challenging terrain of hills. Unregulated and disorganized urban expansion, driven by population pressure, is a widespread issue in many cities within developing countries, leading to urban sprawl that encroaches on natural environments. As a result, selecting suitable areas for urban development while maintaining ecological balance has become a critical component of effective urban planning. This work demonstrates the application of Geographic Information System (GIS) and the Multi-Criteria Analysis (MCA) technique for identifying appropriate sites for urban development in Ranikhet, Uttarakhand. The aim is to identify optimal locations for future urban growth that minimize impacts on natural features. The work also calculates the potential transfer of land suitability from various land use and land cover categories, a unique aspect of this research. Eight criteria distance from roads, land use/cover, distance from water bodies, slope, elevation, soil, geological formation, and population density were used for land evaluation. The thematic maps generated for these criteria were standardized using the Analytical Hierarchy Process (AHP), which involved creating a pairwise comparison matrix. Each criterion was assigned a weight based on its relative importance, leading to the creation of a final site suitability map with five categories: very high suitable, high suitable, moderately suitable, less suitable, and restricted or not suitable. The study highlights the potential zones within the study area and offers valuable insights for sustainable urban development planning. The results are expected to assist planners, stakeholders, and policymakers in identifying the most suitable locations for future intensive development projects.

Keywords: Site Suitability Analysis, Geographic Information System (GIS), Multi-Criteria Analysis (MCA), Urban Development.

1. INTRODUCTION

Ranikhet, a small town nestled in the Himalayan foothills of Uttarakhand, India, is experiencing rapid urban growth that poses serious challenges to its spatial and demographic structure. Urban growth refers to the expansion of urbanized land and the increasing concentration of population in towns and cities, leading to significant change in land use and demographic patterns. This phenomenon is characterized by the transformation of natural ecosystems, such as forests, rural areas, and agricultural land into built-up, impervious surfaces. The issue of urban growth is particularly acute in developing countries like India. Economic opportunities and better living conditions in urban areas attract people from neighbouring rural regions, resulting in unplanned and haphazard development. In Ranikhet, this unplanned growth is leading to urban sprawl, where patches of built-up areas spread out in an uncontrolled manner, encroaching upon valuable natural landscapes. To tackle the issues of urban expansion and promote sustainable growth, it is essential to identify appropriate areas for new urban development. This requires a careful analysis of different land categories and their suitability for urban expansion, taking into account ecological sustainability and the needs of stakeholders. Geographic Information Systems (GIS) combined with Multi-Criteria Decision Making (MCDM) methods offer powerful tools for conducting land suitability analysis. MCDM methods, like the Analytic Hierarchy Process (AHP), help in assessing various criteria's that influence the suitability of land for urban development. AHP involves a hierarchical structure for criteria evaluation and pairwise comparisons to assess the relative importance of each one criterion. This method is particularly useful in urban planning as it helps to standardize criteria and provide a transparent decision-making process. In Ranikhet, the need for sustainable urban development is pressing due to its unique geographical and environmental characteristics. The town's location in a mountainous region makes it susceptible to environmental degradation from unplanned development. Thus, this study seeks to determine the most suitable locations for new urban development in Ranikhet through a GIS-based MCDM analysis utilizing AHP. The analysis will involve consulting experts to determine the weights of various criteria and integrating these criteria into a GIS platform to create a suitability map for future urban growth. This study's findings will help local authorities and planners make informed decisions about urban development in Ranikhet, ensuring that growth is managed in a way that minimizes environmental impact and maintains the ecological balance of the region.

2. NEED OF STUDY

In today's rapidly expanding world, unplanned and unscientific urban growth is prevalent in most cities within developing nations. As a result, conducting suitability analysis or selecting appropriate sites for urban development is crucial to prevent chaotic expansion within limited spaces. To address this issue, GIS-based Multi-Criteria Analysis (MCA) combined with the Analytic Hierarchy Process (AHP) is a straightforward and cost-effective method that can categorize areas by site suitability within a specific area. This research is mandatory as it offers a comprehensive and data-driven approach to strategically locate urban development areas in Ranikhet, striking a crucial balance between urban development and environmental preservation by utilizing GIS techniques, it optimizes land use, ensures efficient infrastructure planning, minimizes environmental impact, enhances community well-being, and establishes a foundation for legally compliant, resilient, and sustainable urban expansion, critically addressing the challenges of a growing city while securing a better future for its residents.

3. METHODOLOGY

The study will utilize a mixed-methods approach, a blend of both primary and secondary data collection and analysis. Primary data will be composed through questionnaire conducted with key stakeholders of the city, including city officials, urban planning experts. Spatial data and non-spatial data gathered form different government sites and official site for this work to perform analyses and visualization. Secondary data will be gathered from relevant academic literature, research papers, books, articles, reports, case studies and scientific journals from web sources to establish a comprehensive understanding of site suitability, selection process, and methods of potential site selection.

3.1 Research Structure

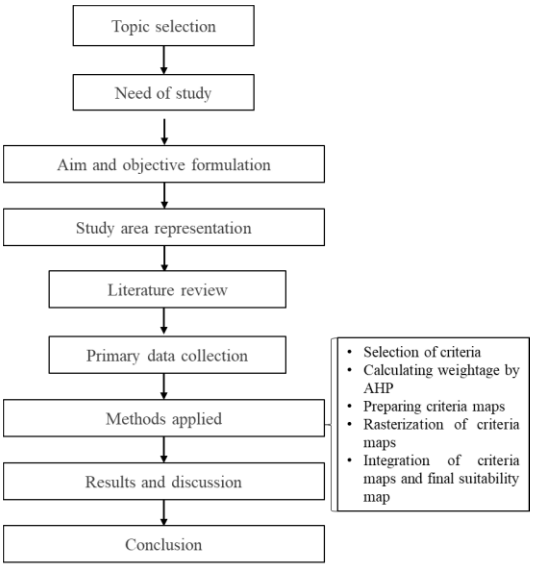

Figure 1: Research Structure

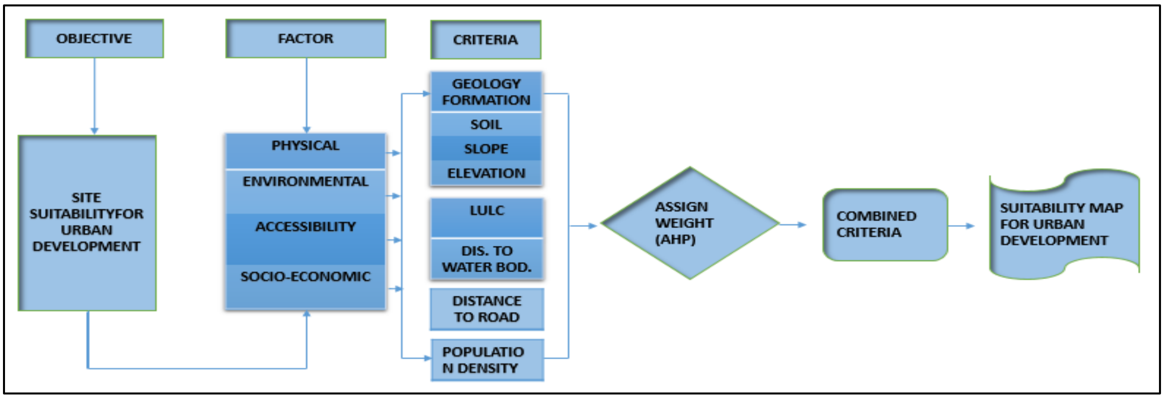

Figure 2: Methodology for urban development site identification

4. DATA COLLECTION FOR SITE SUITABILITY ANALYSIS

4.1 Description of the Study Area

Almora is a hill district situated in the eastern part of Uttarakhand, specifically within the Kumaon Division. It is bordered to the east by Pithoragarh district, to the west by the Garhwal Division, to the north by Bageshwar district, and to the south by Nainital district. The district spans an area of 3,139 square km, with approximately 1,309 square km designated as forested land. The district is characterized by snow-capped mountains, verdant forests, and fertile valleys. Major rivers including the Saryu, Ramganga, Kosi, Gagas, and Suyal traverse the region. Almora is also known for its scenic beauty, dense forests, and diverse wildlife.

Ranikhet taluka of Almora district is selected as the study area because of its importance and the development plane is not available. The latitude of Ranikhet area is 29.6434, and the longitude is 79.4322 with the GPS coordinates of 29° 38' 36" N and 79° 25' 55" E, covering an area of about 1838.995168 square km situated in Almora District, Uttrakhand Ranikhet is situated at an average elevation of 1,869 meters (6,132 feet) and is located 60 kilometers from Nainital. It falls within the Almora district and is positioned to the west of the district headquarters.

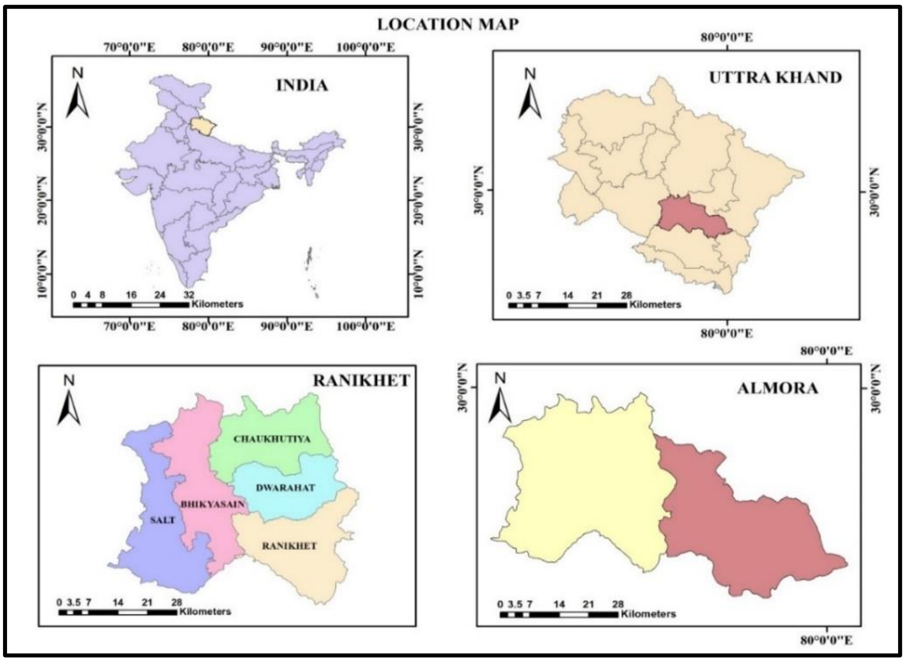

Figure 3: Location map of Ranikhet study area

4.2 Software

The major software's applied in this study include ArcGIS 10.8, Google Earth Pro. ArcGIS is an advanced tool for addressing geographic issues, enabling the creation of various thematic maps, retrieving attribute information for spatial locations, spatial visualization, sharing geographic information services, and managing geographic data within a geodatabase. ArcMap is the primary component used for creating, viewing, editing, and analysing geospatial data. In this work, ArcMap is utilized to digitize and classify land use images, followed by the creation of thematic maps. Arc Catalogue is employed to organize and manage spatial data. The AHP method is used to assign weights to each option and criterion in the Multi-Criteria Analysis (MCA), which employs a linear additive model. The AHP assesses each option and criterion based on their level of importance.

4.3 Data

A pilot study is conducted to data collection. The survey is conducted with a small sample size of ten respondents, out of the ten responses five were collected from the stakeholders, two from civil engineers, and three from urban planning professionals. The process of primary data collection in this research involves a systematic approach starting with a self-survey, where participants directly provide information through questionnaires or interviews. The data collected is measured using an ordinal scale, which requires respondents to prioritize or rank their choices, making it useful for capturing preferences or opinions. The sampling method employed is a non-probability technique, specifically convenience sampling, where respondents are selected based on their accessibility and willingness to participate.

4.4 Geospatial data

The study is primarily based on geospatial datasets collected from various sources. Additionally, primary data were obtained through a close handed survey questionnaire, Accessibility is assessed based on proximity to road, and Criteria include distance from roads which is collected from Google earth pro and bbbike open street map. Environmental considerations include Land Use and Land Cover (LULC) types and distance from to water bodies like rivers and streams, Digital Elevation Model (DEM) data were obtained from the United States Geological Survey (USGS) provide spatial data for analysing LULC, while Google Earth Pro and bbbike open street map supplies data on distances from rivers and canals. Physical factors such as soil type, slope, elevation, and geological formations are critical. Soil type data were sourced from the Digital Soil Map of the World from the Food and Agriculture Organization (FAO). DEMs from USGS are used to analyse slope and elevation, while geological formations are identified using data from the bhukosh is a gate way to all geoscientific data of Geological Survey of India (GSI). All data were converted to the WGS1984 spheroid and projected using Universal Transverse Mercator (UTM) Zone 43 North.

Table 1: Selected criteria and sources of data

Factors	Criteria	Data Type	Source
Physical	Soil type	Raster data	Digital Soil Map of the World Food and Agriculture Organization (FAO)
	Slope	Raster data	Digital Elevation Model (DEM) United State Geological Survey (USGS)
	Elevation	Raster data	Digital Elevation Model (DEM) United State Geological Survey (USGS)
	Geological formation	Raster data	Bhukosh Geological Survey of India (GSI)
Environmental	LULC	Raster data	Esri Land Use/Land Cover
	Distance from water bodies (River/stream)	Polygon data	bbbike Open Street Map and Google earth pro
Accessibility	Distance from road	Polygon data	bbbike Open Street Map and Google earth pro
Socio-economic	Population density	Non spatial data	Primary Census Abstract (PCA) Census of India

5. METHODS OF SITE SUITABILITY ANALYSIS

The study used a combined GIS and Multi-Criteria Analysis (MCA) framework to evaluate site suitability for urban development in Ranikhet, Uttarakhand. Both GIS and MCA are internationally recognized for their outstanding performance in spatial decision support systems, frequently applied in site suitability analysis to tackle complex decisions and improve land-use planning.

5.1 GIS-based Multi-Criteria Analysis (MCA)

According to (Malczewski, 1999), "MCA is a process that generally involves combining conflicting and relevant criteria necessary for decision-making." The main benefit of employing the MCA method is its capability to evaluate complex and diverse factors across different scales, allowing for the integration of these factors into a comprehensive map that identifies suitable land for particular development objectives (Weldu & Deribew, 2016). According to (Al- Shalabi, Mansor, Ahmed, & Shiriff, 2006), "Site selection requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area for a defined land use". "MCA is a procedure that typically multiplies conflicting and corresponding criteria that are essential to be evaluated in decision-making". The primary advantage of the MCA method lies in its ability to evaluate a range of complex and varied factors across different scales, which can then be combined to create a comprehensive map pinpointing suitable land for a specific project. Consequently, multi-criteria analysis involves identifying local factors that are most effective for selecting potential areas for a given use (Hopkins, 1977). As a result, "site suitability is the process of understanding existing site qualities and factors that will determine the location of specific activities." Achieving this goal requires analysing extensive and reliable datasets. To enhance societal benefits, this study took into account the current urban conditions of the study area, incorporating eleven economic and environmental factors to pinpoint potential sites for housing development (Weldu & Deribew, 2016).

5.2 Analytical Hierarchy Process (AHP)

GIS-based multi-criteria site suitability analysis involves mapping and classifying relevant parameters based on their relative importance and suitability scores. According to (Duc, 2006), assigning relative weights to various factors in site analysis to determine optimal locations for specific land uses can be quite challenging. Nevertheless, the Analytic Hierarchy Process (AHP) serves as a rational decision support system adept at managing both qualitative and quantitative data, making it well-suited for tackling complex, multi-criteria systems. (Saaty, 1980) (Xu, et al., 2012). Moreover, AHP is a multi-criteria comparison method in which each criterion is assessed in relation to all other criteria to establish its relative importance. The weight of each factor is determined using the Principal Eigenvalue of the reciprocal matrix within the AHP framework (Eastman, 1999) (Chow & Sadler, 2010). In AHP, the values range from 1 to 9, where a value of 1 signifies equal preference between two factors, and a value of 9 indicates that one factor is significantly preferred over the other. These values are assigned according to the relative importance of each layer, based on relevant literature and the expertise of planning professionals knowledgeable about the urban context of the study area (Eastman, IDRISI Selva Tutorial, 2012) (Drobne & Lisec, 2009) (Ebistu & Minale, 2013).

Table 2: Pairwise Comparison Matrix Source: Satty (1980)

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance

7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

Additionally, the Consistency Ratio (CR) was calculated to assess the level of consistency in the collective judgments made by the experts. (Chow & Sadler, 2010). According (Saaty T. L., 1997) (Park, Jeon, Kim, & Choi, 2011) (Feizizadeh & Blaschke, 2012), The CR can be determined as follows.

Equation 1. Consistency Ratio

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

Here, CI represents the Consistency Index, and RI stands for the Random Index, which is the average consistency index value based on the matrix order.

Table 3: The random inconsistency value (Saaty T. L., Fundamentals of Decision Making and Priority Theory, 2000)

Number of criterion	1	2	3	4	5	6	7	8	9	10
Random Inconsistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Equation 2. Consistency Index

$$\mathrm{CI} = \frac{\lambda_{\max - n}}{n - 1}$$

Moreover, the Consistency Index (CI) is calculated as

Where λmax denotes the largest or principal eigenvalue of the matrix, and n represents the order of the matrix or the number of criteria.

Therefore, a Consistency Ratio (CR) of 1 or less is deemed acceptable and considered reasonable (Park, Jeon, Kim, & Choi, 2011) (Ebistu & Minale, 2013) (Xu., 2002). However, (Kumar & Biswas, 2011) noted that a CR greater than 0.10 indicates inconsistent judgments, necessitating a revision of the matrix.

6. RESULTS AND DISCUSSION

In developing countries, where cities frequently undergo unplanned expansion, it is crucial to identify appropriate sites for sustainable urban growth. The analysis of potential sites was conducted using eight parameters, and the combination of these criteria facilitated the identification of various suitable areas for future urban development.

6.1 Accessibility Factor

The accessibility factor measures how easily people can reach essential services, destinations, and amenities from a specific location. In urban development, it is crucial for enhancing economic viability, improving quality of life, supporting sustainability, and promoting social equity. Good accessibility attracts businesses, increases property values, reduces travel times and costs, encourages public transportation use, and ensures that all communities have access to vital services. It also aids in effective land use planning, prevents urban sprawl, and facilitates efficient emergency management. Integrating accessibility into site suitability analysis helps urban planners make informed decisions that foster economic growth, environmental sustainability, and social inclusivity. The seamless and effective movement, coupled with enhanced connectivity throughout the city and its surrounding regions, is a top priority for individuals seeking to establish new residential or commercial constructions. In this context, proximity to roads plays a crucial role. Building new roads is costly, and the government typically extends road infrastructure to areas with a significant number of settlements. Therefore, people are inclined to settle in locations that already have good road connectivity, ensuring easy access to essential facilities for their homes or businesses.

6.1.1 Distance from Road

The map displays the distance from roads in the Ranikhet area, categorized into five classes. It provides a visual representation of how far various locations are from the nearest road, critical for urban development planning. The data on road distance and the road network for Ranikhet was sourced from bbbike open street map and Google Earth Pro. The raw geographic data underwent cleaning to remove inaccuracies. GIS software was used to calculate the distance from distance from road to different parts of area of Ranikhet.

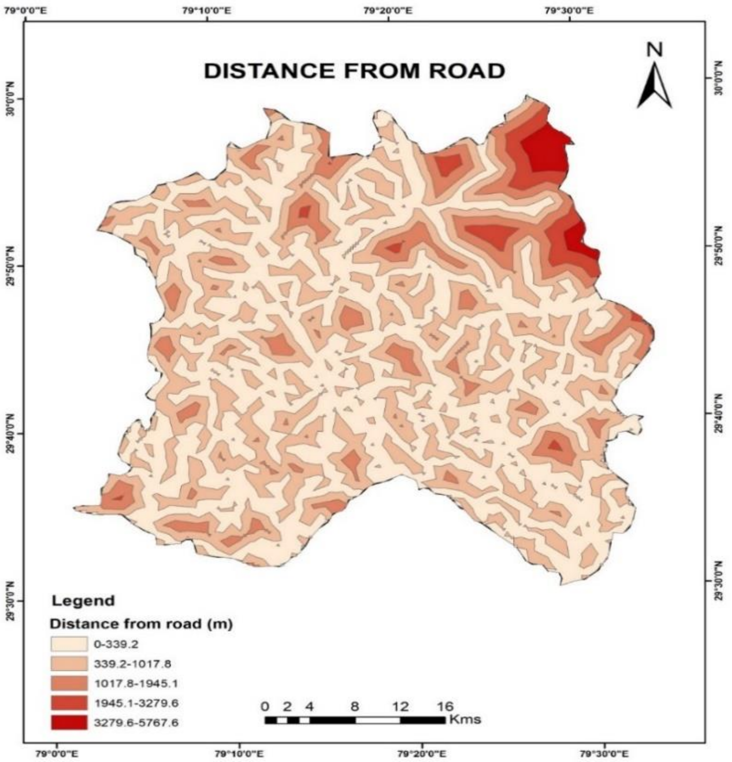

Figure 4: Map of distance from roads

In this work, to assess accessibility throughout the area, roads are primarily classified into five categories: trunk roads, primary roads, secondary roads, tertiary roads, and unclassified roads, which include essential village and municipal roads that connect various locations. No railway stations or airports are present within the study area. To determine optimal accessibility and identify the best locations in terms of their proximity to existing roads, Euclidean distance (Spatial Analyst) was used to create maps with equal intervals. The importance of these roads for urban development was then determined by ranking.

Table 4: Distance from road/reason/level of suitability/ranking

Distance From Road (m)	Reason	Level of Suitability	Rank
0-339.2	Highly suitable due to proximity to roads.	Very High	1
339.2-1017.8	Suitable with moderate accessibility.	High	2

1017.8-1945.1	Moderately suitable, additional infrastructure needed.	Moderate	3
1945.1-3279.6	Less suitable, requires significant investment in road infrastructure.	Less	4
3279.6-5767.6	Least suitable due to high inaccessibility.	Very Less	5

6.2 Environmental Factor

This study assessed the suitability of locations using two environmental factors: land use and land cover types, and the proximity to water bodies such as rivers and streams. The environmental factor involves evaluating the natural conditions and ecological characteristics of a location to determine its suitability for urban development. Incorporating environmental factors into site suitability analysis is essential for promoting sustainable and resilient urban growth. It helps in minimizing environmental degradation, preserving biodiversity, and reducing the risk of natural disasters. By considering these factors, urban planners can ensure that development activities are aligned with environmental conservation goals, enhance the quality of life by maintaining healthy ecosystems. This approach fosters a balanced relationship between development needs and environmental stewardship, leading to more sustainable and liable urban environments.

6.2.1 Land Use/Land Cover (LULC)

The map represent land use and land cover category of a Ranikhet geographic region. Categorize into different types of land uses, including water bodies, vegetation/plantation, agricultural land, settlements, fallow land, and barren land. The data for the LULC map is typically acquired from Esri Land Use/Land cover of Sentinel-2 10-Meter Land Use/Land Cover category of 2023. The LULC images are processed using GIS. Steps include image correction, classification, and validation. The processed images are classified into different land use categories using unsupervised classification relies on software algorithms to categorize the land use types based on image patterns. It aids in monitoring land use changes over time, which is essential for environmental management and planning. It also supports urban planners in making well-informed decisions related to infrastructure development and zoning.

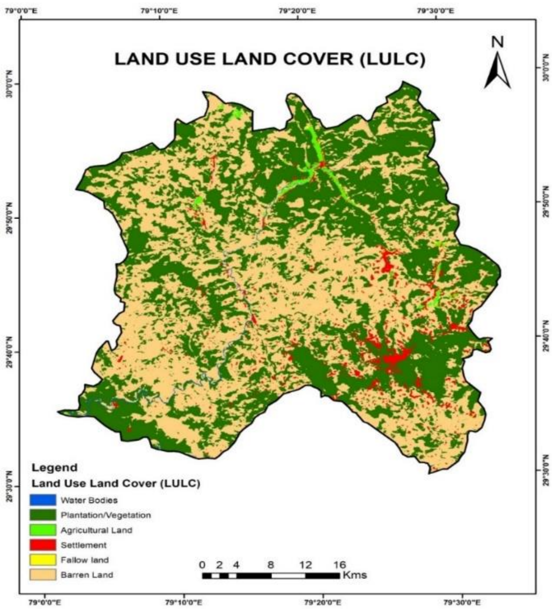

Figure 5: Map of land use/land cover

In the analysis, areas that were already built-up were designated as unsuitable or restricted for further development, though vertical expansion is possible. Similarly, water bodies were also deemed unsuitable for new construction. The focus of this study was to identify vacant lands, prioritizing barren land, fallow land, agricultural land, and plantation or vegetation areas as the most suitable for urban development.

Table 5: Land use land cover/reason/level of suitability/ranking

LULC Category	Reason	Level of Suitability	Rank
Barren Land	Mostly area covered by barren land	Very High	1
Fallow Land	This is the area which is not used any type of development	High	2
Agricultural Land	Suitable with consideration for food security	Moderate	3
Plantation/Vegetation	Suitable for urban development to preserve green spaces.	Less	4
Water Bodies	Restricted for urban development because not possible to any development and preserve ecological balance and water resources.	Restricted	0
Settlements	As these areas are already developed	Restricted	0

6.2.2 Distance from water bodies

The map illustrates the distance from water bodies in Ranikhet, Uttarakhand, colour gradient to show varying distances from water bodies in which areas are divided in to five category and equal distance, providing insights into how close different areas from water bodies. The limit area within (0 - 340.4) meters (light blue) are closest to water bodies and area (1539.3 - 3774.2) meters (blue and dark blue) are farthest from water bodies. Geographic data about water bodies and network collected from bbbike open street and google earth pro in row data. The raw geographic data underwent cleaning to remove inaccuracies. GIS software was used to calculate the distance from these water bodies to different parts of area of Ranikhet.

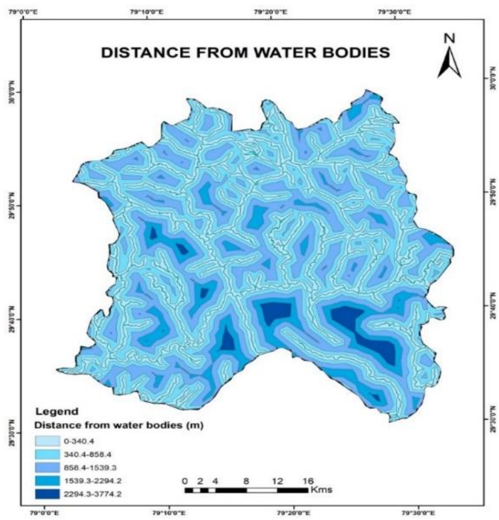

Figure 6: Map of distance from water bodies

Proximity to water bodies can significantly influence the viability, sustainability, and attractiveness of urban areas. Areas closer to water bodies need careful assessment for flood risks. Proper urban planning can mitigate these risks through zoning regulations and the development of flood defences. Incorporating flood risk management into urban planning ensures sustainable development and protects investments in infrastructure and housing. Ranikhet and its surrounding region are situated in the Lesser Himalayas, where there are numerous perennial rivers. In Ranikhet, four major rivers Ramganga, Gagas, Vinod, and Kosi shape the region's landscape. The Ramganga River flows prominently from the north, comes from Chamoli, while the Gagas River divides the central area. The Vinod River is a smaller tributary of the Ramganga, and the Kosi River touches the southern boundary before flowing into Pauri Garhwal. These rivers are crucial to the area's geography and ecological balance. The study area, located in the geodynamical sensitive Kumaun Himalayan region, has experienced frequent landslide disasters over the past fifty years.

Table 6: Distance from water bodies/reason/level of suitability/ranking

Distance From Waterbodies (Meters)	Reason	Level of Suitability	Rank
0 - 340.4	Closest proximity to water bodies	Very Less	5
340.4 - 858.4	Close proximity to water bodies	Less	4
858.4 - 1539.3	Moderate proximity to water bodies	Moderate	3
1539.3 - 2294.2	Farther from water bodies	High	2
2294.3 - 3774.2	Farthest from water bodies.	Very High	1

According to (Saha & Roy, 2021) For identifying the best location, we apply Euclidean distance (Spatial Analyst) to create maps by taking equal interval has been prepared, A ranking system from 1 to 5 was applied based on the proximity to existing water bodies. Areas adjacent to rivers or streams were ranked 5, indicating very low suitability, while areas located beyond 2294.2 meters were ranked 1, signifying very high suitability. This ranking reflects a preference for higher ground to minimize flood risks and enhance residential desirability.

6.3 Physical Factor

The physical factor involves assessing the natural characteristics of a site to determine its appropriateness for urban development. Key elements of Physical factors include, elevation slope, soil, and geology formation are basic parameters for establishing settlements in hilly terrain generally. Evaluating these factors is essential to ensure the structural integrity and longevity of buildings and infrastructure. By identifying suitable land for construction and avoiding areas prone to erosion, landslides, or flooding, planners can mitigate risks and reduce construction costs. Additionally, effective analysis of physical factors supports efficient land use, proper drainage planning, and sustainable resource management. Integrating these considerations into site suitability analysis promotes resilient, cost-effective, and sustainable urban development that harmonizes with the natural landscape.

6.3.1 Geological formation

The map illustrates the geological formations of the Ranikhet area, using distinct colors to represent different geological groups. The area features five geological formations: Almora Group, Jaunsar Group, Garhwal Group, Siwalik Group, and Ramgarh Group. The Almora Formation covers the largest portion of the area. Geological data was sourced from Bhukosh, the Geological Survey of India's repository for geoscientific information. Data extraction involved collecting information on geological formations, digitizing the data, and mapping it using GIS software. The raw data was processed through various GIS techniques to create a clear and accurate representation of different geological formations. Understanding geological formations is crucial for urban planning, especially in hilly areas. It helps in identifying properties of rock formation and its properties and other geological hazards. The data supports sustainable development by guiding the construction of buildings, roads, and other infrastructure in safer zones.

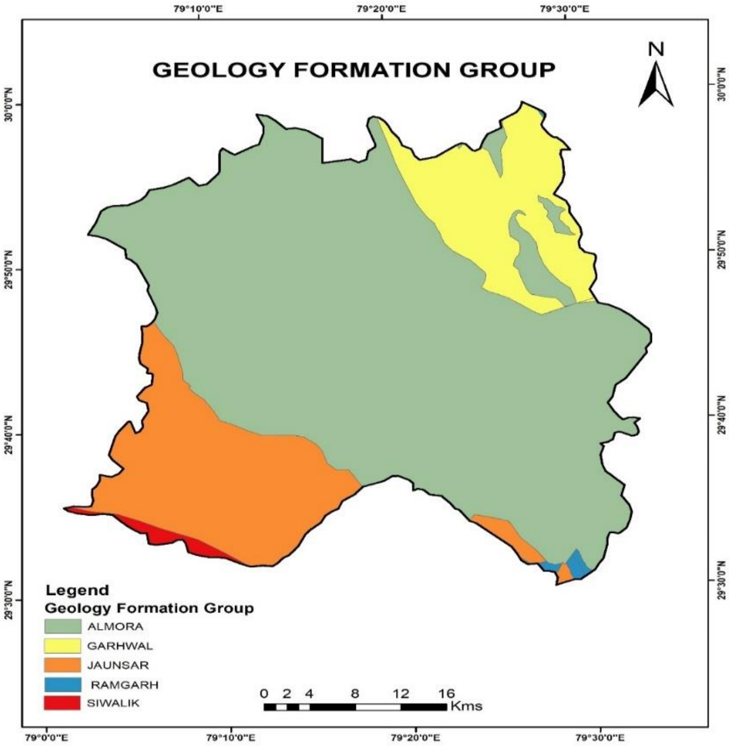

Figure 7: Map of geology formation group

It is essential for assessing the area's suitability for urban development. Understanding the geological formations provides insight into the stability, erosion potential, and overall suitability for urban development. In table provided ranks to the geological formation as their properties according to their suitability. The Almora Group offers the most stable and suitable conditions for urban development and for this it has been ranked as 1, while the Siwalik Group presents the greatest challenges due to its instability, high erosion-prone formations, primarily found in riverbeds and consisting of sediments, are deemed unsuitable for new construction. Therefore, these areas are ranked as 5, indicating they are not appropriate for development.

Table 7: Geology formation group/reason/level of suitability/ranking

Geology Formation Group	Reason	Level of Suitability	Rank
Almora Group	Predominantly consists of medium- to high-grade metamorphic rocks	Very High	1

	Composition: Gneisses, schists, quartzites, Stability: Generally stable Erosion: Less prone to erosion		
Garhwal Group	Characterized by a sequence of metasedimentary rocks Composition: Phyllites, slates, low-grade schists, Stability: Moderately stable Erosion: Prone to erosion	High	2
Jaunsar Group	Includes a variety of sedimentary rocks Composition: Sandstones, shales, limestones, Stability: Variable, Erosion: Moderate erosion risk	moderate	3
Ramgarh Group	Consists of a sequence of low-grade metamorphic rocks, Composition: Phyllites, quartzites,Stability: Moderate,Erosion: Higher erosion potential	less	4
Siwalik Group	Comprises predominantly fluvial deposits Composition: Conglomerates, sandstones, mudstones Stability: Less stable, Erosion: Highly prone to erosion	Very less	5

6.3.2 Soil Type

The map illustrates the soil types in Ranikhet, showing that the study area predominantly consists of two soil types: loam and clay loam. The soil data was obtained from the Digital Soil Map of the World, provided by the Food and Agriculture Organization (FAO). Removed inconsistencies and outliers from raw data Imported data into GIS software and classified in to soil types. Created visual representations using ArcGIS for better interpretability.Different soil types have varying load-bearing capacities, which directly impact the stability and safety of building foundations. Proper identification of soil types helps in designing foundations that can support the intended structures without risk of settling or shifting. Using soil data supports sustainable development by guiding construction to safer zones, avoiding areas prone to geological hazards. It helps in planning green spaces and agricultural areas, ensuring long-term environmental sustainability.

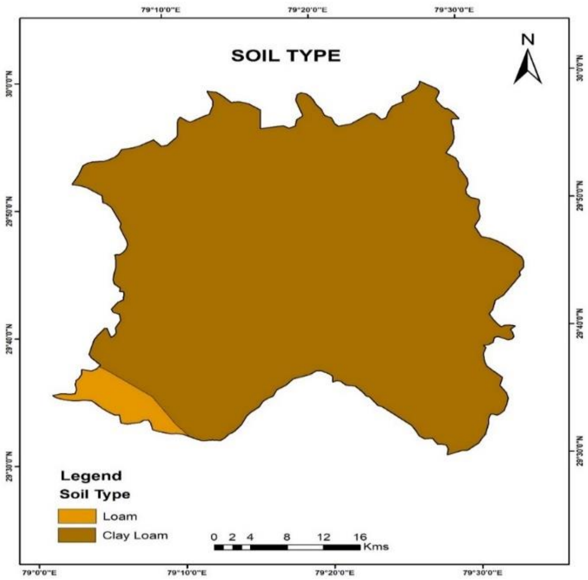

Figure 8: Map of soil type

In Ranikhet two predominant soil types often considered are clay loam and loam, each with its unique characteristics influencing their effectiveness for suitability analysis. Clay loam is generally preferred in situations where stability and load-bearing capacity are prioritized, despite the need for additional drainage solutions. Loam, while easier to work with and better at handling water, is less stable and more vulnerable to erosion, making it a secondary choice in areas where these factors are critical.

Table 8: Soil type/reason/level of suitability/ranking

Soil Type	Reason	Level Of Suitability	Rank
Clay Loam	Excellent stability, High load-bearing capacity, Poor drainage, requires engineered solutions	High	1
Loam	Good drainage, Moderate load-bearing capacity, Easier to excavate, Susceptible to erosion	Moderate	2

Clay Loam is characterized by its excellent stability and high load-bearing capacity, making it highly suitable for supporting structures and heavy loads. However, its poor drainage is a significant drawback, often requiring engineered solutions to manage water flow and prevent issues such as waterlogging or foundation instability. Due to its strengths in stability and load-bearing, Clay Loam is ranked with a high level of suitability Rank 1. On the other hand, Loam offers good drainage and moderate load-bearing capacity, making it easier to manage water flow naturally without extensive engineering. This soil type is also easier to excavate, which can reduce construction costs and time. However, its susceptibility to erosion poses a risk, particularly in areas prone to heavy rainfall or surface water runoff. Consequently, Loam is assigned a moderate level of suitability Rank 2.

6.3.3 Slope

This is the slope map of Ranikhet. The map represents the varying degrees of slope across the area, which is crucial for understanding the topography and its implications for land use, construction, and disaster management. It helps identify areas prone to landslides, soil erosion, or slope instability.

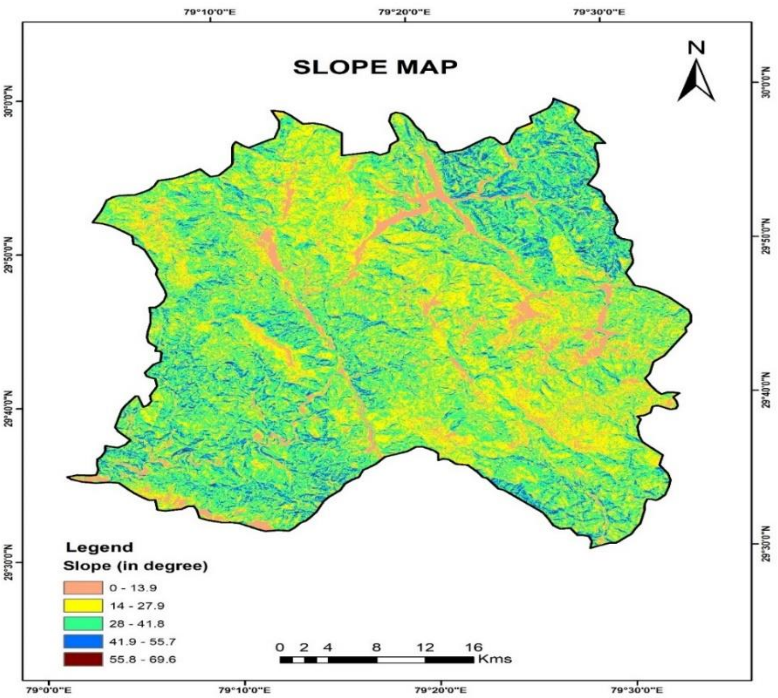

Figure 9: Map of slope

By assessing slope conditions and helps determine optimal routes for infrastructure, minimizing construction costs and the potential for damage due to natural hazards. The data for the slope map is typically acquired from Digital Elevation Models (DEMs) such as the data provided by Bhuvan is an Indian web-based platform that enables users to explore a range of geographic content created by the Indian Space Research Organization (ISRO). The raw elevation data is processed using GIS. Steps include interpolation, slope calculation, and visualization. Removal of errors and ensuring data consistency. The final slope map is generated, displaying different slope categories. It guides land use decisions by identifying appropriate areas for various types of development, such as residential, commercial, or recreational. Steep slopes are unsuitable for construction due to higher costs and increased risk. Hence, gentle slopes are preferred for building. The slope's steepness or grade is critical to consider. Cutting into hill slopes can lead to ecological damage and instability in nearby areas; thus, such activities should only be carried out with proper measures to prevent these issues and ensure site safety. In India, the Model Town and Country Planning Legislation Zoning Regulations Development (2007) governs building regulation by-laws for areas deemed hazardous. The National Building Code (NBC, 2005) advises that construction should generally be avoided on slopes exceeding 30 degrees or in areas designated as landslide hazard zones. In flat regions, these factors have minimal impact on new construction. However, for significant projects such as high-rise buildings, shopping malls, hotels, townships, and apartments, a thorough examination of the geological setup is crucial. This is particularly important for the study area, which is in a hilly region with substantial tourism growth, increasing the likelihood of urban development.

Table 9: Slope/reason/level of suitability/ranking

Slope Range (Degrees)	Reason	Level of Suitability	Rank
0 - 13.9	Most suitable for development, due to stability and low risk of natural hazards.	Very High	1
14 - 27.9	Moderately suitable for development with certain precautions and specific construction techniques to ensure stability.	High	2
28 - 41.8	Limited suitability for development due to increased risk of erosion and landslides; agricultural activities may require soil conservation measures.	Moderate	3
41.9 - 55.7	Generally unsuitable for development due to high risk of landslides; limited agricultural use with significant soil conservation efforts.	Less	4
55.8 - 69.6	Highly unsuitable for most activities due to extreme risk of landslides.	Very Less	5

The study area has been classified into five slope categories, spanning from 0 to 13.9 degrees and from 55.8 to 69.6 degrees. As the slope angle increases, the stability of the land decreases, leading to a higher risk of landslides and reduced suitability for development. As per (Rawat, 2010) slope significantly influences land suitability for development, with gentler slopes 0-13.9 degrees being the most stable and ideal for construction due to their low risk of natural hazards Rank 1 except those area with near the water bodies. As slopes increase 14-27.9 degrees, suitability decreases, requiring specific precautions and construction techniques to ensure stability Rank 2. Steeper slopes 28-41.8 degrees pose moderate risks of erosion and landslides, limiting their development potential and necessitating soil conservation measures for agricultural use Rank 3. Slopes between 41.9 and 55.7 degrees are largely unsuitable for development due to high landslide risks, though limited agricultural activities may be possible with significant soil conservation efforts Rank 4. Slopes exceeding 55.8 degrees are highly unstable and unsuitable for most activities, with an extreme risk of landslides Rank 5.

6.3.4 Digital Elevation Model (DEM)

The DEM map shows the elevation variations across Ranikhet, with different colours representing different elevation bands ranging from 419 to 2720 meters. The map includes geographical coordinates for accurate location reference and elevation details. The elevation data was obtained from the Digital Elevation Model (DEM) provided by Bhuvan, an Indian web-based service. This data was processed to develop a digital model depicting the terrain's elevation and was visualized using a GIS platform to generate the map.

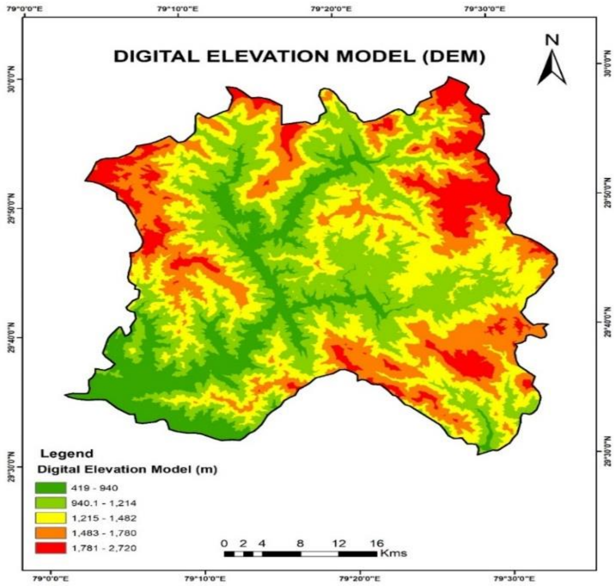

Figure 10: Map of Digital Elevation Model (DEM)

DEM provide detailed information about the terrain, including elevation, slope. This information is essential for understanding the topographic characteristics of a site, which can influence suitability for various purposes i.e. flat areas might be suitable for urban development or agriculture, while steep slopes might be suitable for conservation purposes. It can be used to model the flow of water across the landscape. By analysing the flow accumulation, flow direction, and watershed delineation derived from DEMs, It helps in identify areas prone to flooding, suitable locations for water catchment or drainage systems, and sites suitable for projects.

Table 10: Digital Elevation Model (DEM)/reason/level of suitability/ranking

Elevation Band (m)	Reason	Level of Suitability	Rank
419 - 940 (Green)	Lower elevation, High stability, Easier access, Low risk of landslides	Very High	1
940.1 - 1214 (Light Green)	Moderate elevation, Good stability, Moderate risk of landslides	High	2

1215 - 1482 (Yellow)	Moderate to high elevation, Moderate stability, Increased risk of landslides	Moderate	3
1483 - 1780 (Orange)	High elevation, Lower stability, High risk of landslides	Less	4
1781 - 2720 (Red)	Very high elevation, Lowest stability, Very high risk of landslides	Very Less	5

After further analysis as elevation increases, the stability of the land tends to decrease, while the risk of landslides increases, inversely affecting the land suitability for development. Lower elevation bands are generally more favourable for development due to their stability and ease of access, while higher elevations require careful assessment and additional safety measures to mitigate natural hazards. The elevation band from 419 to 940 meters (Green) is the most suitable, offering high stability, easy access, and low landslide risk Rank 1. As elevation increases, the stability decreases, and the risk of landslides increases. The band from 940.1 to 1214 meters (Light Green) is still highly suitable with moderate landslide risk Rank 2. Between 1215 and 1482 meters (Yellow), suitability drops to moderate due to increased landslide risk Rank 3. Higher elevations, from 1483 to 1780 meters (Orange), have lower stability and a high landslide risk, making them less suitable Rank 4. The highest elevation band, 1781 to 2720 meters (Red), is the least suitable, with the lowest stability and very high landslide risk Rank 5.

6.4 Socio-Economic Factor

People generally seek residential locations that offer social advantages, often preferring to live near others who share similar cultural backgrounds. However, this is not always feasible in rapidly expanding cities. In such cities, many people opt for cheaper plots located farther from the city centre, while others are willing to pay higher prices for properties within the city to access better civic amenities. Overall, land price is a crucial factor in new development, alongside population density and housing density. Most individuals prefer to settle in areas with low to medium density rather than in overcrowded environments.

6.4.1 Population density

The map represents the population density of Ranikhet. It is expressed as the number of persons per square kilometre. It shows varying population densities across different area of Ranikhet. The southeast area of Ranikhet, marked in dark brown, has the highest population density (204.3 - 233 persons/sq.km).

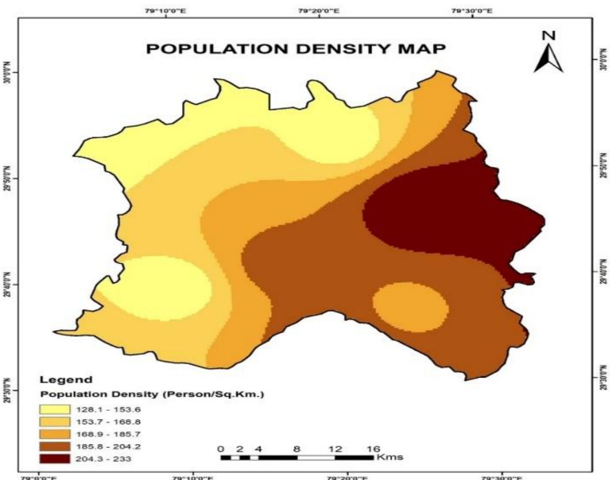

Figure 11: Map of population density

This area have more developed infrastructure and housing, attracting more residents. The population density data collected from Primary Census Abstract (PCA) census of India. Then processed to calculate the number of people per square km. It ensures that new developments provide access to essential services, improve the quality of life for all residents and reduce socio-economic disparities. By integrating socio-economic factors into site suitability analysis, we can create equitable, vibrant, and economically viable communities that meet the diverse needs of their populations.

Table 11: Population density/reason/level of suitability/ranking

Population Density (persons/sq.km)	Reason	Level of Suitability	Rank
128.1 - 153.6	Lowest population density, suggesting underdeveloped or rural areas needing more infrastructure.	Very High	1
153.7 - 168.8	Lower population density, indicating less development and fewer infrastructures	High	2
168.9 - 185.7	Moderate population density	Moderate	3
185.8 - 204.2	High population density, suggesting balanced development.	Less	4
204.3 - 233	Highest population density, indicating well-developed infrastructure and amenities.	Very Less	5

Population density is a key factor in determining development suitability for this study, the entire area was categorized into five population density groups, ranging from 128.1 to 153.6 people per square km, up to 204.3 to 233 people per square km. As most people prefer living in areas with lower population density, with the lowest population densities (128.1 - 153.6 persons/sq.km) are most suitable for development Rank 1 because they are underdeveloped and have significant potential for infrastructure expansion. As density increases to 153.7 - 168.8 persons/sq.km, the area remains highly suitable Rank 2 but with existing, though limited, infrastructure. Moderate density areas (168.9 - 185.7 persons/sq.km) offer moderate suitability Rank 3, where development is feasible but more balanced. Higher densities (185.8 - 204.2 persons/sq.km) suggest less suitability (Rank 4) due to well-established infrastructure and urbanization challenges. The highest densities (204.3 - 233 persons/sq.km) are least suitable (Rank 5) for further development due to overcrowding and limited space for expansion.

6.5 Pair wise comparison matrix

In this research, eight criteria were utilized, resulting in the development of 28 questions for the questionnaire. The most pertinent responses were chosen for further examination. Out of the 64 cells in the pairwise comparison matrix, 28 were populated based on the questionnaire data. The diagonal cells were assigned a value of 1 to represent equal importance among identical criteria, while the remaining cells were filled with the reciprocal values of the corresponding entries, as illustrated in Table 12.

Table 12: Pair wise comparison matrix by AHP

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
	RD	LULC	PD	SP	RV	GL	DEM	S
R1	1	2	3	1	3	2	1	2
R2	0.5	1	2	2	2	3	2	4

R3	0.333333	0.5	1	2	3	2	1	4
R4	1	0.5	0.5	1	3	2	1	3
R5	0.333333	0.5	0.333333	0.333333	1	1	1	2
R6	0.5	0.333333	0.5	0.5	1	1	1	1
R7	1	0.5	1	1	1	1	1	3
R8	0.5	0.25	0.25	0.333333	0.5	1	0.333333	1
Sum	5.166666	5.583333	8.583333	8.166666	14.5	13	8.333333	20

6.6 Normalized pair wise comparison matrix

Following the pairwise comparison matrix, the normalized pairwise comparison matrix is used to determine the final weights for each criterion. This process involves dividing each entry in the pairwise matrix by the sum of its column. The weight for each criterion is then calculated by averaging the normalized values in each row, as outlined in Table 13.

Table 13: Normalized pair wise comparison matrix

		C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**		
		RD	**LULC**	**PD**	**SP**	**RV**	**GL**	**DEM**	**S**	**Criterion Weights**	**Rank**
R1	**RD**	0.193548	0.282353	0.349515	0.196721	0.24	0.166667	0.096774	0.095238	0.202602	1
R2	**LULC**	0.096774	0.141176	0.23301	0.295082	0.16	0.083333	0.193548	0.190476	0.174175	2
R3	**PD**	0.064516	0.070588	0.116505	0.196721	0.24	0.166667	0.193548	0.190476	0.154878	4
R4	**SP**	0.193548	0.282353	0.058252	0.098361	0.08	0.25	0.193548	0.142857	0.162365	3
R5	**RV**	0.064516	0.070588	0.038835	0.032787	0.08	0.083333	0.096774	0.047619	0.064307	7
R6	**GL**	0.096774	0.047059	0.058252	0.04918	0.08	0.083333	0.096774	0.142857	0.081779	6
R7	**DEM**	0.193548	0.070588	0.116505	0.098361	0.08	0.083333	0.096774	0.142857	0.110246	5
R8	**S**	0.096774	0.035294	0.029126	0.032787	0.04	0.083333	0.032258	0.047619	0.049649	8
Sum		1	1	1	1	1	1	1	1	1	

The criterion "Road to distance" holds the highest influence, with a weightage of (20.26%), followed by land use land cover (17.41%), Slope (16.23, Population density (15.48%), ,Digital Elevation Model (11.02%),Geology formation (8.17%),), River to distance (6.43%), On the other hand, soil has the least impact on people's decisions for setting up residences, with a weightage of only (4.96%). The normalized pairwise comparison matrix clearly demonstrates that the "Distance from Roads" factor is the most crucial in decisions related to urban development.

Table 14: Computation of consistency vector

		C1 RD	C2 LULC	C3 PD	C4 SP	C5 RV	C6 GL	C7 DEM	C8 S	SUM	CV(λ)
R1	**RD**	[(1 ∗ 0.2026) + (2∗ 0.1741) + (3 ∗ 0.1548) + (1 ∗ 0.1623) + (3 ∗ 0.0643) + (2 ∗ 0.0817) + (1 ∗ 0.1102) + (2 ∗ 0.0496)]								1.7432	8.6041
R2	**LULC**	[(0.5 ∗ 0.2026) + (1 ∗ 0.1741) + (2 ∗ 0.1548) + (2 ∗ 0.1623) + (2 ∗ 0.0643) + (3 ∗ 0.0817) + (2 ∗ 0.1102) + (4 ∗ 0.0496)]								1.7021	8.7724
R3	**PD**	[(0.33 ∗ 0.2026) + (0.5 ∗ 0.1741) + (1 ∗ 0.1548) + (2 ∗ 0.1623) + (3 ∗ 0.0643) + (2 ∗ 0.0817) + (1 ∗ 0.1102) + (4 ∗ 0.0496)]								1.2982	8.3821
R4	**SP**	[(1 ∗ 0.2026) + (0.5 ∗ 0.1741) + (0.5 ∗ 0.1548) + (1 ∗ 0.1623) + (3 ∗ 0.0643) + (2 ∗ 0.0817) + (1 ∗ 0.1102) + (3 ∗ 0.0496)]								1.1447	7.0499
R5	**RV**	[(0.33 ∗ 0.2026) + (0.5 ∗ 0.1741) + (0.33 ∗ 0.1548) + (0.33 ∗ 0.1623) + (1 ∗ 0.0643) + (1 ∗ 0.0817) + (1 ∗ 0.1102) + (2 ∗ 0.0496)]								0.614	8.5472
C6	**GL**	[(0.5 ∗ 0.2026) + (0.33 ∗ 0.1741) + (0.5 ∗ 0.1548) + (0.5 ∗ 0.1623) + (1 ∗ 0.0643) + (1 ∗ 0.0817) + (1 ∗ 0.1102) + (1 ∗ 0.0496)]								0.6231	7.6194
R7	**DEM**	[(1 ∗ 0.2026) + (0.5 ∗ 0.1741) + (1 ∗ 0.1548) + (1 ∗ 0.1623) + (1 ∗ 0.0643) + (1 ∗ 0.0817) + (1 ∗ 0.1102) + (3 ∗ 0.0496)]								1.0118	8.1772
R8	**S**	[(0.5 ∗ 0.2026) + (0.25 ∗ 0.1741) + (0.25 ∗ 0.1548) + (0.33 ∗ 0.1623) + (0.5 ∗ 0.0643) + (1 ∗ 0.0817) + (0.33 ∗ 0.1102) + (1 ∗ 0.0496)]								0.4369	8.7998

It's important to assess the consistency of the judgments. Before calculating the Consistency Ratio (CR), it is necessary to calculate the Consistency Index (CI) and λ values. Table 14 shows the process used to compute the consistency vector.

Calculation of lambda (λ)

CI = (λ −n) ⁄ (n−1)

= (8.79−8) ⁄ (8−1)

= 0.1128

CR = CI ⁄ RI ∗ 100

= 0.1128⁄1.41 = 0.80 ∗ 100 = 8% **(OK)**

Since the consistency ratio (CR) is below 10%, it indicates that the judgments are consistent and the results can be used for further analysis.

6.7 Analysis of final suitability map

Once the final weights for each criterion were established and thematic maps were created on the GIS platform, these maps were converted into raster format using a conversion tool for a more detailed suitability analysis. The raster maps were then combined, and their sub-layers were reclassified into a 5-point scale for land suitability using the reclassification tool. Subsequently, the weighted overlay analysis tool was applied to identify and define areas suitable for future urban development. The final suitability map was classified into five categories: very highly suitable, highly suitable, moderately suitable, less suitable, and very less suitable or restricted. Table 15 shows that around 49.78 km² is designated as restricted, meaning that new development is prohibited in this region due to the presence of existing built-up areas and water bodies. The highly suitable zone is relatively small, covering only 0.57% or 10.26 km², as only a limited amount of land meets all the criteria. This indicates that the area is already well-developed, and any further development could adversely affect productive land, such as agricultural or vegetated areas.

Table 15: Different suitability categories and their area

Suitability Category	Area in sq. km	Area in percentage
Restricted	49.78429427	2.777874
Less Suitable	6.914720899	0.385829
Moderate Suitable	1191.009489	66.4562
High Suitable	534.1947519	29.80711
Very High Suitable	10.2689644	0.57299
Grand Total	1792.172221	100

The final site suitability map divides the study area into five levels of suitability: restricted or not suitable, less suitable, moderately suitable, highly suitable, and very highly suitable. The areas for each category are as follows: 49.78 km² for restricted or not suitable, 6.91 km² for

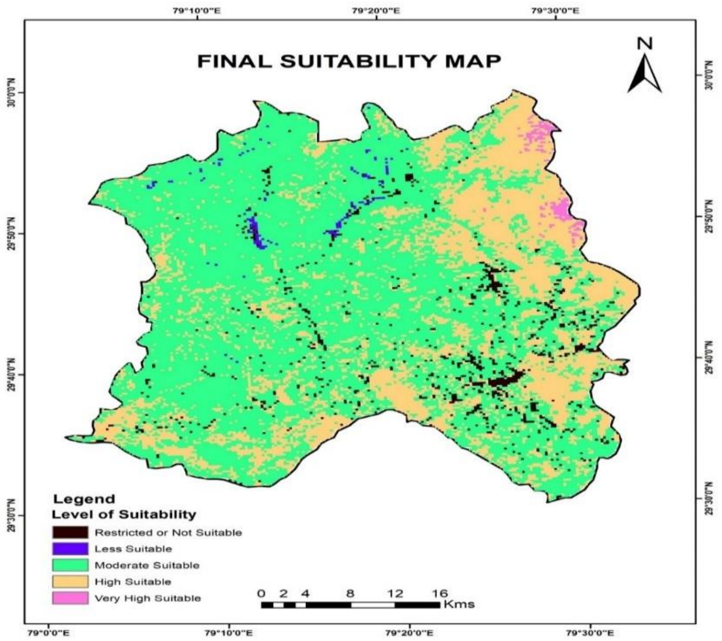

Figure 12: Final suitability map of Ranikhet for urban development

less suitable, 1191.00 km² for moderately suitable, 534.19 km² for highly suitable, and 10.26 km² for very highly suitable. Approximately 2.77% of the total area is classified as restricted, with a small portion of 0.38% categorized as less suitable. The majority of the area, 66.45%, is deemed moderately suitable, making it the largest category for suitability in Ranikhet. Only 30.37% of the land is identified as highly or very highly suitable.

Table 16: Land use land cover categories and their area

Category	Area in Sq. Km	Percentage (%)
Barren Land	**889.5775231**	**49.00665745**
Fallow Land	**2.828228125**	**0.155806552**
Agricultural Land	**17.1530821**	**0.944960047**
Plantation/ Vegetation	**847.3584393**	**46.68081611**

Settlements	**51.95810187**	**2.862362002**
Water Bodies	**6.342331407**	**0.349397837**
Grand Total	**1815.217706**	**100**

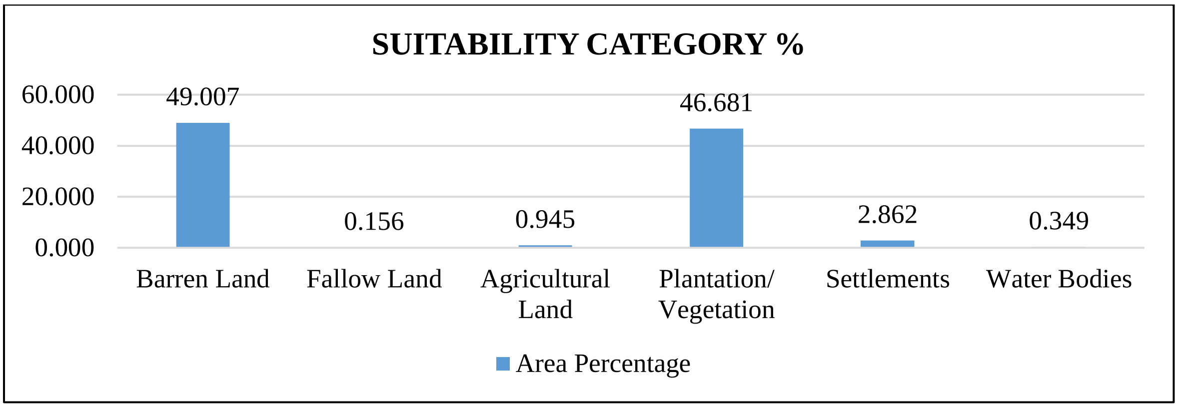

Figure 13: Bar graph of Land use land cover categories and area percentage

Table 17: Different suitability categories and their area

Suitability Category	Area in Sq. Km	Area In Percentage
Restricted	**49.78429427**	**2.777874**
Less Suitable	**6.914720899**	**0.385829**
Moderate Suitable	**1191.009489**	**66.4562**
High Suitable	**534.1947519**	**29.80711**
Very High Suitable	**10.2689644**	**0.57299**
Grand Total	**1792.172221**	**100**

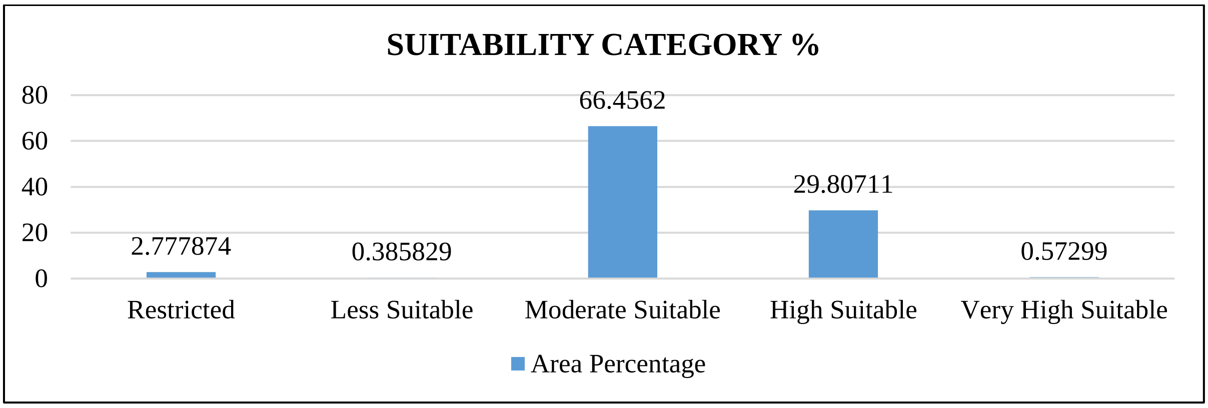

Figure 14: Bar graph of Different suitability categories and area percentage

After further analysis, it is evident that barren land accounts for the largest portion of land use, covering 889.57 sq. km, or 49.00% of the total area. This observation is reinforced by the suitability map, which indicates that a significant portion of the barren land falls within the "Moderate Suitable" category, covering approximately 66.45% of the area.

6.8 Tehsil wise map, area and their suitability

Tehsil-wise maps, area analysis, and their suitability are important components of urban development planning. They provide detailed spatial information that allows for granular decision-making, ensuring that land use is optimized and resources are allocated efficiently. These analyses support the creation of zoning regulations and inform policy decisions, leading to well-ordered and community-oriented urban development.

6.8.1 Final suitability map and suitability area for Salt and Bhikyasain tehsil

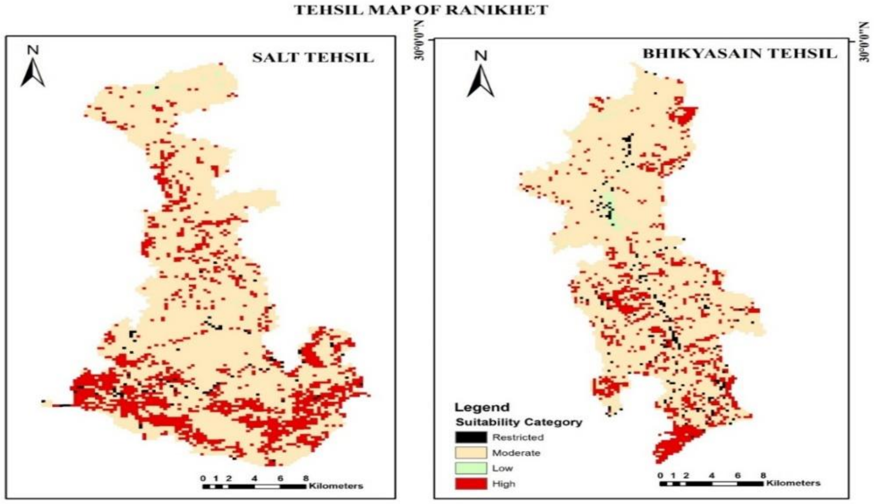

Figure 15: Final suitability map for Salt and Bhikyasain tehsil

Table 18: Salt suitability categories and their area

Suitability Category	Area in Sq. Km	Area In Percentage
High	**84.2898538**	**21.43907**
Low	**0.758286273**	**0.19287**
Moderate	**304.1079795**	**77.34967**
Restricted	**4.003922722**	**1.018395**
Grand Total	**393.1600423**	**100**

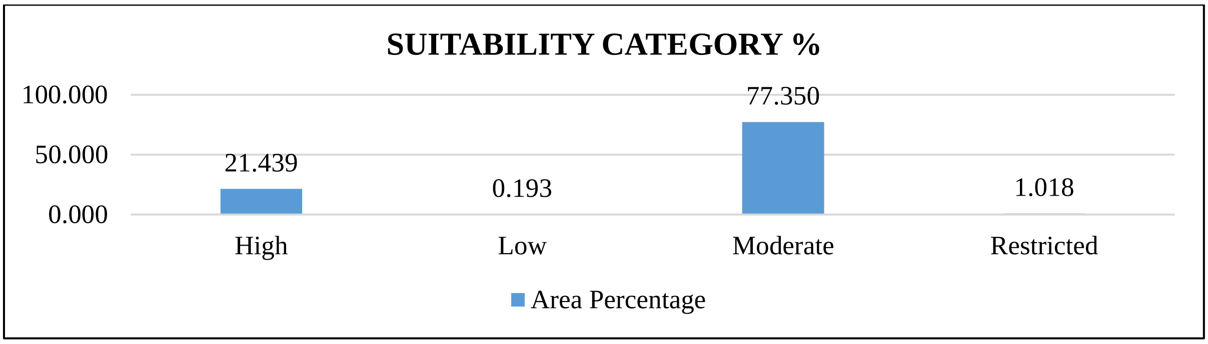

Figure 16: Bar graph of Salt suitability categories and area percentage

The largest portion of salt tehsil area falls under the "Moderate" suitability category, accounting for 77.35% of the total area. This suggests that the majority of the land is moderately suitable for the intended use. The "High" suitability category comprises 21.439% of the area. This indicates that a significant portion of the land is highly suitable, meaning it meets all or most of the criteria for the intended use. However, this category is much smaller compared to the "Moderate" category, suggesting that ideal conditions are less common. The "Restricted" category represents 1.018% of the area and "Low" suitability category is the smallest, covering only 0.193% of the area. This indicates that a very small portion of the land is considered unsuitable or restricted and low suitability area in salt tehsil.

Table 19: Bhikyasain suitability categories and their area

Suitability Category	Area in Sq. Km	Area In Percentage
High	56.01752499	14.17884
Low	3.069732145	0.776993
Moderate	327.8809066	82.99135
Restricted	8.110269928	2.052825
Grand Total	395.0784337	100

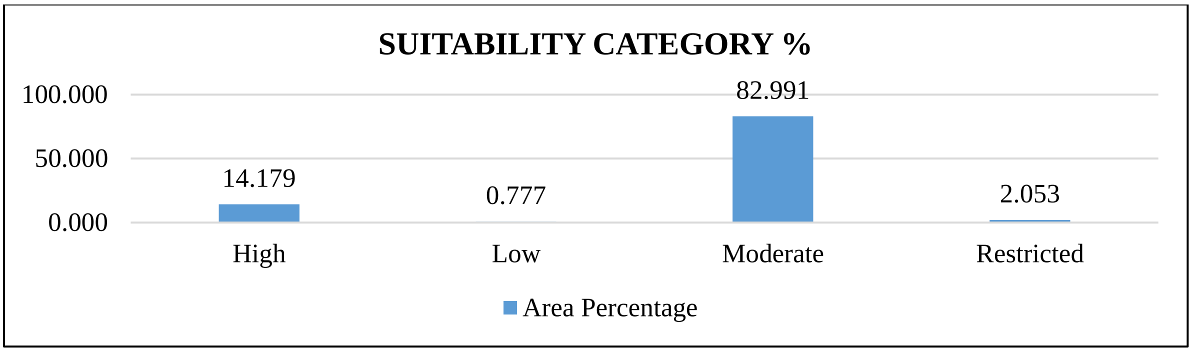

Figure 17: Bar graph of Bhikyasain suitability categories and area percentage

The bar graph illustrates the percentage area distribution of Bhikyasain tehsil land across different suitability categories. The majority of the area, 82.991%, falls under the "Moderate" suitability category, indicating that most of the land is moderately suitable for the intended use. The "High" suitability category covers 14.179% of the area, suggesting that a smaller portion of the land is highly suitable and meets most or all of the necessary criteria. The "Restricted" category, which represents 2.053% of the area, includes land that is unsuitable for development due to constraints like environmental or legal factors. Finally, the "Low" suitability category, making up only 0.777% of the area, represents land with marginal suitability, likely requiring significant interventions.

6.8.2 Final suitability map and suitability area for Chaukhutiya and Dwarahat tehsil

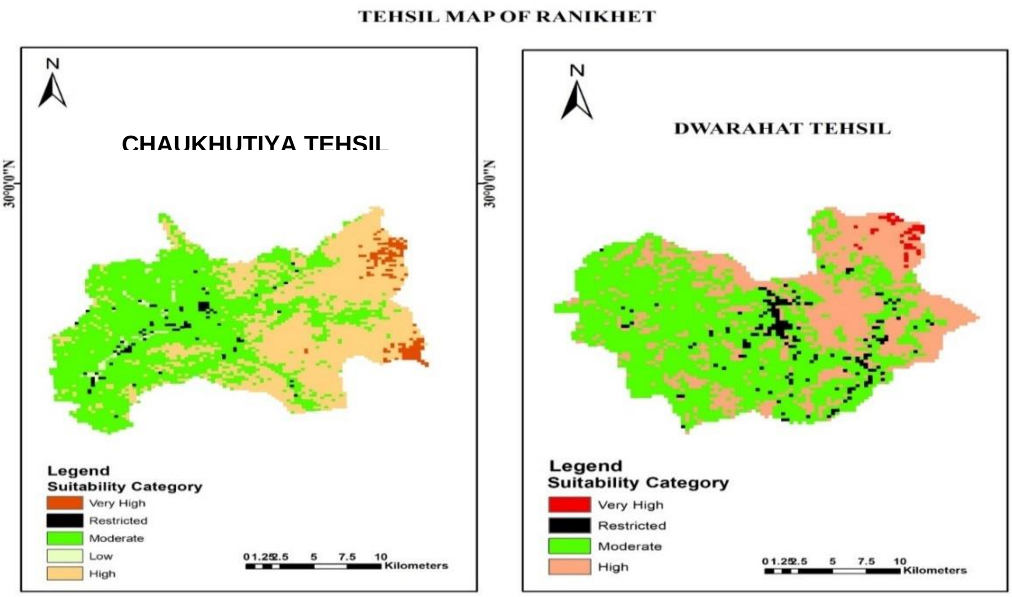

Figure 18: Final suitability map for Chaukhutiya and Dwarahat tehsil

Table 20: Chaukhutiya suitability categories and their area

Suitability Category	Area In Sq. Km	Area In Percentage
High	138.4548796	42.69652
Low	2.931506205	0.904014
Moderate	170.7426508	52.65338
Restricted	4.245892699	1.309342
Very High	7.901806723	2.436748
Grand Total	324.276736	100

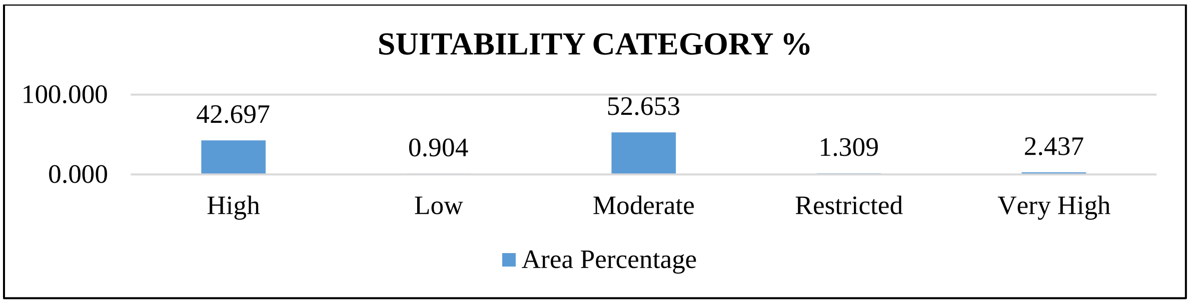

Figure 19: Bar graph of Chaukhutiya suitability categories and area percentage

The bar graph of chaukhutiya illustrates the distribution of land suitability across five categories. The majority of the area, 52.653%, falls under the "Moderate" suitability category, indicating that over half of the land is moderately suitable for development, requiring some adjustments. A significant portion, 42.697%, is classified as "High" suitability, meaning this land is well-suited for development with minimal modifications. A smaller percentage, 2.437%, is deemed "Very High" suitability, representing the land that is ideally suited for development. The "Restricted" category, covering 1.309% of the area, includes land that is unsuitable for development due to various constraints. Lastly, the "Low" suitability category, at 0.904%, represents the smallest portion of land, which is marginally suitable and likely requires significant interventions.

Table 21: Dwarahat suitability categories and their area

Suitability Category	Area in Sq. Km	Area In Percentage
High	**94.62802142**	**36.7898**
Moderate	**151.2511268**	**58.80391**
Restricted	**9.0661625**	**3.524773**
Very High	**2.267373094**	**0.881517**
Grand Total	**257.2126838**	**100**

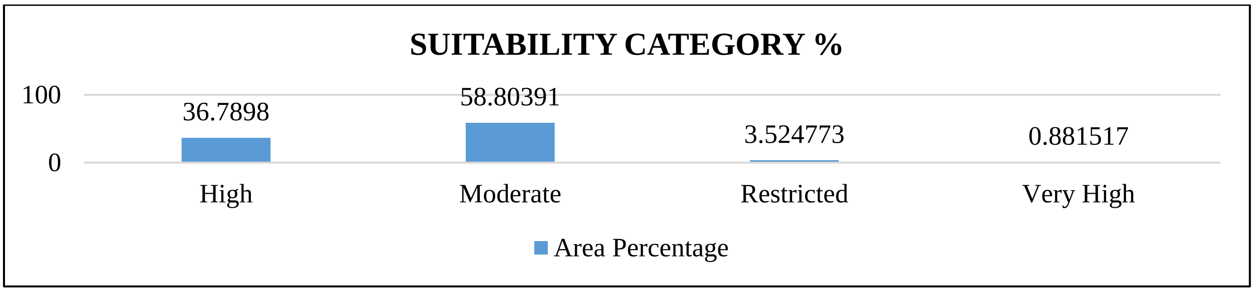

Figure 20: Bar graph of Dwarahat suitability categories and area percentage

The bar graph of Dwarahat tehsil illustrates the percentage distribution of different suitability categories for urban development within Ranikhet, based on a GIS-based multi-criteria evaluation. The majority of the area, approximately 58.80%, is categorized as "Moderate" suitability, indicating that most of the region is somewhat favorable for urban development, balancing various factors such as accessibility, environment, physical conditions, and socio-economic aspects. Following this, around 36.74% of the area falls under the "High" suitability category, suggesting that over one-third of the area is highly conducive to urban development due to advantageous physical and socio-economic characteristics. In contrast, a much smaller portion of the area, about 3.52%, is classified as "Restricted" suitability. This indicates that these areas might be under settlement or water bodies. The smallest percentage, approximately 0.88%, falls under the "Very High" suitability category, representing areas with the most optimal conditions for urban development, possibly due to favorable terrain, proximity to roads, or suitable land use. Overall, the graph reveals that the majority of the land in Dwarahat tehsil is either moderately or highly suitable for urban development, with only a small fraction of the area being either exceptionally suitable or significantly restricted for development.

6.8.3 Final suitability map and suitability area for Ranikhet tehsil

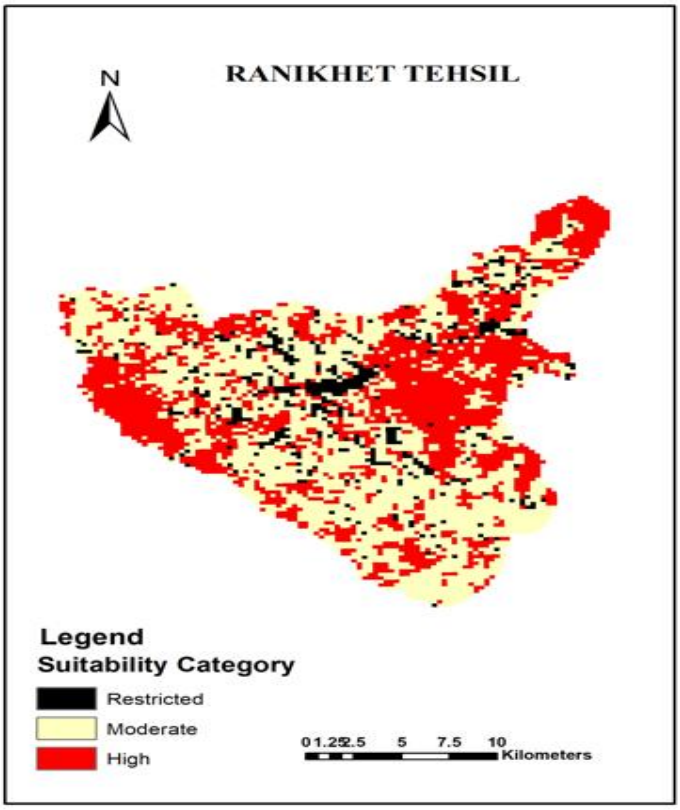

Figure 21: Final suitability map for Ranikhet tehsil

Table 22: Ranikhet suitability categories and their area

Suitability Category	Area in Sq. Km	Area In Percentage
High	138.5185723	39.93434
Moderate	184.069385	53.06646
Restricted	24.27781164	6.999195
Grand Total	346.8657689	100

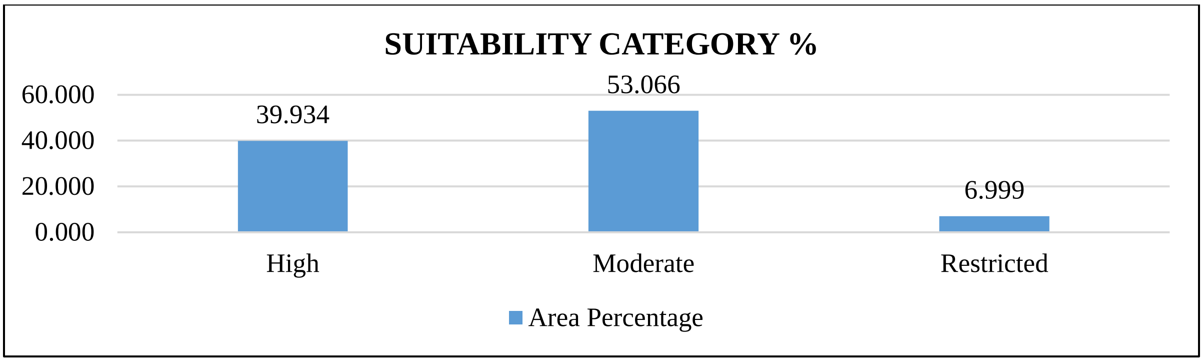

Figure 22: Bar graph of Ranikhet suitability categories and area percentage

The bar graph displays the percentage distribution of land area across three suitability categories High, Moderate, and Restricted for urban development within the Ranikhet tehsil. The largest portion of the area, approximately 53.07%, falls under the "Moderate" suitability category, indicating that over half of the region is moderately favorable for urban development. This suggests that while the area may be generally suitable, certain factors such as terrain or environmental constraints might limit its full potential for urbanization. The "High" suitability category accounts for about 39.93% of the area, indicating a substantial portion of the region is highly conducive to urban development. This reflects favorable conditions in terms of physical and socio-economic factors, making these areas particularly attractive for development projects. Lastly, the "Restricted" suitability category encompasses about 7.00% of the area. This suggests that a small portion of the land is not suitable for urban development, likely due to significant limitations such settlement or water bodies. In summary, the majority of the Ranikhet Tehsil Area is either moderately or highly suitable for urban development, with a small percentage of land being less suitable due to constraints.

7. CONCLUSION

In the context of site suitability of urban development in Ranikhet and similar hilly areas, the challenge of limited suitable land is Intensified by rapid growth in the tertiary and Research and development (R&D) sector. This diminishes the availability of land for development, necessitating land suitability analysis to guide urban planning. The GIS-based multi-criteria Analysis (MCA) method is a straightforward and adaptable tool used to identifying potential sites for urban development. This method not only facilitates the urban decision-making process but also encourages public participation, aiding planners and authorities in creating sustainable development plans. Due to the limited availability of suitable land in hilly regions i.e. Ranikhet and the rapid growth of tertiary and quaternary sectors, developmental work faces significant constraints. In many developing cities, unscientific and haphazard growth of built-up areas is common, leading to inefficient use of limited land. To address these challenges, conducting a suitability analysis for urban development is crucial. This analysis helps to identify the best locations for development and prevents haphazard growth. Implementation of GIS-based Multi-Criteria Analysis (MCA) or GIS MCE Technique is simple, cost-effective, and flexible, allowing for the analysis of potential urban development sites. It considers multiple criteria, providing a comprehensive assessment of land suitability. The model promotes public involvement in urban planning, ensuring that the needs and opinions of the community are considered in decision-making. Use of Analytic Hierarchy Process (AHP). AHP is combined with GIS-based MCA to assign weights to various criteria and determine different suitability categories within a chosen area. This process aids in selecting suitable sites for development, considering multiple factors and Stakeholder or community opinions. The case study of Siliguri demonstrates the application of this methodology. Only 1.76% of the area was classified as highly suitable for development, with most of this land coming from agricultural areas. Moderately suitable land comprised 52.33%, mainly from agricultural and wasteland areas. The study revealed a preference for development near existing roads, highlighting the importance of accessibility in land suitability. The final site suitability map of Ranikhet classifies the study area into five distinct levels of suitability. The areas classified as restricted or not suitable, less suitable, moderately suitable, highly suitable, and very highly suitable measure 49.78 km², 6.91 km², 1191.00 km², 534.19 km², and 10.26 km², respectively. Approximately 2.77 % of the total area falls under the categories of restricted and very few area in the category of less suitable area that is .38 % and moderate suitable areas is 66.45 which is the maximum area for suitability or we can say maximum area come under moderately suitable in Ranikhet. Only 30.37% of the land is categorized as either highly suitable or very highly suitable for development. This study reveals that just 10.26 km² (0.57%) of the area has been identified as highly suitable for development, and this zone is situated at a significant distance from the city center. In contrast, the majority of the area, totaling 1191 km² (66.45%), is classified as moderately suitable for new urban development. The majority of the highly suitable land is concentrated in the Chaukhutiya and Dwarahat tehsils, accounting for 10.16 km². This area is expected to be most beneficial for residential use, as the cost of land in this category is lower compared to the highly suitable areas. Although the AHP method has been utilized in various studies for determining the weight of different criteria, some limitations of this approach were encountered during this work. This limitation necessitates careful selection and possible subdivision of criteria. It is challenging to use AHP when the number of sub criteria exceeds ten. So, we have to limit our sub criteria at eight based on their requirement and availability of data, as it requires n (n-1)/2 comparisons, making it impractical. The inclusion of multiple experts can complicate the matrix for weight assignment, involving more than ten respondent can complicate the pairwise comparison process, so we limited the decision-making to ten respondent from different fields. This combined approach of GIS-based MCA and AHP supports planners, policymakers, and stakeholders in identifying areas suitable for intensive development. It enables a systematic, efficient, and transparent planning process, ensuring sustainable urban growth. By integrating GIS-based MCA and AHP, this approach offers a structured solution to the challenges of urban development in hilly areas, promoting sustainable and planned growth while considering multiple criteria and public input.

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