KATHMANDU UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF GEOMATICS ENGINEERING

A PROJECT REPORT ON

# IDENTIFICATION OF APPROPRIATE LOCATION FOR WINDMILL SITES USING GIS AND FAHP APPROACH

## A CASE STUDY OF GANDAKI PROVINCE

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January 2024

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## Abstract

Wind energy is one of the most attractive renewable energy sources because of its low operating, maintenance, and production costs as well as its low environmental impact. The goal of this study is to discover the best locations in the Gandaki province of Nepal for wind farms to be built and operated efficiently. This study applied the Geographic Information System (GIS) and Fuzzy Analytical Hierarchy (FAHP) methodologies to examine the eight important criteria upon which the suitability of locations is highly dependent. The eight criteria are Wind Speed, Slope, Elevation, Proximity to Roads, Proximity to Built-Up Areas, Proximity to Transmission Lines, Land Cover Suitability, and Airport Proximity. The importance of each criterion was based on experts' opinions. The ratings for each criterion were based on the available literature review. Based on the ratings, normalized weights of each criterion were calculated using the FAHP approach. For each criterion, a separate suitability map with five classes of suitability, ranging from least suitability rated as 1 to highest suitability rated as 5, was created. The final suitability map, obtained by performing a weighted overlay of eight maps, consists of five classes ranging from 1 to 5, whereas 5 represents the highest suitability sites and 1 represents the least suitability sites in Gandaki. This study shows that 11.12 $km^2$ and 926 km2 area of Gandaki have the highest and high suitability for the installment of wind turbines while 367.4 $km^2$ and 12778 $km^2$ area have the least and low suitability. In conclusion, this research will contribute to the enhancement of the available renewable energy resources in Gandaki province if the selected sites are utilized for wind turbines.

## Acknowledgement

We would like to sincerely thank everyone who helped us to successfully complete this project and to express our appreciation. First and foremost, we extend my deepest thanks to Mr. Ajay Kumar Thapa and Mr. Sandesh Sharma Dulal, our project supervisors for their invaluable guidance, unwavering support, and insightful feedback throughout the research process. Their knowledge and support have been crucial in determining the focus and caliber of this investigation. We also owe a debt of gratitude to the Department of Geomatics Engineering faculty, whose proficiency and insight have consistently served as a source of motivation and direction.

Special thanks go to Prof. Dr. Bivek Baral of Department of Mechanical Engineering Kathmandu University, Mr. Santosh Rai Senior Officer of Alternate Energy Promotion Center (AEPC) and those who generously shared their time, expertise, and resources, without which this project would not have been possible. Their cooperation and assistance in providing crucial data and information were indispensable to the success of this study.

Lastly, we extend our heartfelt appreciation to all the respondents and participants who took the time to contribute their insights and perspectives, enhancing the depth and relevance of this research.

Thank you all for your invaluable contributions.

Sincerely,
Abhinav Chand
Pragyan Baral
Rishav Khatiwada
Saurav Nepal
Shisir Kharel

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADB | Asian Development Bank |
| AEPC | Alternate Energy Promotion Centre |
| AHP | Analytic Hierarchy Process |
| CEIC | Census and Economic Information Center |
| COA | Center of Area |
| CR | Consistency Ratio |
| DM | Decision Maker |
| EIA | Energy Information Administration |
| FAHP | Fuzzy Analytic Hierarchy Process |
| GIS | Geographic Information System |
| GW | Gigawatt |
| LULC | Land Use/Land Cover |
| m | meter |
| MCDM | Multi-Criteria Decision Making |
| MW | Megawatt |
| MWh | Megawatt-hour |
| NBC | Nepal National Building Code |
| NEA | Nepal Electricity Authority |
| OECD | Organization for Economic Co-operation and Development |
| PJ | Peta Joule |
| PV | Photovoltaics |
| PWh | Petawatt-hour |
| RES | Renewable Electricity Sources |
| RETA | Renewable Energy Transmission Authority |
| s | seconds |
| SPVP | Solar Photovoltaic Plant |
| ToE | Tons of Oil Equivalent |
| TWh | Terawatt-hour |

# 1 INTRODUCTION

## 1.1 Background

In general terms, energy is defined as the ability to do any work. All forms of manufacturing and even consumption require energy as a resource. Diverse resources, including wood, human and animal power, rivers, coal, oil, natural gas, nuclear energy, hydrogen, and boron, have helped people as sources of energy over time. The production of energy from clean, limitless Renewable Electricity Sources (RES) has gained popularity as a result of the depletion of fossil fuels and the harm they cause to the environment (EROĞLU et al., 2022).

Renewable energy is the energy that is derived from resources that can be replenished over a period of time, making it sustainable energy despite its consumption by humankind (Banton, 2022). Renewable energy is essential because it lowers greenhouse gas emissions, slows climate change, and gives a growing world population a sustainable and clean supply of energy. Renewable energy can be produced using solar, wind, hydropower, biomass, and geothermal energy without using fossil fuels, which warm the globe (National Geographic, 2023). Of all the cleaner energy production possibilities (geothermal, solar, tidal, biomass, and hydro), wind power is the most deserving of greater widespread deployment from a technological, environmental, socioeconomic, and political standpoint (Talinli et al., 2011). One of the most alluring sustainable energy sources is wind energy due to its low production, operating, and maintenance costs as well as its comparatively minimal environmental impact (A. S. Zalhaf et al., 2022).

Nepal is a mountainous country with a high potential for wind energy. On average, Nepal gets 18 hours of wind every day in particular areas and at least two days a week, it is really windy all over the country. The analysis done by the Solar and Wind Energy Resource Assessment concludes that about 6, 074 sq km of land all over the country has the potential for wind power with density greater than 300 watt per square meter. The analysis established that two districts, Mustang and Manang, have a potential of more than 2500MW. Wind generation capacity is particularly high in the river corridors and mountain valley.(*Wondering about Wind*, 2024)

The total energy consumption of the Nepal which was 8,616,000 tons of oil equivalent (ToE) 15 years ago has increased to 14,464,000 tons of oil equivalent in 2022 A.D. (Nepal Energy Outlook, 2022). Only 58% of Nepalese households have access to the national grid, and 9% of them depend on renewable energy sources that are not grid-connected (OECD, 2016). According to the Government of Nepal's Economic Survey 2019/20, in mid-March 2020, 90% of Nepal's population had access to electricity. 9,316 GWh of total electric power were consumed in Nepal in 2022, according to data, which, in 2021, was 2,021 GWh (CEIC, 2021). Around 20% of Nepal's total energy consumption is made up of modern energy sources like electricity, petroleum, and renewable energy. Petrol use leads all sources of contemporary energy with a share of roughly 65% of overall consumption; electricity has a share of about 15%; and the remaining 20% is made up of other contemporary energy sources like coal and others (Nepal Energy Outlook, 2022). The energy consumption by fuel types in 2021 shows the dominance of traditional energy with 66% share and that of commercial and renewables share (excludes electricity) reached 31% and 2.4% respectively. Compared to 2009, the traditional energy shares however decreased from 87% whereas there is an increase in commercial and renewable shares. The total energy consumption in 2021 has increased to 626 PJ from 566PJ (163 TWh) in 2020 and 589 PJ (157 TWh) in 2019 (Water and Energy Commission Secretariat, 2022).

The Nationally Determined Contribution has set a target to increase the production of clean energy from 1,400 to 15,000 megawatts by 2030, of which 5-10% will come from mini- and micro-hydropower, solar, wind, and bio-energy. Through the Integrated National Power System, a total of 24,105 Megawatt-hours (MWh) of electrical energy have been made available up to this point, of which 22% came from Nepal Electricity Authority (NEA) plants, 40% came from independent power producers, and 38% came from India. A Solar and Wind Energy Resource Assessment estimates that simply wind energy can produce roughly 3,000 megawatts, which is much more than Nepal's need for electricity (Chhetri, 2023). Meanwhile, wind expert and Electrical Engineer Amrit Singh Thapa feels that Nepal has the capacity to generate "more than 10,000 MW from wind power as the districts of Himalayan range still need to be explored". According to Alternate Energy Promotion Centre (AEPC), two 10kW wind turbines were installed in Kagbeni, Mustang by NEA, 8 Wind Energy Pilot Projects of 3.2 kW were installed by AEPC itself, 12 Pilot Wind Project of 6.8 kW by Practical Action and major breakthrough was achieved by 10 kW wind and 2 kWp Solar PV hybrid pilot project (RETA, ADB)/2010 at Dhaubadi, Nawalparasi.

Integrating GIS and MCDM can offer help as a decision support tool to select the most suitable areas for wind turbines considering multiple impossible factors to manage and analyze traditionally because MCDM methods aim to evaluate many criteria together and suggest an optimal solution. However, in most of these methods used in this context, expert opinion is sought to determine the importance of the criteria(Nasery et al., 2021a). Selection of suitable location for renewable energy sources could make use of Geographic Information System (GIS). The best places for wind farms and even the placement of individual turbines to maximize resource potential can be determined using site selection criteria. In this study, the use of the Fuzzy Analytic Hierarchy Process (FAHP) and GIS utilized to pick a potential location for wind turbines in Nepal's Gandaki Province (Al-Shabeeb et al., 2016). Many types of evaluation criteria should be incorporated into the site selection process, including some geological and geomorphic factors, the factors associated with the local ecosystem and residents, and the distance from the public infrastructure (including roads and power lines). Therefore, it is urgent to evaluate the potential location suitability of the wind farm by the aid of the Multi-Criteria Decision Making (MCDM) method, where a comprehensive evaluation index system including social and environmental evaluation criteria was established and the reasonable position was identified based on systematic and scientific decision-making methods. With regard to the large amount of geographic and spatial information involved in site selection, the GIS tool was capable of analyzing and organizing the spatial data, estimating the candidate site score corresponding to each criterion through the raster calculation, and providing the visual map for the result demonstration. Therefore, the combination of GIS and MCDM was extensively explored to tackle the problem of wind farm location.(Li et al., 2020)

## 1.2 Problem Statement

Renewable energy has only 3% share in energy consumption pattern in Nepal till 2021 (Water and Energy Commission Secretariat, 2022). Despite having good potential for wind energy production in Gandaki province, not much windmills are installed there. The usage of fossil fuels, natural gases and coils are contributing in greenhouse gases emission, climate change and environmental pollution. The purpose of our study is to promote the usage of renewable energy directly or indirectly by determining the suitable site locations for installation of windmills in Gandaki province. This work will consider a number of factors, such as wind direction and speed, rainfall, terrain features, proximity to infrastructure and electricity grids to help decision-makers choose the location that maximize the energy output.

## 1.3 Objectives

Primary Objective

- To ascertain the suitable geographical zones for wind turbine deployment.

Secondary Objectives

- To provide information regarding the installment and establishment of wind farms to the concerned authorities and policy makers.

## 1.4 Scope

The goal of this project is to assess the potential for renewable energy while considering a variety of factors that are important for the development and use of sustainable energy. This study aims to address several key aspects:

**1. Spatial Analysis**: Geographic Information Systems (GIS) are extensively used in the research to perform spatial analysis and mapping. It need finding and characterizing locations that are suitable for installing wind turbines while taking into account variables like wind speed, topography, and environmental concerns.

**2. Integration of expert opinions**: The Fuzzy Analytic Hierarchy Process (FAHP) is used in this study to incorporate expert preferences and opinions into the decision-making process. This makes sure that when choosing the best locations for windmills, local knowledge and practical considerations are taken into account in addition to technical ones.

**3. Environmental Impact Assessment**: Analyzing the environmental effects of windmill placement while taking into account elements like wildlife habitats and land use, is another part of the scope.

**4. Future Expansion and Replicability**: In addition, the scope may include suggestions for the future development of renewable energy infrastructure, as well as the applicability of the GIS-FAHP strategy in other areas with comparable energy issues.

In conclusion, this research has a broad scope and aims to provide a comprehensive understanding of the potential assessment of renewable energy, with a focus on wind energy. It aims to direct the development of sustainable energy while taking technical, environmental, economic, and policy factors into account, ultimately helping to create more sustainable energy future.

# 2 LITERATURE REVIEW

## 2.1 Wind energy as prominent source of renewable energy

Due to the importance of selecting a renewable energy source or determining the facility/location for the selected renewable energy or determining the materials to be used or activities related to it renewable energy farm investment, many studies exist in the literature. Several research papers and articles on the potential of wind energy generation over some region of Nepal and in some countries of the world, were studied and researched upon. The continuation of life on Earth depends on energy. It will continue to be the fundamental basis for societal, economic, and international peace growth. The global need for energy has been rising rapidly. It is obvious that Earth's conventional energy resources are finite. The worldwide shortage of fossil fuel reserves, their finite supply, and their volatile costs have forced an urgent search for alternate energy sources and sharply raised interest in renewable energy sources (Al-Shabeeb et al., 2016). Not only for reducing the consumption of the fossil fuels, the enhancement and development of renewable energy also helps in minimizing the global warming. In order to quickly decarbonize and prevent further global warming, renewable energies like solar and wind power are essential (Neupane et al., 2022).

There are several ways to produce renewable energy, but wind energy has been hailed as one of the most promising for supplying the world's rising energy needs (Chedid & Rahman, 1997). According to Talinli et al. (2011), out of all the cleaner energy production possibilities (geothermal, solar, tidal, biomass, and hydro), wind power is the most deserving of greater widespread deployment from a technological, environmental, socioeconomic, and political standpoint. Because wind is free, clean, and renewable, many people have begun to understand the importance of wind energy as a key long-term renewable energy source. As a result, employing wind energy lessens reliance on conventional fossil fuel-based power generation. In turn, this guarantees both supply security and environmental sustainability (Talinli et al., 2011). Most of the articles have given a clear view on windmill energy generation being more advantageous and favorable than other sources of renewable energy.

Neupane et al. (2022) mentioned that up to 1,686 MW of wind energy could be used to generate a sizable amount of renewable energy in Nepal. The provinces of Karnali and Gandaki have the best potential for wind energy since they have a high proportion of suitable places and high-quality resource availability. Mentioning that Nepal has high potential of wind energy, but the database being poor, it is not sufficient to make realistic assessment of wind energy, Upreti & Shakya (2010) provided the information that up to 46.76 m/s of extreme wind speed and 238 kW/m$^2$ of power density are present. About 3.387 MWh/m$^2$ of energy may be produced annually on average. 6074 sq. km of the country's land might be used for wind energy, with a wind power density of more than 300 watts per square meter. At 5 MW per sq kilometer, more than 3,000 MW of electricity might be produced. Nepal only began compiling wind speed statistics from 1967. Till 2010, according to Upreti & Shakya (2010), 29 out of 40 wind measuring stations installed by the Department of Hydrology and Meteorology were functioning effectively. Out of the 29 stations, 7 were in the higher Himalayan region, 11 in middle mountain region and 11 in the Terai plains in the south. Upreti & Shakya (2010) also provided the conclusive information that in comparison to high altitude valleys and mountain ridges, low altitude valleys have wind speeds that are smaller in magnitude. Nepal National Building Code NBC 104 :1994 on wind load has divided the whole country into two regions; The lower plains and hills generally including the southern plains (Terai), Kathmandu Valley and areas generally below 3000 m altitude where the basic wind velocity of 47 m/s is adopted and the second zone lies above 3000 m where the basic wind velocity of 55 m/s is adopted. According to Department of Hydrology and Meteorology, there are currently 36 wind measuring stations in Nepal including Agrometeorology station, Synoptic station and Aeronautical station, and among them, there are 9 wind measuring working condition stations in Gandaki Province.

## 2.2 Using GIS with Multi-Criteria Evaluation (Fuzzy AHP) for suitability Analysis

Decision making by using multi criteria decision analysis is an attractive solution for obtaining an integrated decision-making result. Al-Shabeeb et al. (2016) incorporated five criteria viz. Wind Speed, Rainfall, Slope, Altitude and Land use for identifying suitable and highly suitable area for windfarm development in the North West of Jordan. Their ratings for each of the criterion were based on experts' opinion and available literature review. Likewise, Baseer et al. (2017) also used MCDM approach-based GIS modeling based on different climatic, economic, aesthetic and environmental criteria like wind resource, accessibility by roads, proximity to the electrical grid, and optimum distance from various settlements and airports for windmill establishment in Saudi Arabia. In order to determine the most appropriate sites to host large scape WPPs and SPVP, Rekik & El Alimi (2023) used GIS and AHP based on MCDM. Above mentioned research works used

AHP for the suitability analysis. Weight of the criteria were calculated according to their relative importance which is a significant task as different criteria have different important for a same problem.

Zalhaf et al. (2022) introduced an eight-criteria high-resolution mapping of the suitability of wind farms based on FAHP and GIS methodologies considering technological, environmental, social, and geographical factors. Milecz (2020) applied GIS integrated with MCDM, for identifying suitable areas for wind turbine applications in Texas. Socioeconomic criteria such as distance from roads, closeness to airports, and urban areas, as well as local ecological factors including terrain slope and distance from rivers, affected waterbodies, and wildlife management areas, were considered. The National Renewable Energy Laboratory's definition of the most important criterion, wind power density, which considers wind quantity and quality, topographical complexity, and geographic resource variability, was also considered (Milecz, 2020). Different map overlay approaches, such as Weighted Sum, Weighted Overlay, and Fuzzy Overlay were carried out by Milecz (2020) to create GIS analytical models. Each input factor was categorized and weighted using an AHP for Weighted Sum and Weighted Overlay.

Although Lee et al. (2009), Kaya and Kahraman (2010) and Tegou et al. (2010) has studied wind farm site selection by using different kinds of AHP, Buckley’s analysis of FAHP is used in this study. A multi-criteria decision-making analysis based on the FAHP method is employed to assign appropriate weights for the addressed criteria with respect to their relative importance.

# 3 METHODOLOGY

## 3.1 Conceptual Framework

The power of GIS tools is demonstrated by their integration from geographical analysis to the strategic planning of new facilities and in the simulation of supply-demand scenarios with various technological possibilities for satisfaction for renewable energy sources (RES). RES have some special "geographical qualities" for their treatment with GIS.(Domínguez & Amador, 2007).Visualization of appropriate location for windmill can be interpreted on the map using GIS based FAHP process. Users' innate ability to visualize is one factor in the rapid uptake of GIS technology. Visualization must be used during the digital outdoor data collection process in order to identify and decipher visual patterns. These patterns can be directly compared to the outdoor condition because they appear on maps and other visuals on the pen computer screen. (Pundt & Brinkkötter-Runde, 2000).

The concept of partial truth values ranging from absolutely true to absolutely false has been addressed by the fuzzy set theory. In order to handle imprecision or vagueness and achieve tractability, robustness, and affordable solutions for real-world problems, fuzzy set theory has emerged as the go-to tool. (Emrouznejad & Ho, n.d.). According to A. S. ; Zalhaf et al., (2021) Since the traditional AHP method, which was found employed in the majority of the relative case-studies, is not efficient in dealing with uncertainty when experts use a basic scale (0 to 1) for their assessments, the FAHP provides more flexible scales through the utilized fuzzy membership functions and the natural linguistic variables. A high-resolution wind farms suitability mapping based on Fuzzy Analytical Hierarchy Process (FAHP) and Geographic Information System (GIS) approaches considers technical, environmental, social, and spatial aspects, representing criteria. First, a multi-criteria decision-making analysis based on the FAHP method is employed to assign appropriate weights for the addressed criteria with respect to their relative importance. Since the traditional AHP method, which was found employed in the majority of the relative case-studies, is not efficient in dealing with uncertainty when experts use a basic scale (0 to 1) for their assessments, the FAHP provides more flexible scales through the utilized fuzzy membership functions and the natural linguistic variables. Consequently, this helps to facilitate the assessments made by experts and increases the precision of the obtained results (weights). Next, the high-resolution GIS is used to carry out a spatial analysis and integrate various factors/criteria throughout the proposed index to produce the final suitability map and identify the unsuitable areas.

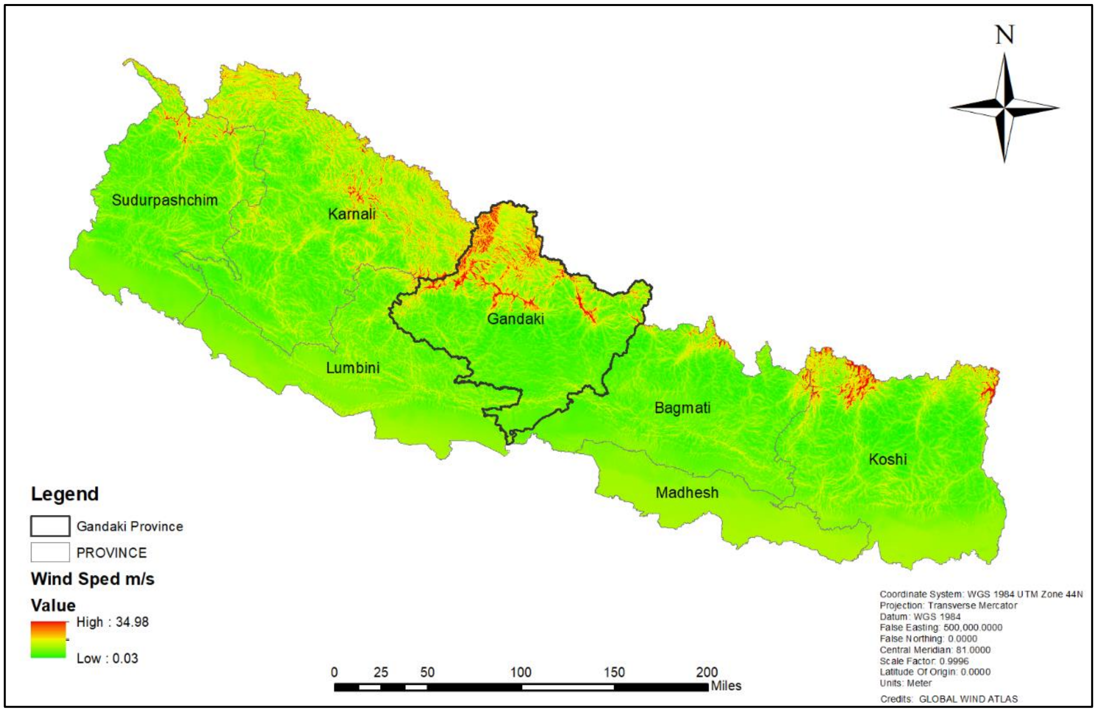


*Figure 1: Gandaki Province showing maximum wind velocity in Nepal*

Gandaki province possess areas where the average annual velocity of wind above 50m from ground level is maximum as seen in the Figure 4 below. One of factors for high wind velocity is considered as Tundra climate on high altitude of the province. Alpine tundra frequently experiences strong above the ground, and they quite frequently reach 120 to 200 km per hour (roughly 75 to 125 miles per hour) in the high reaches of the Rocky Mountains and the Alps.(Britannica, n.d.).

## 3.2 Study Area

The study area has been determined to be Gandaki Province. It is located in the country's western region. It is located between latitudes 27026'15" and 29012'01" north and longitudes 82052'45" and 85012'01" east. 21914.97 square kilometers, or 14.75% of the country's total area, make up its size. The province's land is forested to the extent of 38.01%. 17.8% of the province's land is arable, 24.7% of it is covered in snow, and 0.4% of it is submerged in water. The Himalayan regions at an altitude of 3000 to 4500 meters have an Alpine climate, while areas between 1500 and 3000 meters have a temperate climate. Tundra climate conditions can be found in the province's High Himalayan region(Nepal Outlook, n.d.). According to Global Wind Atlas (2023) the mean power density for the 10% windiest area in the Western Region (Paschimanchal) of

Nepal is 781 w/m$^2$ with an average wind velocity 9.01m/s which is highest than other zones of Nepal

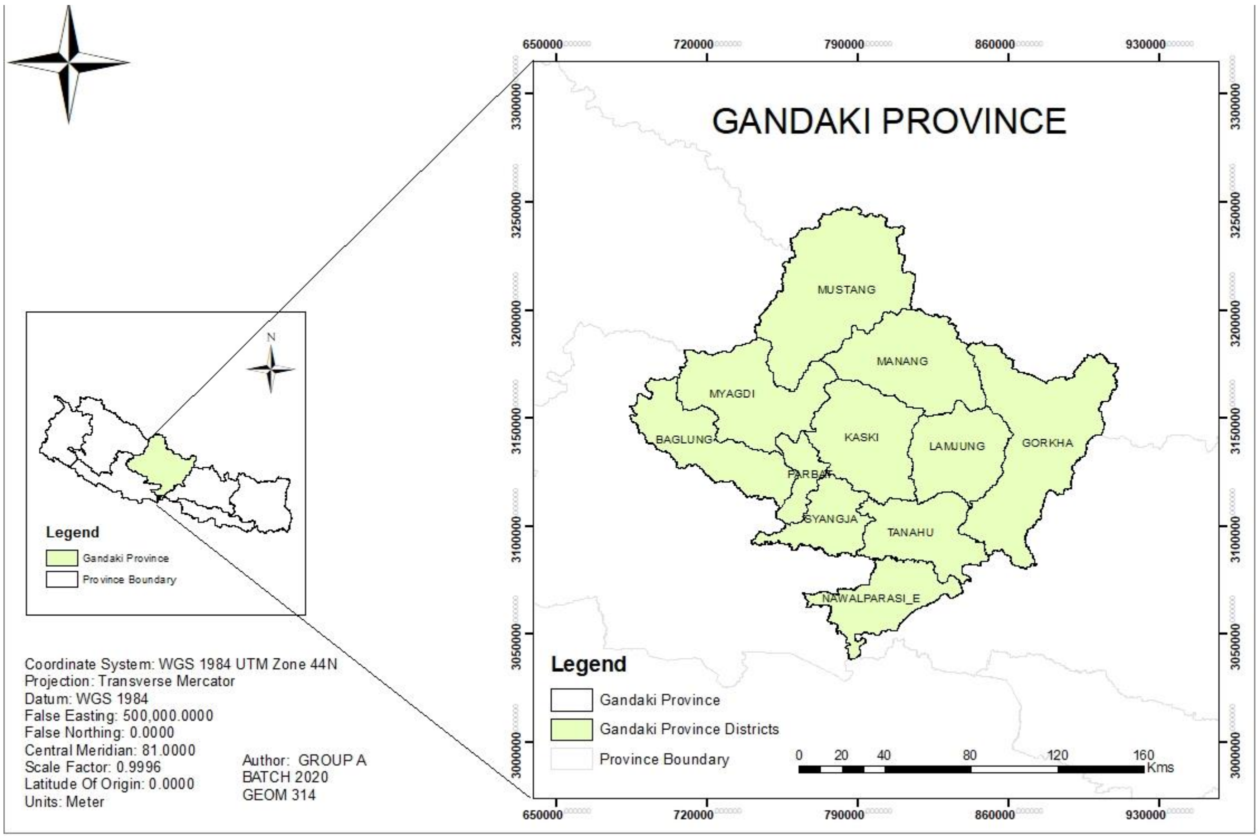


*Figure 2: Map of Gandaki Province*

## 3.3 Study Workflow

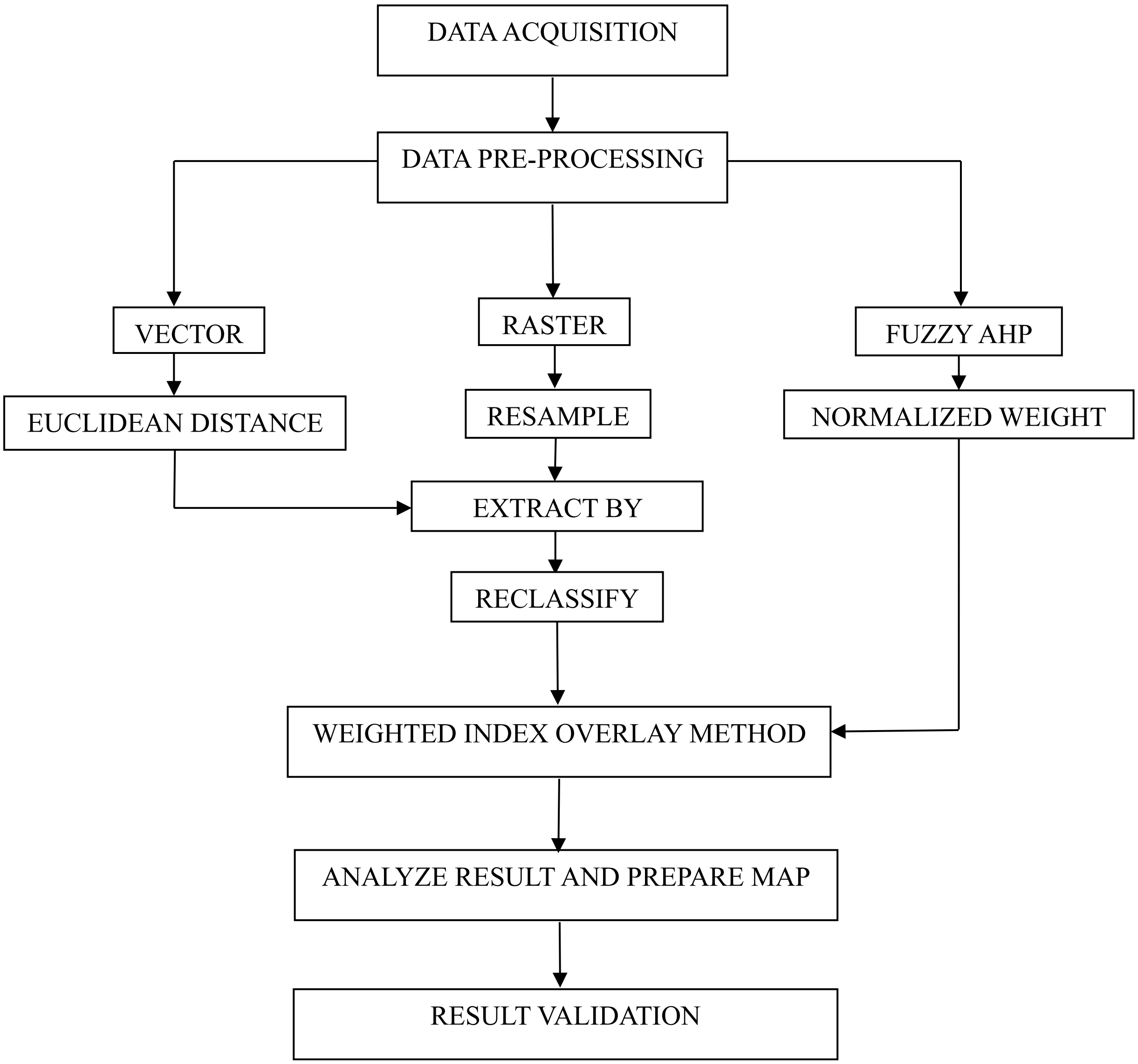


*Figure 3: Workflow Diagram*

The collection of data related to the project is the initial concern of any project. Raster, vector data according to the criterion and Digital Elevation Model (DEM), Land Use Land Cover (LULC) of study area are the primary data to begin the work. The suitability analysis for the best location of windmill in Gandaki Province is done by MCDA using FAHP technique as show in the figure 3.

## 3.4 Data description of wind farm siting criteria

### 3.4.1 Wind Speed

The average interpolated wind speed is the main and highest weighted criterion in siting a wind farm in almost all reviewed studies (Albraheem & AlAwlaqi, 2023; Al-Shabeeb et al., 2016; Baseer et al., 2017; Krewitt & Nitsch, 2003; Mentis et al., 2015; Sliz-Szkliniarz & Vogt, 2011; Tercan, 2021; Van Haaren & Fthenakis, 2011). In this study, the average wind speed data from the Global Wind Atlas is used. According to the multiple literatures that were reviewed, generally, the wind speed less than 4.8 m/s and more than 25 m/s are not suitable due to the cut-in and cut-out speed of the wind turbines (*Power Output Variation with Wind Speed (Cut in/out Speed)*, n.d.).

The classification of average wind speed into different classes of suitability is as follows:

*Table 1: The classification of average wind speed into different classes of suitability*

| Ranking | Class | Wind Speed (m/s) |
|---|---|---|
| 1 | Least Suitability | <4.8m/s and >25m/s |
| 2 | Low Suitability | 4.6-6.1 m/s |
| 3 | Moderate Suitability | 6.1-7.5 m/s |
| 4 | High Suitability | 7.5-9 m/s |
| 5 | Highest Suitability | 9-25 m/s |

### 3.4.2 Proximity to roads

Distance to roads is a significant economic consideration, and the wind farm location should be accessible from the existing road network to avoid constructing a new highway. Additionally, construction and maintenance expenses will be significantly reduced if the vehicles can easily access the site (Pamucar et al., 2017). To minimize the potential of accidents and fatalities caused by ice-throwing and falling turbine parts, a minimum safety distance of 500 m must be maintained (Moradi et al., 2020). The further classification of distance from roads into suitability classes is done on the basis of (Albraheem & AlAwlaqi, 2023; Al-Shabeeb et al., 2016; Baseer et al., 2017; EROĞLU et al., 2022; Milecz, 2020; Rekik & El Alimi, 2023; Tercan, 2021).

The classification of distance from road networks into different classes of suitability is as follows:

*Table 2: The classification of distance from road networks into different classes of suitability*

| Ranking | Class | Distance from Roads |
|---|---|---|
| 1 | Least Suitability | 0-500 m |
| 2 | Low Suitability | >15000 m |
| 3 | Moderate Suitability | 8000-15000 m |
| 4 | High Suitability | 5000-8000 m |
| 5 | Highest Suitability | 500-5000 m |
| | | |

#### 3.4.3 Distance from Transmission Lines

Transporting power to customers using existing power transmission lines enormously decreases the cost of the project (Nasery et al., 2021b; Pamucar et al., 2017; Talinli et al., 2011). Similar to the proximity to roads, a distance of 500m is considered as having least suitability because of the safety reasons. The further classification of distance from transmission lines into suitability classes is done based on (Albraheem & AlAwlaqi, 2023; Baban & Parry, 2001; El Bouanani et al., n.d.; Islam et al., 2022; Nasery et al., 2021b; Tercan, 2021).

The classification of distance from transmission lines into different classes of suitability is as follows:

*Table 3: The classification of distance from transmission lines into different classes of suitability*

| Ranking | Class | Distance from Transmission Lines |
|---|---|---|
| 1 | Least Suitability | 0-500 m |
| 2 | Low Suitability | >15000 m |
| 3 | Moderate Suitability | 8000-15000 m |
| 4 | High Suitability | 5000-8000 m |
| 5 | Highest Suitability | 500-5000 m |

#### 3.4.4 Land Use/ Land Cover Suitability

Land use has an impact on the choice of a wind farm because there are some locations where wind farms cannot be built even though there is sufficient wind speed, like in a forest, wetland, aviation zone, archaeological site, etc. Therefore, it can be generally said that the most suitable types of land are grassland, barren land, and shrubland while forests, water bodies and built up areas are considered to be least suitable (Al-Shabeeb et al., 2016; Benti et al., 2023; Milecz, 2020).

The classification of different types cover according to their suitability is done as follows:

*Table 4: The classification of different types cover according to their suitability*

| Ranking | Class | Land Cover Type |
|---|---|---|
| 1 | Least Suitability | Waterbody, Built-up Areas, Forests |
| 2 | Low Suitability | Ice, Snow |
| 3 | Moderate Suitability | Crops, Agricultural Lands |
| 4 | High Suitability | Rangeland |
| 5 | Highest Suitability | Open areas, Bare grounds |

#### 3.4.5 Distance from Built-Up Areas

The locating of wind farms close to residential areas negatively influences the environment. These effects may include noise, flickering shadows, light reflections, or landscape effects (O'Sullivan, 2020). A minimum safe distance must be maintained from urban and residential areas to the wind farm site to evict the residents of the wind farm's neighboring regions. For the wind farm project to be economically viable, a balance must be maintained between maintaining a safe distance from communities and rising transmission power losses and costs (Islam et al., 2022).

The following classification of the distance from built-up areas into different suitability classes is done based on multiple literatures like (Baban & Parry, 2001; Mentis et al., 2015; Nasery et al., 2021b; Sliz-Szkliniarz & Vogt, 2011; Talinli et al., 2011; Villacreses et al., 2017).

*Table 5: The following classification of the distance from built-up areas into different suitability classes*

| Ranking | Class | Distance from Built-Up Areas |
|---|---|---|
| 1 | Least Suitability | 0-2000 m |
| 2 | Low Suitability | 2000-5000 m |
| 3 | Moderate Suitability | 5000-10000 m |
| 4 | High Suitability | 10000-15000 m |
| 5 | Highest Suitability | >15000 m |

### 3.4.6 Distance from Airports

The process of communication, navigation, and surveillance systems used in air traffic control and related to air travel safety may be seriously affected by wind turbines (Albraheem & AlAwlaqi, 2023). Distance of at least 2500 meters from airports should be allocated for the region where the installation of wind turbines is considered least suitable (Gigović et al., 2017; Islam et al., 2022).

The following is the classification of areas of proximity from airports into different suitability classes:

*Table 6: The following is the classification of areas of proximity from airports into different suitability*

| Ranking | Class | Distance from Airports |
|---|---|---|
| 1 | Least Suitability | 0-2500 m |
| 2 | Low Suitability | 2500-6000 m |
| 3 | Moderate Suitability | 6000-9000 m |
| 4 | High Suitability | 9000-15000 m |
| 5 | Highest Suitability | >15000 m |

### 3.4.7 Slope

The slope is a major factor when choosing a suitable wind farm or turbine location. More costs are required for the turbine to cut, fill, and construct barriers on a steeper slope. Most importantly, steeper slopes make it impossible for installation equipment like cranes and trucks to lay downwind turbines to the installation location (Albraheem & AlAwlaqi, 2023; Baseer et al., 2017; Pamucar et al., 2017). In literature, the allowed maximum slope threshold range from 10% (Baban & Parry, 2001) to 30% (Tegou et al., 2010). In few studies, (Hansen, 2005; Rahman et al., 2012; Talinli et al., 2011), the slope is not at all considered as a criteria. Also, Al-Shabeeb et al., (2016) classified the region having slope upto 15% as the most suitable region.

Since the Gandaki region has slope ranging up to about 2700%, instead of classifying slopes up to 15% into multiple classes like (Albraheem & AlAwlaqi, 2023; Islam et al., 2022; Milecz, 2020), the region with slopes upto 15% is ranked as highest suitable as in (Al-Shabeeb et al., 2016).

The following is the classification of areas according to slopes into different suitability classes:

*Table 7: classification of areas according to slopes*

| Ranking | Class | Slope |
|---|---|---|
| 1 | Least Suitability | 0-15 % |
| 2 | Low Suitability | 15-25 % |
| 3 | Moderate Suitability | 25-35% |
| 4 | High Suitability | 35-45 % |
| 5 | Highest Suitability | >45 % |

### 3.4.8 Elevation

Wind direction and speed are greatly influenced by the site's elevation. Typically, wind turbines are located on higher ground to catch winds at more powerful speeds (A. S. Zalhaf et al., 2022). Sites on lower land are more likely to have obstacles (such as buildings) and may cause wind turbulence. Sites at higher elevations would be more suitable due to decreased interference from windbreakers (Effat & El-Zeiny, 2022). There are fewer wind turbulences at higher elevations and wind speeds are more consistent. Thus, higher elevations are more desirable for wind farm locations (Baban & Parry, 2001).

Since, the elevation of Gandaki ranges from about 100 meters to about 8200 meters, the classification of Gandaki into suitability classes with regards to elevation is done according to the corresponding proportion as done by Al-Shabeeb et al., (2016) and Effat & El-Zeiny, (2022).

Also, according to Khadka et al., (2020), the Snow Line Altitude (SLA) lies in the elevation zone above 4750 meters in the case of the central region of Nepal, hence the region having elevation above that is considered as least suitable region.

*Table 8: Classification on basis of Elevation*

| Ranking | Class | Elevation |
|---|---|---|
| 1 | Least Suitability | <1000 m & >4750 m |
| 2 | Low Suitability | 1000-1500 m |
| 3 | Moderate Suitability | 1500-2500 m |
| 4 | High Suitability | 2500-3500 m |
| 5 | Highest Suitability | 3500-4750 m |

## 3.5 Working with FAHP approach

The AHP is the most popular criterion weighting technique in problems involving multi-criteria decision-making (MCDM) (Alzouby et al., 2019). It cannot, however, deal with ambiguity in human reasoning. Exact numbers are replaced by fuzzy language terms, known as FAHP, to address the imprecision in AHP and provide more accurate and sufficient judgment (Galankashi et al., 2016). (A. S. Zalhaf et al., 2022) . Buckley's Fuzzy-AHP algorithm is used to define criterial weights because it is more practical in extending to the fuzzy case and assures a sole solution to the comparison matrix; the steps of this approach are relatively easier than the other Fuzzy-AHP approaches:(El Bouanani et al., 2019)

1. Create a hierarchical arrangement comprising a chief objective at the highest level, choosing intermediate criteria, and various options at the lowermost level.

2. Every individual who is knowledgeable or responsible for making decisions creates a fuzzy matrix for comparing pairs. This matrix represents the relative significance of various criteria related to the objective using a scale of relative importance, as shown in Table 9.

3. Put the DMs' ratings into one fuzzy pairwise comparison matrix ratings of various DMs could differ. Their thoughts should be aggregated to generate a single result. To explain, let ($DM_1$, $DM_2$, , $DM_2$) be the n DMs, ($F_1$, $F_2$, . . . ,$F_x$) be the x KPC, and F~ij(n) = ($l_{ij}$(n), $m_{ij}$(n), $h_{ij}$(n)) be a triangular fuzzy number representing the relative importance of Fi over Fj judged by DMn, be the aggregated relative importance of Fi over Fj. Using the geometric mean method represented in (Liu et al., 2020), the different judgments of DMs $\tilde{F}_{ij}$ = () can be aggregated.

$$\widetilde{F_{ij}} = (l_{ij}, m_{ij}, h_{ij}) = (\prod_{k=1}^{n} \widetilde{F_{ij}^{k}})^{\frac{1}{n}} = (\widetilde{F_{ij}^{1}} * \widetilde{F_{ij}^{2}} * \ldots * \widetilde{F_{ij}^{n}})^{\frac{1}{n}}$$

$$=[(\prod_{k=1}^{n} \widetilde{l_{ij}^{k}})^{\frac{1}{n}}, (\prod_{k=1}^{n} \widetilde{m_{ij}^{k}})^{\frac{1}{n}}, (\prod_{k=1}^{n} \widetilde{h_{ij}^{k}})^{\frac{1}{n}}]$$

4. Add up the fuzzy weights of the various criteria sets in the matrix computed in step-4 into a single fuzzy set. The fuzzy weights are calculated using the Geometric mean method illustrated by Equation (3) (Torfi et al., 2010).

$$\widetilde{F_i} = (\widetilde{F_{i1}} * \widetilde{F_{i2}} * \ldots * \widetilde{F_{ix}})^{\frac{1}{x}}$$

$$\widetilde{W_i} = \frac{\widetilde{F_i}}{\sum_{k=1}^{n} \widetilde{F_i}}$$

5. Make the fuzzy weights crisp for further comparison by defuzzing them sets are hard to accurately evaluate as they are partly instructed instead of stringently arranged crisp values. The center of area (CAO) method shown in Equation (4) (Liu et al., 2020) is employed to defuzzify the fuzzy weights.

$$W^* = \frac{l+m+h}{3}$$

6. Normalize the obtained weights as a final step to ascertain that the totality of all weights is exactly equal to 1.

*Table 9: Linguistic values for pairwise comparison of each criterion*

| Linguistic Variables | Triangular Fuzzy Number |
|---|---|
| Extremely important | (9,9,9) |
| Very important | (6,7,8) |
| Important | (3,5,7) |
| Moderately important | (1,3,5) |
| Intermediate | (1,2,3), (3,4,5), (5,6,7), (7,8,9) |

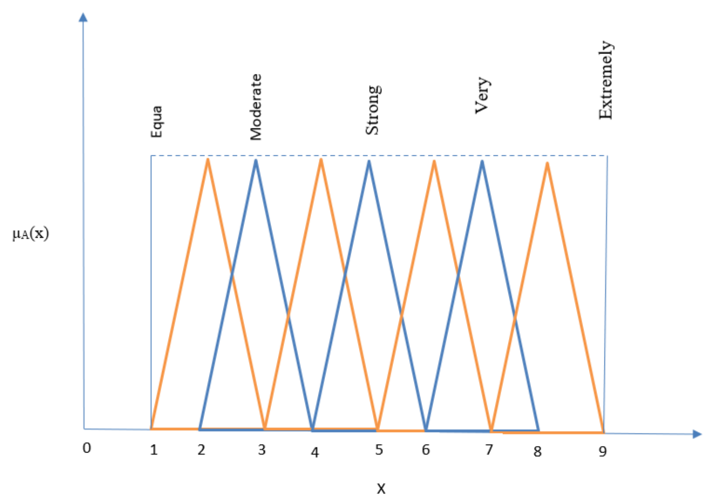


*Figure 4: Graph showing Triangular Membership Function*

*Source: Çalik, A., Paksoy, T., & Pehlivan, N. Y. (2017). Comparison of Methods in FAHP with Application in Supplier Selection. In Fuzzy Analytic Hierarchy Process (pp. 67-98). Chapman and Hall/CRC*

Hence the steps are followed as mentioned above to calculate weights of our selected criteria:

*Table 10: Distinct Numbers Given to Criteria*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Criteria | Wind | Slope | Proximity to Road | National Electricity Grid | Proximity to Residential Area | LULC | Elevation | Proximity to Airport |

**Step 1:** Creating Pairwise Comparison Matrix:

*Table 11: Creation of Pairwise Comparison Matrix*

| CRITERIA | Wind speed | Elevation | LULC | National Electricity Grid | Proximity to Settlements | Road Networks | Proximity to Airports | Slope |
|---|---|---|---|---|---|---|---|---|
| Wind Speed | (1,1,1) | (3,4,5) | (5,6,7) | (3,4,5) | (6,7,8) | (5,6,7) | (4,5,6) | (2,3,4) |
| Elevation | (1/5, 1/4, 1/3) | (1,1,1) | (1,1,1) | (1,2,3) | (2,3,4) | (2,3,4) | (1,2,3) | (1/4,1/3,1/2) |
| LULC | (1/7,1/6,1/5) | (1,1,1) | (1,1,1) | (1/4,1/3,1/2) | (2,3,4) | (1/4,1/3,1/2) | (1,2,3) | (1/6,1/5,1/4) |
| National Electricity Grid | (1/5, 1/4, 1/3) | (1/3,1/2,1) | (2,3,4) | (1,1,1) | (2,3,4) | (1,2,3) | (1,1,1) | (1/4,1/3,1/2) |
| Proximity to Settlements | (1/8,1/7,1/6) | (1/4,1/3,1/2) | (1/4,1/3,1/2) | (1/4,1/3,1/2) | (1,1,1) | (1,1,1) | (1/3,1/2,1) | (1/5, 1/4, 1/3) |
| Road Networks | (1/7,1/6,1/5) | (1/4,1/3,1/2) | (2,3,4) | (1/3,1/2,1) | (1,1,1) | (1,1,1) | (1/3,1/2,1) | (1/6,1/5,1/4) |
| Proximity to Airports | (1/6,1/5,1/4) | (1/3,1/2,1) | (1/3,1/2,1) | (1,1,1) | (1,2,3) | (1,2,3) | (1,1,1) | (1/4,1/3,1/2) |
| Slope | (1/4,1/3,1/2) | (2,3,4) | (4,5,6) | (2,3,4) | (3,4,5) | (4,5,6) | (2,3,4) | (1,1,1) |

$$\tilde{A}^{-1} = (l, m, n)^{-1} = (1/u, 1/m, 1/n)$$

**Step 2:** To calculate Fuzzy Geometric Mean Value ($\check{r}_i$):

*Table 12: Calculating Fuzzy Geometric Mean Values*

| CRITERIA | Wind speed | Elevation | LULC | National Electricity Grid | Proximity to Settlements | Road Networks | Proximity to Airports | Slope | Fuzzy Geometric Mean Value ři |
|---|---|---|---|---|---|---|---|---|---|
| Wind Speed | (1,1,1) | (3,4,5) | (5,6,7) | (3,4,5) | (6,7,8) | (5,6,7) | (4,5,6) | (2,3,4) | (3.19,3.96,4.69) |
| Elevation | (1/5, 1/4, 1/3) | (1,1,1) | (1,1,1) | (1,2,3) | (2,3,4) | (2,3,4) | (1,2,3) | (1/4,1/3,1/2) | (0.82,1.15,1.49) |
| LULC | (1/7,1/6,1/5) | (1,1,1) | (1,1,1) | (1/4,1/3,1/2) | (2,3,4) | (1/4,1/3,1/2) | (1,2,3) | (1/6,1/5,1/4) | (0.48,0.59,0.79) |
| National Electricity Grid | (1/5, 1/4, 1/3) | (1/3,1/2,1) | (2,3,4) | (1,1,1) | (2,3,4) | (1,2,3) | (1,1,1) | (1/4,1/3,1/2) | (0.71,0.96,1.3) |
| Proximity to Settlements | (1/8,1/7,1/6) | (1/4,1/3,1/2) | (1/4,1/3,1/2) | (1/4,1/3,1/2) | (1,1,1) | (1,1,1) | (1/3,1/2,1) | (1/5, 1/4, 1/3) | (0.33,0.4,0.54) |
| Road Networks | (1/7,1/6,1/5) | (1/4,1/3,1/2) | (2,3,4) | (1/3,1/2,1) | (1,1,1) | (1,1,1) | (1/3,1/2,1) | (1/6,1/5,1/4) | (0.44,0.55,0.75) |
| Proximity to Airports | (1/6,1/5,1/4) | (1/3,1/2,1) | (1/3,1/2,1) | (1,1,1) | (1,2,3) | (1,2,3) | (1,1,1) | (1/4,1/3,1/2) | (0.51,0.71,1.01) |
| Slope | (1/4,1/3,1/2) | (2,3,4) | (4,5,6) | (2,3,4) | (3,4,5) | (4,5,6) | (2,3,4) | (1,1,1) | (2.10,2.34,2.95) |

$$\tilde{A}_1 * \tilde{A}_2 = (1_1, m_1, n_1) * (l_2, m_2, n_2) = (l_1{*}l_2, m_1{*}m_2, n_1{*}n_2)$$

$$\check{r}_i = ((l_1{*}\ m_1{*}\ n_1 \ldots\ldots k_n)^{1/n},\ (l_2{*}\ m_2{*}\ n_2 \ldots\ldots k_n)^{1/n},\ ((l_3{*}\ m_3{*}\ n_3 \ldots\ldots k_n)^{1/n}))$$

**Step 3:** Calculating Fuzzy Weight ($\hat{w}_i$):

*Table 13: Calculating Fuzzy Weights*

| CRITERIA | Wind speed | Elevation | LULC | National Electricity Grid | Proximity to Settlements | Road Networks | Proximity to Airports | Slope | Fuzzy Geometric Mean Value ři | Fuzzy Weights ŵ |
|---|---|---|---|---|---|---|---|---|---|---|
| Wind Speed | (1,1,1) | (3,4,5) | (5,6,7) | (3,4,5) | (6,7,8) | (5,6,7) | (4,5,6) | (2,3,4) | (3.19,3.96,4.69) | (0.24,0.37,0.84) |
| Elevation | (1/5, 1/4, 1/3) | (1,1,1) | (1,1,1) | (1,2,3) | (2,3,4) | (2,3,4) | (1,2,3) | (1/4,1/3,1/2) | (0.82,1.15,1.49) | (0.06,0.11,0.27) |
| LULC | (1/7,1/6,1/5) | (1,1,1) | (1,1,1) | (1/4,1/3,1/2) | (2,3,4) | (1/4,1/3,1/2) | (1,2,3) | (1/6,1/5,1/4) | (0.48,0.59,0.79) | (0.04,0.06,0.14) |
| National Electricity Grid | (1/5, 1/4, 1/3) | (1/3,1/2,1) | (2,3,4) | (1,1,1) | (2,3,4) | (1,2,3) | (1,1,1) | (1/4,1/3,1/2) | (0.71,0.96,1.3) | (0.05,0.09,0.23) |
| Proximity to Settlements | (1/8,1/7,1/6) | (1/4,1/3,1/2) | (1/4,1/3,1/2) | (1/4,1/3,1/2) | (1,1,1) | (1,1,1) | (1/3,1/2,1) | (1/5, 1/4, 1/3) | (0.33,0.4,0.54) | (0.02,0.04,0.1) |
| Road Networks | (1/7,1/6,1/5) | (1/4,1/3,1/2) | (2,3,4) | (1/3,1/2,1) | (1,1,1) | (1,1,1) | (1/3,1/2,1) | (1/6,1/5,1/4) | (0.44,0.55,0.75) | (0.03,0.05,0.13) |
| Proximity to Airports | (1/6,1/5,1/4) | (1/3,1/2,1) | (1/3,1/2,1) | (1,1,1) | (1,2,3) | (1,2,3) | (1,1,1) | (1/4,1/3,1/2) | (0.51,0.71,1.01) | (0.04,0.07,0.18) |
| Slope | (1/4,1/3,1/2) | (2,3,4) | (4,5,6) | (2,3,4) | (3,4,5) | (4,5,6) | (2,3,4) | (1,1,1) | (2.10,2.34,2.95) | (0.16,0.22,0.53) |

$$\hat{w}_i = \check{r}_i * (\check{r}_1 + \check{r}_2 + \check{r}_3 + \ldots\ldots + \check{r}_n)^{-1}$$

**Step 4:** To calculate Final Weights ($\hat{W}_i$)

*Table 14: Calculation of Average Weights*

| CRITERIA | Fuzzy Geometric Mean Value ři | Fuzzy Weights ŵ | Weights Ŵi |
|---|---|---|---|
| Wind Speed | (3.19,3.96,4.69) | (0.24,0.37,0.84) | 0.48 |
| Elevation | (0.82,1.15,1.49) | (0.06,0.11,0.27) | 0.15 |
| LULC | (0.48,0.59,0.79) | (0.04,0.06,0.14) | 0.08 |
| National Electricity Grid | (0.71,0.96,1.3) | (0.05,0.09,0.23) | 0.12 |
| Proximity to Settlements | (0.33,0.4,0.54) | (0.02,0.04,0.1) | 0.05 |
| Road Networks | (0.44,0.55,0.75) | (0.03,0.05,0.13) | 0.07 |
| Proximity to Airports | (0.51,0.71,1.01) | (0.04,0.07,0.18) | 0.1 |
| Slope | (2.10,2.34,2.95) | (0.16,0.22,0.53) | 0.3 |
| Total | | | 1.35 |

$$\hat{W}_i = \left(\frac{l+m+n}{3}\right)$$

**Step 5**: Lastly, we have to calculate Normalized weight if sum of Final Weight ($\hat{W}_i$) is not equal to 1. Normalized weight is calculated by dividing each Final Weight ($\hat{W}_i$) by sum of Final Weight ($\hat{W}_i$)

*Table 15: Calculation of Final Normalized Weights*

| CRITERIA | Fuzzy Geometric Mean Value ři | Fuzzy Weights ŵ | Weights Ŵi | Normalized Weights |
|---|---|---|---|---|
| Wind Speed | (3.19,3.96,4.69) | (0.24,0.37,0.84) | 0.48 | 0.36 |
| Elevation | (0.82,1.15,1.49) | (0.06,0.11,0.27) | 0.15 | 0.11 |
| LULC | (0.48,0.59,0.79) | (0.04,0.06,0.14) | 0.08 | 0.06 |
| National Electricity Grid | (0.71,0.96,1.3) | (0.05,0.09,0.23) | 0.12 | 0.09 |
| Proximity to Settlements | (0.33,0.4,0.54) | (0.02,0.04,0.1) | 0.05 | 0.04 |
| Road Networks | (0.44,0.55,0.75) | (0.03,0.05,0.13) | 0.07 | 0.05 |
| Proximity to Airports | (0.51,0.71,1.01) | (0.04,0.07,0.18) | 0.1 | 0.07 |
| Slope | (2.10,2.34,2.95) | (0.16,0.22,0.53) | 0.3 | 0.22 |
| Total | | | 1.35 | 1 |

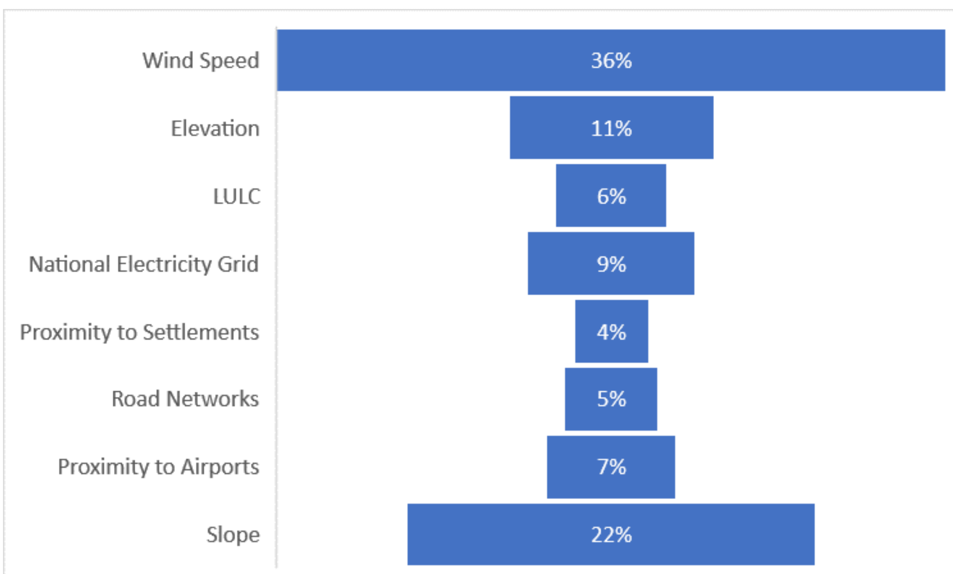


*Figure 5: Final Weight of Criteria in Percentage*

# 4 Data Sources

The data required for this project is according to the criteria used for decision making. Table showing the required data and its respective sources are shown below. Data are the most important factors to help identify the best required result. However, it is not easy to obtain all the required data, some are open and freely available whereas we also must visit governments officials with proper recommendations for other national data like LULC and Digital Elevation Model (DEM).

*Table 16: Data Sources*

| S.N. | Data | Data Sources |
|---|---|---|
| **1** | Wind Speed | Global Wind Speed |
| **2** | LULC | Esri Global Land Cover |
| **3** | National Electricity Grid | Rastriya Prasaran Grid Company Limited |
| **4** | Settlements | Esri Global Land Cover |
| **5** | Road Network | ICIMOD |
| **6** | Airports proximity | Open Street Map |
| **7** | DEM | United States Geological Survey (USGS) |

# 5 Softwares

The lists of softwares used for the completion of this work are:

1. Microsoft Office packages
2. GIS Environment

# 6 GANTT CHART

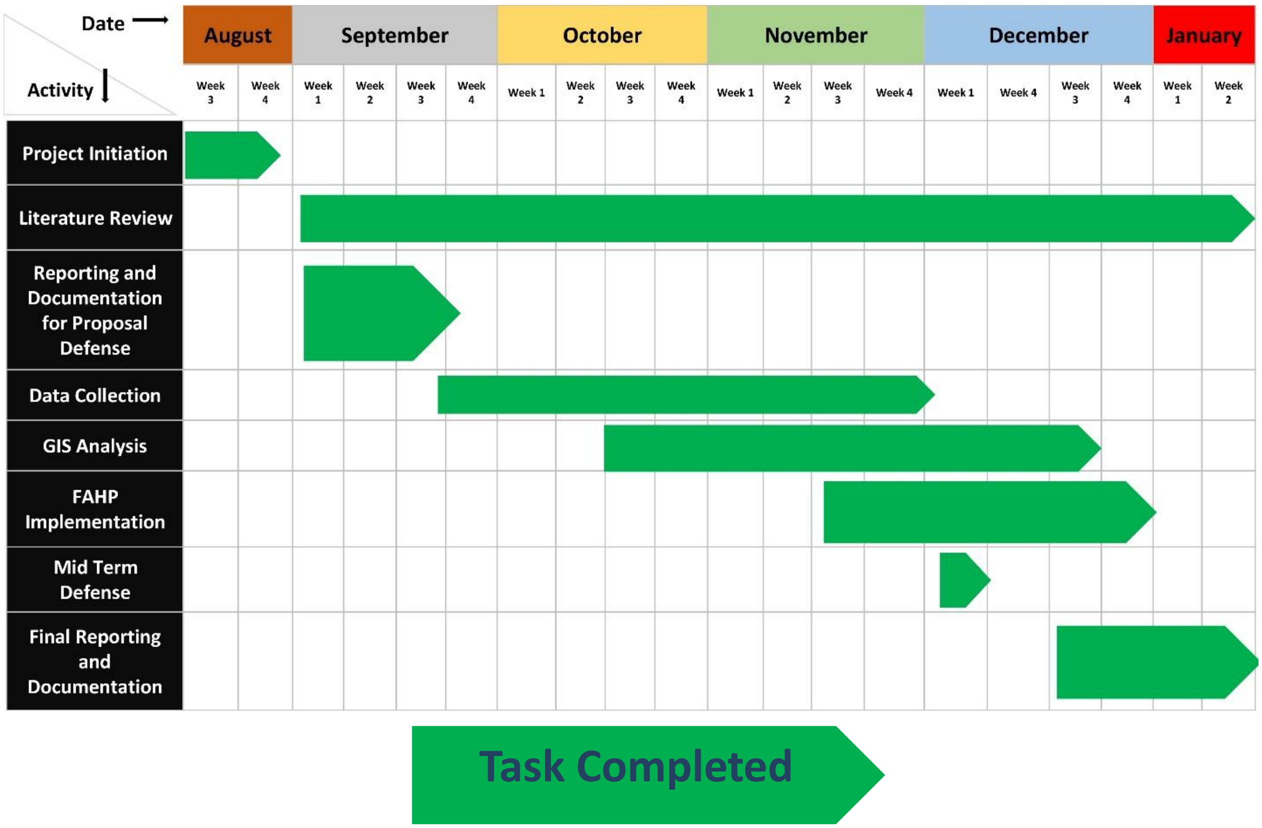


*Figure 6: GANNT Chart*

# 7 RESULTS AND DISCUSSION

The five different layers of criteria utilized in this suitability analysis are schematically depicted in Figures 7 through 14. The weighted overlay method is used to combine all data layers, and the scores obtained from the weighted overlay are reclassified into five classes to determine the final suitability indices for the province. Figure 15 displays the final wind farm suitability map. There are five classes on this map: class 1 is the area least suited for the development of wind farms, and class 5 is the best suited. The table below shows the area and percentage of land covered by different classes of suitability.

*Table 17: Area and Area-percetage of Suitability Zones*

| **Suitability Type** | **Area in sq.km** | **Percentage** |
|---|---|---|
| Least Suitability | 567.4 | 1.67% |
| Low Suitability | 12278.01 | 58.13% |
| Moderate Suitability | 7899.9 | 35.94% |
| High Suitability | 926.05 | 4.21% |
| Highest Suitability | 11.12 | 0.05% |

Among criteria we selected for this suitability analysis it was found that alongside windspeed (most important criterion with weight 36%) slope and elevation are other crucial factor to determine the best suited location within the province having weights of 22% and 11% respectively as shown in figure 5. The upper region of the province where wind velocity, slope and elevation are maximum, is shown as the best suited location for establishment of windmill.

The figure 16 shows the suitability map with two classes, high and highest suitable which help in validation of our output.

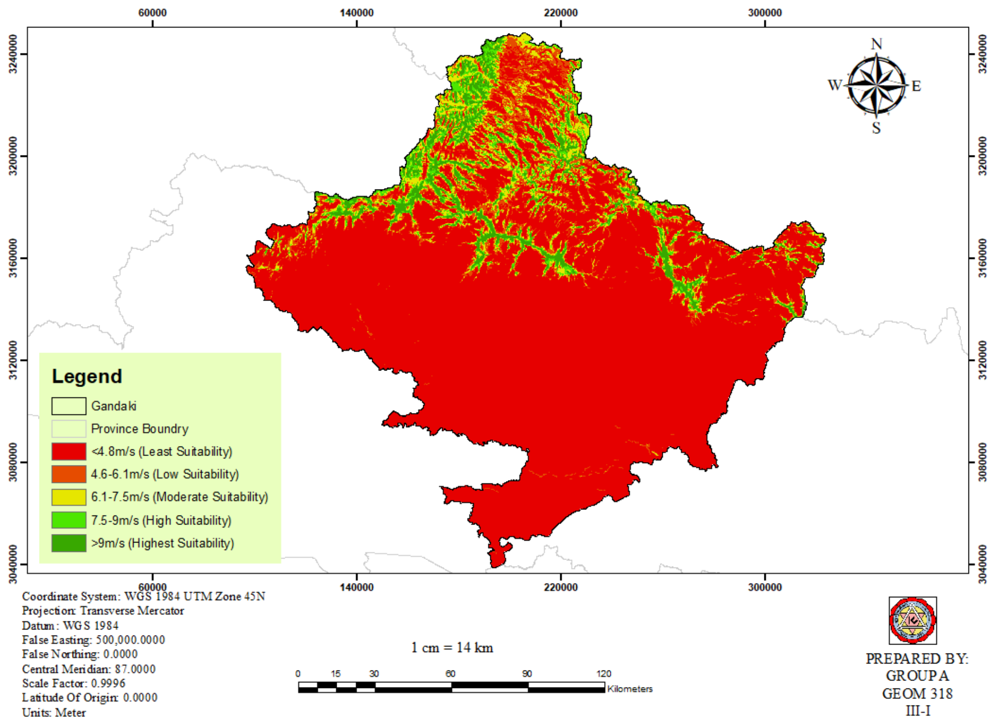


*Figure 7: Wind Suitability Map*

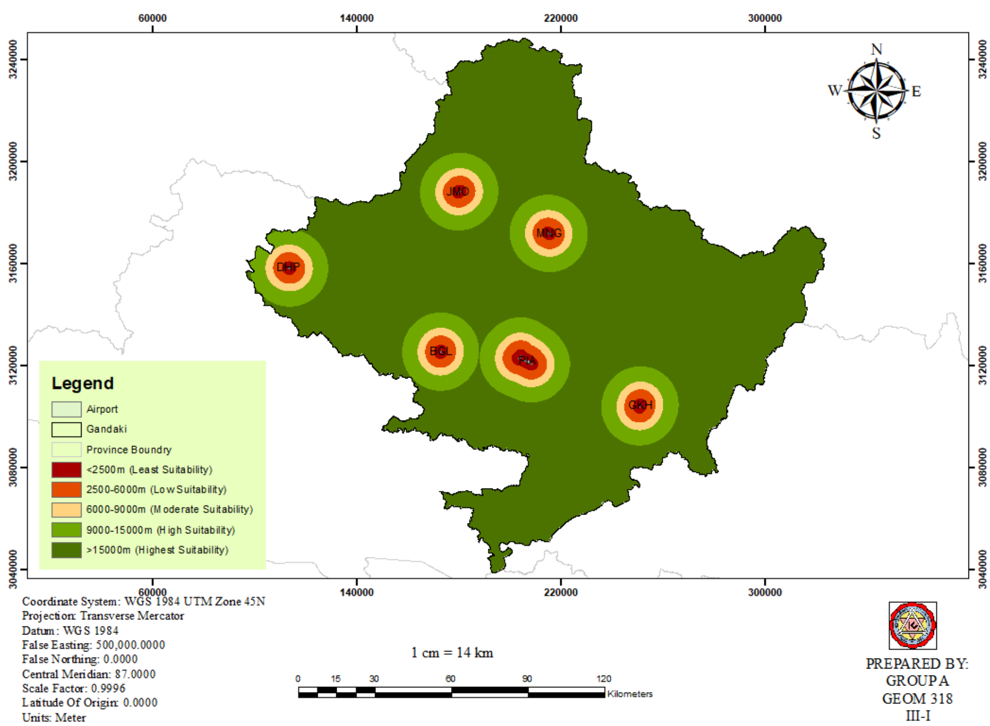


*Figure 8: Airport Proximity Suitability Map*

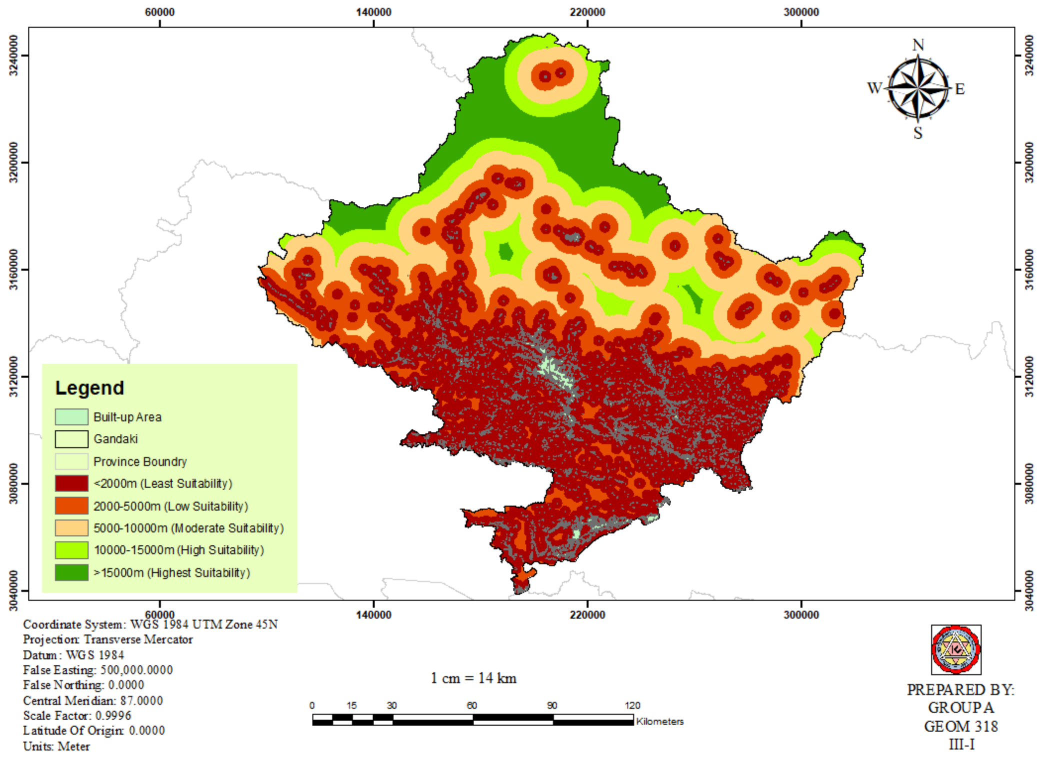


*Figure 9: Built-up Area Proximity Map*

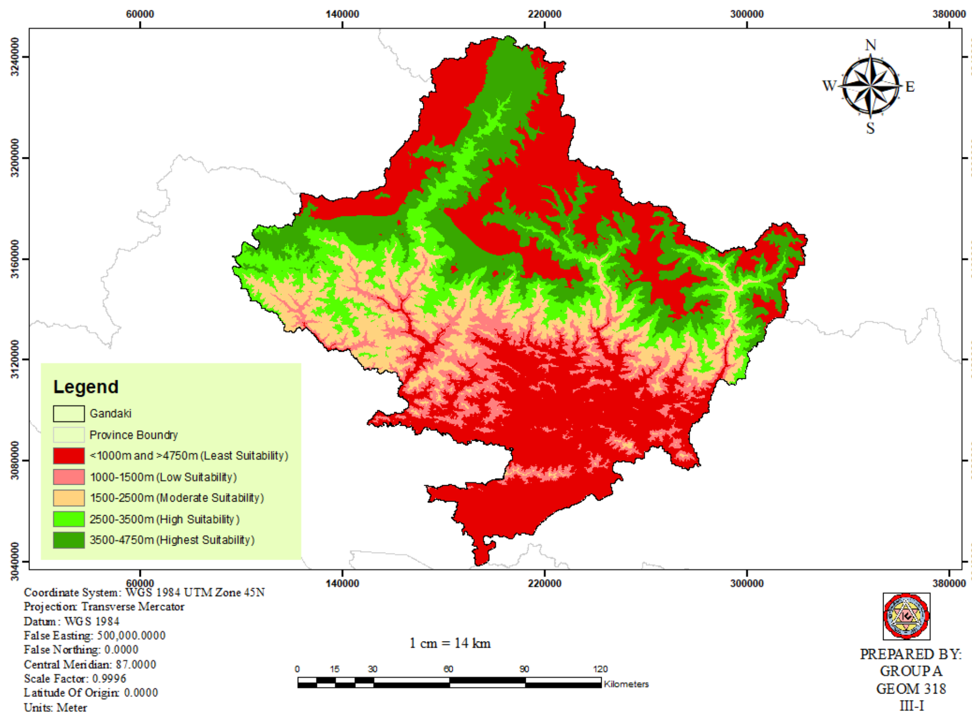


*Figure 10: Elevation Suitability Map*

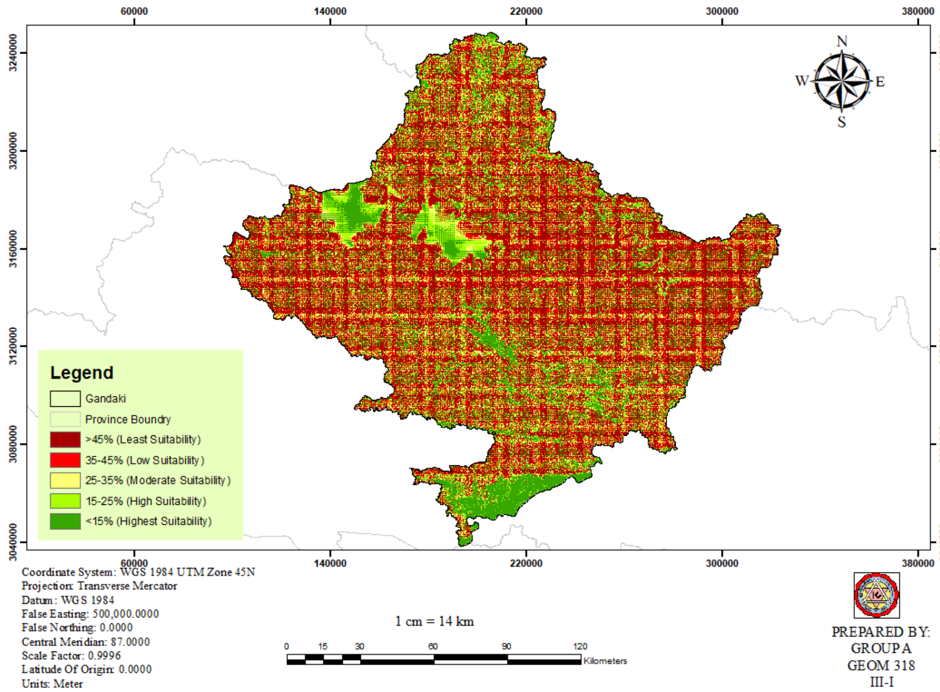


*Figure 11: Slope Suitability Map*

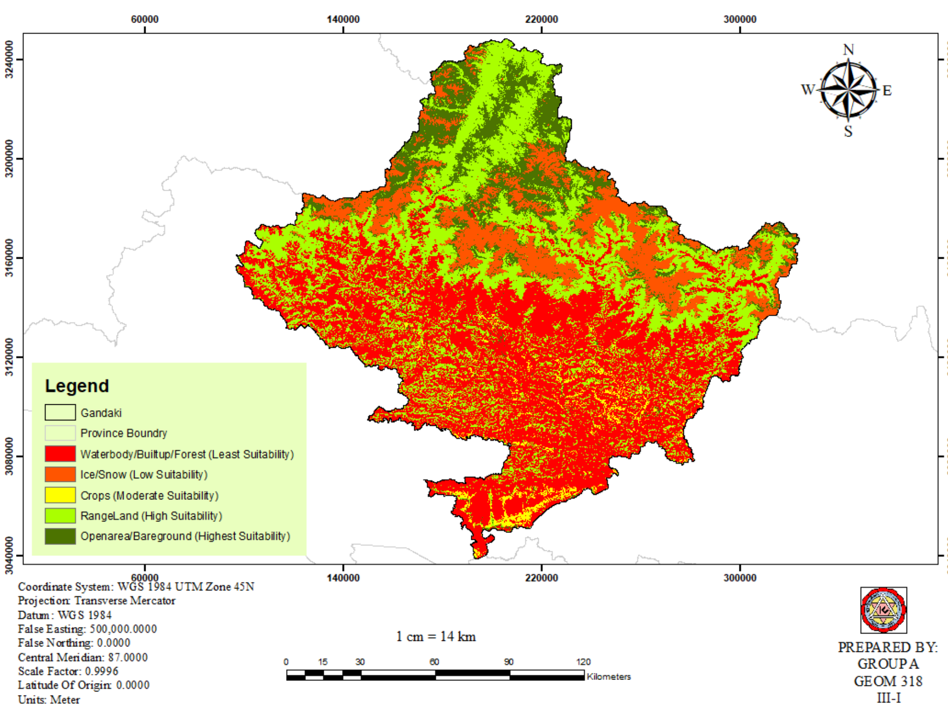


*Figure 12: Land Cover Suitability Map*

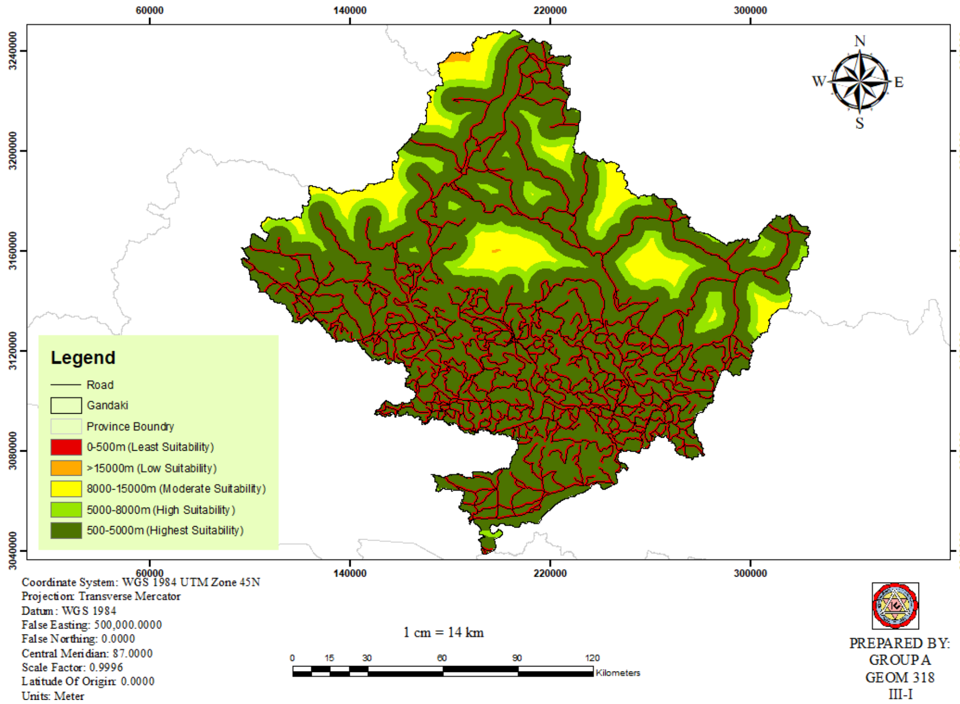


*Figure 13: Road Proximity Suitability Map*

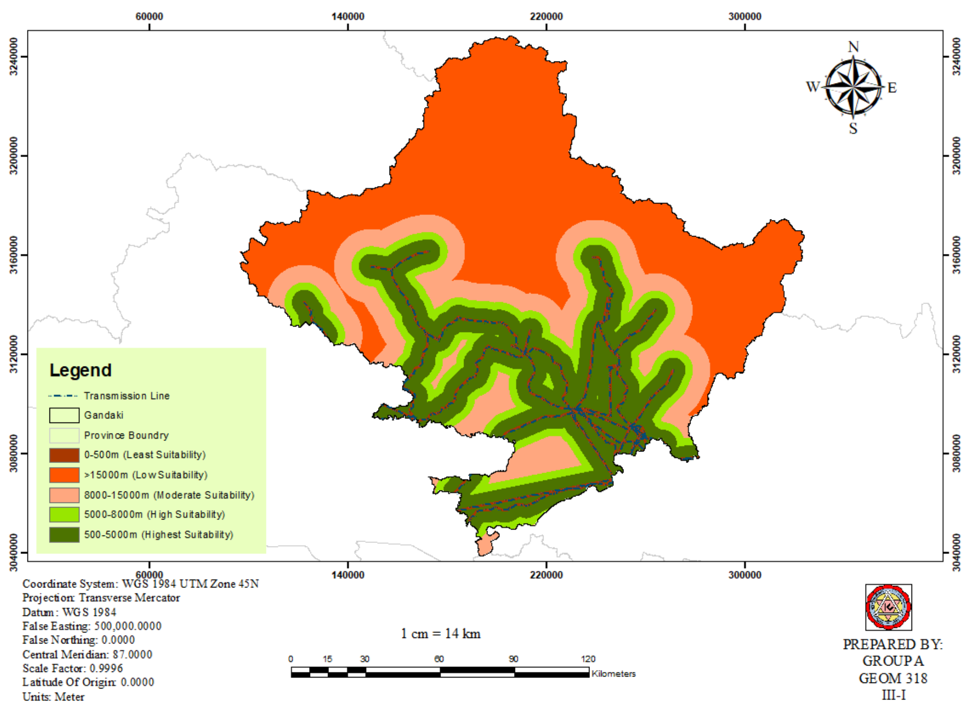


*Figure 14: Transmission Line Proximity Suitability Map*

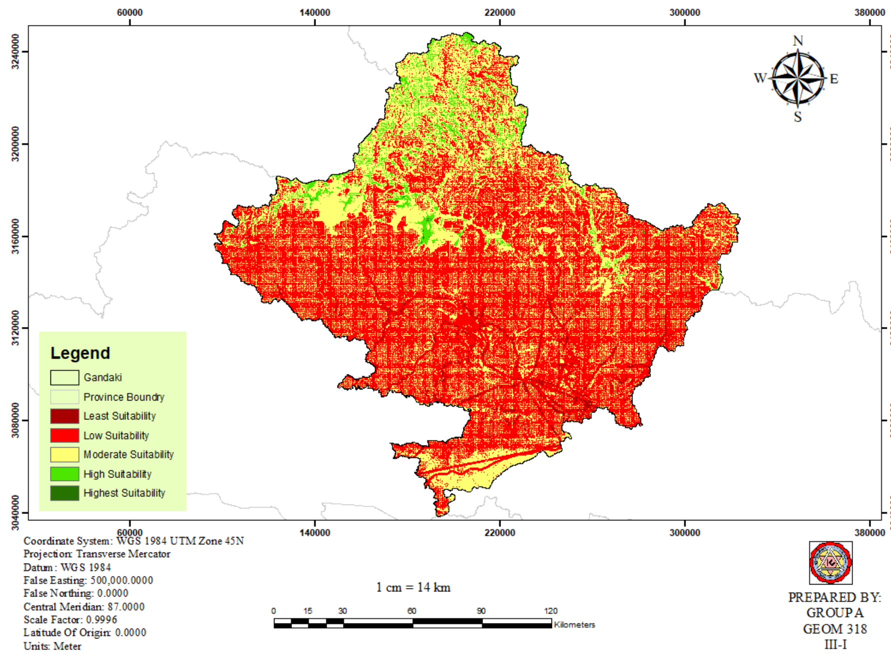


*Figure 15: Final Suitability Map*

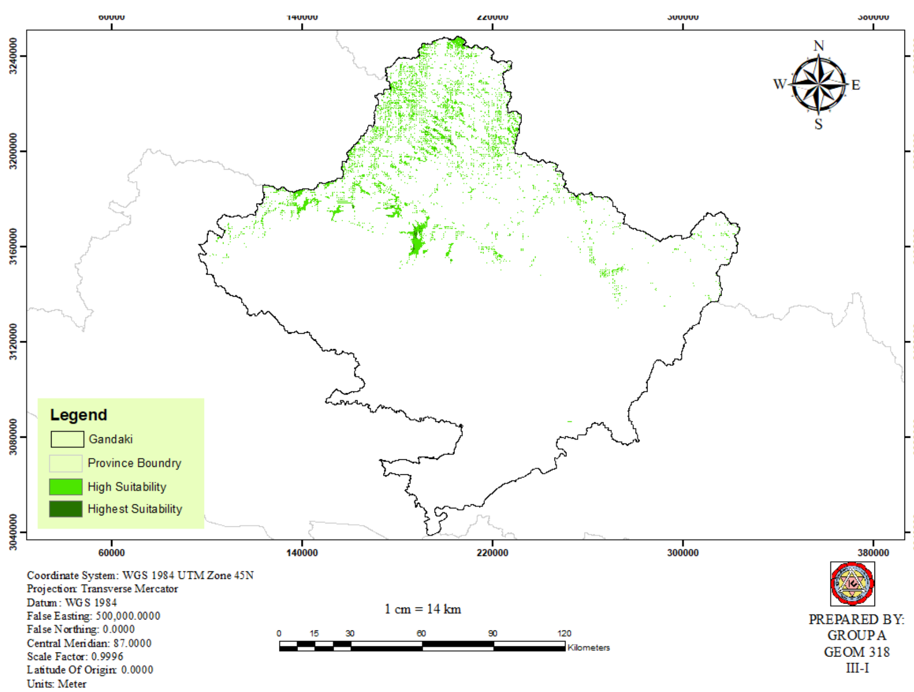


*Figure 16: Suitability Map showing only Suitable Regions*

# 8 VALIDATION

The validation process for our project involved confirming the accuracy and reliability of our findings derived from secondary data sources. To ensure the validity of our suitability analysis, we cross-referenced our final suitability map with existing wind turbine locations in the Gandaki region. From data provided by the Alternative Energy Promotion Center (AEPC) we identified four existing wind turbine projects in Gandaki Region (i.e.: Lomanthang Mustang, Kagbeni Mustang, Kawasoti Nawalparasi, and Devchuli Nawalparasi).

Remarkably, the overlay of our suitability map revealed a significant correlation demonstrating that three existing projects situated in (Lomanthang , Kagbeni , Devchuli) were located within the high suitability zones and one project situated at Kawasoti was located in moderately suitable zone. This alignment serves as validation affirming the efficacy and reliability of our project's methodology and the accuracy of our identified suitable locations for windmill outputs in Gandaki Province.

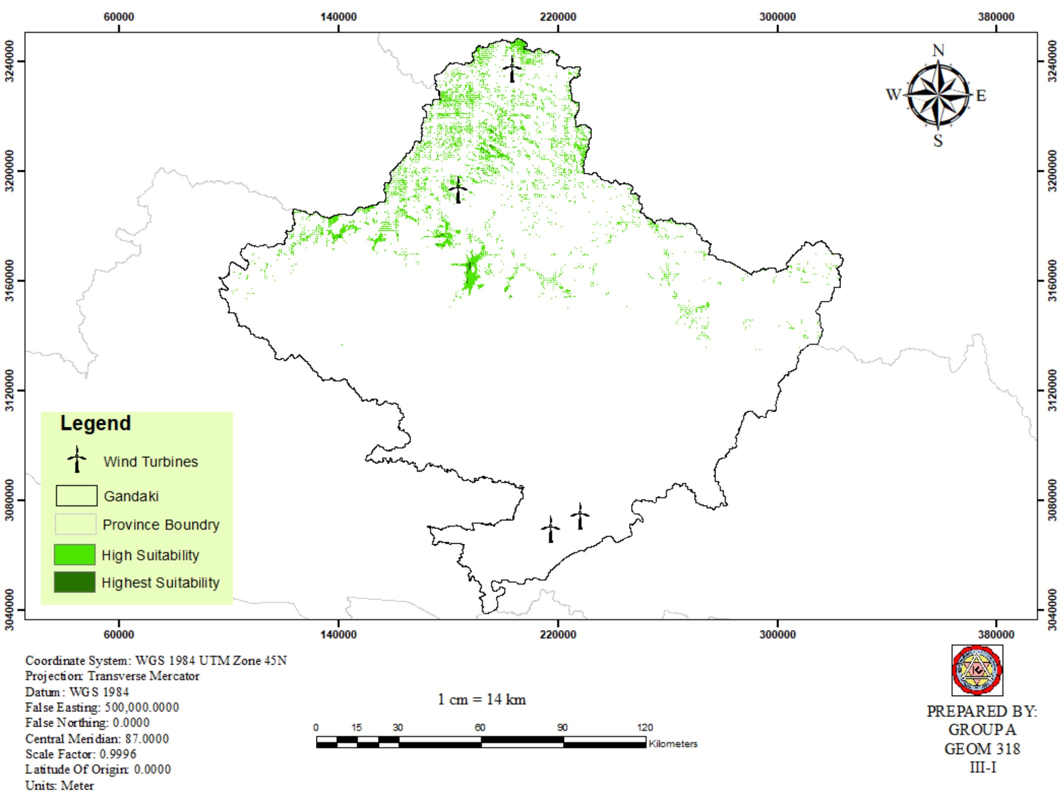


*Figure 17: Validating Existing Wind Turbine Within Suitable Region*

# 9 LIMITATION

Some of the limitations of this research include the use of publicly available internet and free data. Data used here have low resolution and cannot be verified because field measurements would be necessary and would be expensive. Furthermore, there are other variables that may impact the development of these projects, like soil studies and migratory bird routes about which data is not available. Similarly, several aspects require examination including the financial viability assessment and its influence on selecting the optimal sites. Hence it is recommended that before using result of this paper one must keep in mind the criteria and its importance for their desired work.

# 10 RECOMMENDATION AND FUTURE WORK

In order to help decision-makers set future plans for urban development and renewable energy projects, this study is regarded as a preliminary investigation. Putting these studies into practice at a smaller scale governorates and cities can yield comprehensive construction plans for wind turbine projects. This study can also help in the suitability mapping of hybrid energy systems such as photovoltaics which necessitates addressing new and significant criteria in the applied methodology.

The suitability model should be updated with more recent wind patterns, microclimate assessments, additional FAHP criteria and sophisticated GIS techniques. The environmental impact studies can be incorporated in project to guarantee the least amount of ecological disturbance in the study area. It is possible to conduct research on the social and economic impacts of wind energy projects in order to ensure community acceptance and equitable benefits. The study's scope can be expanded from Gandaki to a national or multi-provincial scale.

# 11 CONCLUSION

In order to increase the use of renewable energy sources rather than fossil fuels or nuclear energy, wind energy has become widely used in recent years. Thus, choosing a wind farm site is an important decision that needs to be carefully considered in order to generate wind power effectively from an economic and technical standpoint without endangering the environment or society. Nonetheless, a comprehensive approach to decision-making necessitates the systematic hierarchy organization of the many factors that influence the choice of wind farm location. Uncertainties concerning these factors' effects may lead difficulty for quantitative analysis. These factors make Buckley’s analysis of FAHP an appropriate technique for making decisions on wind farm sites.

The Gandaki province of Nepal has a high potential for wind energy throughout the year, hence, it is one of the best places to put up wind turbines. A comprehensive review of the literature found that no prior research had been done in this area regarding the appropriate site selection for wind farms using the GIS and MCDA method. An MCDA-based and GIS-based technique to determine the best location for wind farm siting in the Gandaki Province has been presented in this paper as it is best suited method to remove conflict decision to make for appropriate selection of entity among its related components that may affects the result. Triangular membership function of fuzzy AHP helped to find criteria weight by quantitative analysis using three elements for each criterion.

The spatial analysis indicated that 59.8% of the province areas are low suitable for wind farms construction. The majority of these sites belonged to the southern part of the province and basically avoided because of the wind speed, slope and elevation restrictions. On the other side, a total of 40.2% of the country area was found feasible (35.94% moderate, 4.213% is high, 0.050% is highest suitable) for installation of wind farms. Additionally, the results revealed that both the Northern and the Mustang, Manang area enjoy an excellent capacity to invest in wind energy projects to cover the current and future electricity needs in Nepal. The obtained findings are expected to reduce the investments, construction time, and resources for developing and implementing wind energy projects in Nepal.

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