KATHMANDU UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF GEOMATICS ENGINEERING

FINAL REPORT ON WINDMILL SUITABILITY IN MANANG DISTRICT USING GIS-BASED MULTI-CRITERIA ANALYSIS

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ABSTRACT

The objective of this study was to find the most suitable places for wind power plants by using geographic information systems (GIS) and the analytic hierarchy process (AHP) in Manang district. To this purpose, an AHP–GIS-based model was developed with 5 main criteria relevant to wind power plants. These included several important criteria that play a pivotal role in constructing windmills. Weights showing the degree of importance of each criteria were calculated via the analytic hierarchy process method and integrated into the model. The geographic data for the sample study area were collected and processed via GIS, and a suitability map for wind power plants and restricted regions in the sample study area was generated by overlaying all the weighted maps. As a result of the study, restricted areas, the most suitable areas and less suitable areas for the study area were determined with the help of the suitability map created by introducing the new criteria. This study determines the most suitable areas for windmills in Manang district of Nepal to promote the use of renewable energy sources mainly wind energy.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to all those who have contributed to the successful completion of this mini-project. This endeavor would not have been possible without the support and assistance of several individuals and resources. First and foremost, I extend my heartfelt thanks to Mr. Ajay Thapa whose guidance and expertise were invaluable throughout the entire duration of the project. Your encouragement, constructive feedback, and patience have played a pivotal role in shaping the project and enhancing its quality. I would also like to extend my appreciation to my group members Sudhan Oli, Aarya Pant, and Lochan Pant whose collaboration and dedication significantly contributed to the project's success. The synergy within our team fostered a positive and creative working environment.

In conclusion, this project has been a fulfilling learning experience, and I am grateful to everyone who played a role, big or small, in its accomplishment.

Thank you all.

Sincerely,

Sonik Neupane

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
DEM	Digital Elevation Model
GIS	Geographic Information System
GW	Gigawatt
GWh	Gigawatt hour
km	Kilometer
KW	Kilowatt
LULC	Land Use Land Cover
m	Meter
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
MW	Megawatt
NBC	National Building Code
WGS	World Geodetic System
WLC	Weighted Linear Combination
WSM	Weighted Sum Method

1 INTRODUCTION

1.1 Background

Global energy demands have undergone unprecedented changes in today's rapid population growth and industrial expansion era. Since the Industrial Revolution, the widespread consumption of conventional fossil fuels has triggered the release of various greenhouse gases (such as CO2, CH4, etc.), resulting in an unprecedented increase in average global temperatures and environmental concerns. These traditional fuels have inflicted adverse impacts on the environment, economy, and human health, including deforestation, environmental pollution, and the depletion of soil nutrients due to increased reliance on agricultural waste and animal dung. The combustion of dung and wood as cooking fuels has escalated the risk of acute respiratory infections. As a response, the prioritization of environmentally friendly energy sources has become imperative (Alizadeh, et al., 2020).

Renewable energy sources, often referred to as eco-friendly alternatives, have emerged as primary replacements for traditional energy resources, presenting the potential to meet escalating energy demands. These sources, encompassing wind, solar, hydro, biomass, and geothermal energy, are abundant, clean, and free, contrasting finite fossil fuel reserves (Aydin, et al., 2010). Recognized for their environmental suitability, renewable energy outperforms conventional systems by mitigating air pollution inherent in fossil fuel combustion. Among these, wind and solar energy have reached technological and economic maturity, with wind energy standing out due to its cost-effectiveness, efficient multi-megawatt turbines, and accessibility.

Nepal, being a country characterized by its mountainous terrain, exhibits significant wind energy potential. On average, specific regions of Nepal experience approximately 18 hours of wind daily, and at least two days a week witness consistently strong winds across the entire nation. According to the findings from the Solar and Wind Energy Resource Assessment, an extensive 6,074 square kilometers of land throughout the country possesses wind power potential with a density exceeding 300 watts per square meter. The assessment specifically identifies the districts of Mustang and Manang as having a combined potential exceeding 2500 megawatts. Notably, areas such as river corridors and mountain valleys exhibit particularly high wind generation capacity, as highlighted by the analysis (Upreti & Shakya, 2009).

Site selection for wind energy projects demands meticulous consideration of diverse variables, integrating environmental, infrastructure, and land use factors. Multi-criteria decision-making (MCDM) methods, encompassing techniques such as the weighted sum method (WSM), Analytical Hierarchy Process (AHP), weighted linear combination (WLC), and more, are employed for wind farm location assessments. Among these, AHP stands out for its simplicity, ease of use, and capability to evaluate decision consistency. AHP allows for the incorporation of both qualitative and quantitative criteria, empowering decision-makers to assign relative weights based on their expertise. Previous studies have successfully combined AHP with Geographic Information System (GIS) to select wind energy sites based on various factors (Sisman & Aydinoglu, 2020).

1.1.1 Multi-criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) is a set of systematic procedures for analyzing complex decision problems. It aims to establish a connection by dividing the decision problem into small, simple, and understandable parts so that a meaningful result can be obtained from these parts. MCDAs are used as a decision-support system for problems where conflicting economic, environmental, social, and technical objectives are involved (Sisman & Aydinoglu, 2020). Multi-criteria decision analysis provides a set of strategies, procedures, and calculations for organizing choice issues, planning processes, assessing, and prioritizing from the multiple sets of alternatives.

1.1.2 Analytical Hierarchy Process

The Analytic Hierarchy Process is a decision-making model that aids us in making decisions in our complex world. It is a three-part process which includes identifying and organizing decision objectives, criteria, constraints and alternatives into a hierarchy; evaluating pairwise comparisons between the relevant elements at each level of the hierarchy; and the synthesis using the solution algorithm of the results of the pairwise comparisons over all the levels. Further, the algorithm result gives the relative importance of alternative courses of action (Saaty, 1988).

1.2 Problem Statement

Wind energy has a great potential in areas like Manang but not enough windmills are constructed. The usage of fossil fuels, natural gases and coils are contributing in greenhouse gases emission, climate change and environmental pollution. The purpose of this study is to promote the usage of renewable energy directly or indirectly by determining the suitable site locations for installation of windmills in Manang district. This work will consider a number of factors, such as wind speed, elevation, landuse, proximity to infrastructure and power transmission station to help decision-makers choose the location that maximize the energy output.

1.3 Objective

Primary objective

- To select suitable location for windmill in Manang District.

Secondary objective

- To know the practical application of GIS-based MCDA using AHP.
- To get familiar with tools of ArcGis.

1.4 Scope

This study aims to identify an optimal windmill location in Manang district and help decision makers to choose suitable place for maximum benefit. Factors like roads, landuse, power staions, elevation and wind speed were taken as criteria. This study provides reliable and efficient site for constructing windmills using GIS applications.

2 LITERATURE REVIEW

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. 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 fossil fuels, the enhancement and development of renewable energy also helps in minimizing global warming. To quickly decarbonize and prevent further global warming, renewable energies like solar and wind power are essential (Neupane, et al., 2022).

The technological development of wind energy has made it the most promising alternative to conventional energy systems (Lee, et al., 2009), and thus, wind energy has taken an important place in the world energy market (Pechak, et al., 2011). Criteria determination is a very important process in wind power plant site selection studies. In an actual wind power plant project, ignoring criteria will negatively afect the environment and the cost of the project

Mostafaeipour et al., 2011 conducted feasibility study of wind energy of Shahrbabak, Kaman province, of Iran. The author used two-parameter Weibull distribution function for wind analysis and wind power density for energy generation and concluded that the site is suitable for the installation of small wind energy farm. Mostafaeipour in another work conducted the feasibility study of wind potential of Yazd province of Iran. In this work, the author analyzed the 13-year wind data and used the measured data at the height of 10 m. The study suggested that the site is suitable for wind farm development (Mostafaeipour, 2010).

Keyhani investigated the wind climate for the energy production at Tehran, the capital of Iran. In this work, the author used the two-parameter Weibull distribution function for seasonal wind analysis using measured data at the height of 10 m (Keyhani, et al., 2010). Kwon investigated the wind uncertainty of a Kwangyang Bay of Chonnam Peninsula of the southern coast of Korea and found 11% wind uncertainty. The author used probability models for wind variability including air density, surface roughness factor, wind speed, Weibull parameters, and error estimation of long-term wind speed based on the Measure-Correlate-Predict method for uncertainty analysis (Kwon, 2010).

Although there are several ways to generate renewable energy, one of the most promising is wind energy, which might help meet the world's growing energy needs (Chedid & Rahman, 1997). From a technological, environmental, socioeconomic, and political perspective, wind power is the most deserving of a wider widespread deployment among all the cleaner energy production options (geothermal, solar, tidal, biomass, and hydro), according to Talinli. Many people are starting to recognize the significance of wind energy as a crucial long-term renewable energy source since it is clean, free, and renewable. Using wind energy hence reduces dependency on traditional fossil fuel-based electricity generation. Consequently, this ensures environmental sustainability as well as supply security (Talinli, et al., 2011).

Upreti & Shakya, 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, 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 also provided 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 the Department of Hydrology and Meteorology, there are currently 36 wind measuring stations in Nepal including an Agro meteorology station, Synoptic station, and Aeronautical station, and among them, there are 9 wind measuring working condition stations in Gandaki Province (Upreti & Shakya, 2009).

3 METHODOLOGY

3.1 Study Area

Manang district is located in the northern part of Gandaki Province and is located at latitude 28°40′22.80″ north, longitude 84°10′45.84″ east. The headquarter of Manang district is Chame. The total area covered by this district is 2246 km^2. The population of Manang according to the census of 2021 is 5645 and the population density is 2.9/km^2.

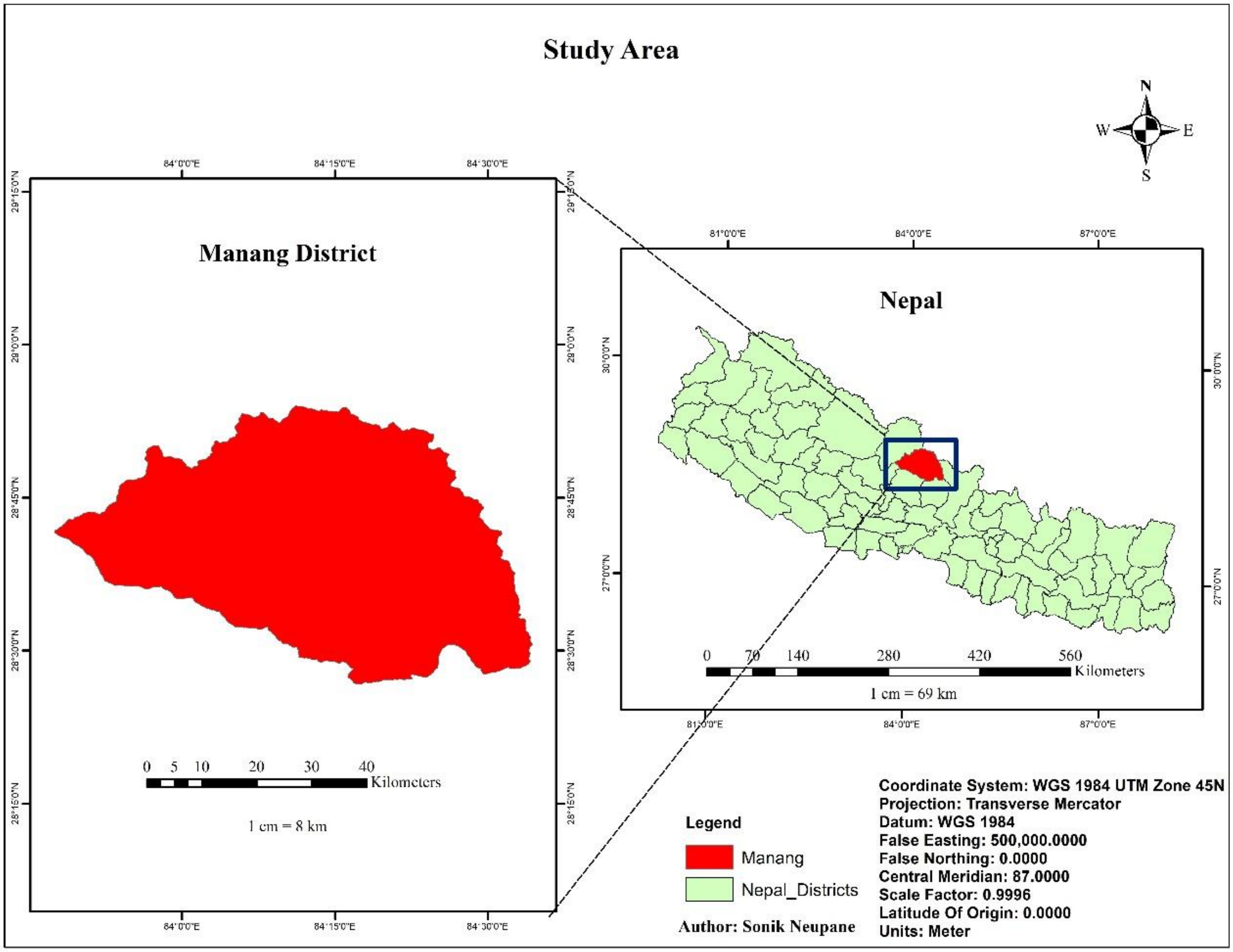

Figure i: Study Area

3.2 Materials Used

3.2.1 Data Used

The project supervisor provided the data required for this project. Five different data were used. All the data were converted to the same projection system i.e. WGS 1984 UTM zone 45N.

Table 1: Types of data used

S.N.	Data	Data Type
1	Road Network of Nepal	Vector
2	Land Use of Nepal	Raster
3	DEM of Nepal	Raster
4	Power Stations of Nepal	Vector
5	Wind speed in Nepal	Raster

3.2.2 Software Used

Esri ArcGis 10.8 was used in this project. An online APH calculator was used to determine the weightage for each criterion on a pairwise comparison basis.

3.3 Work Flow

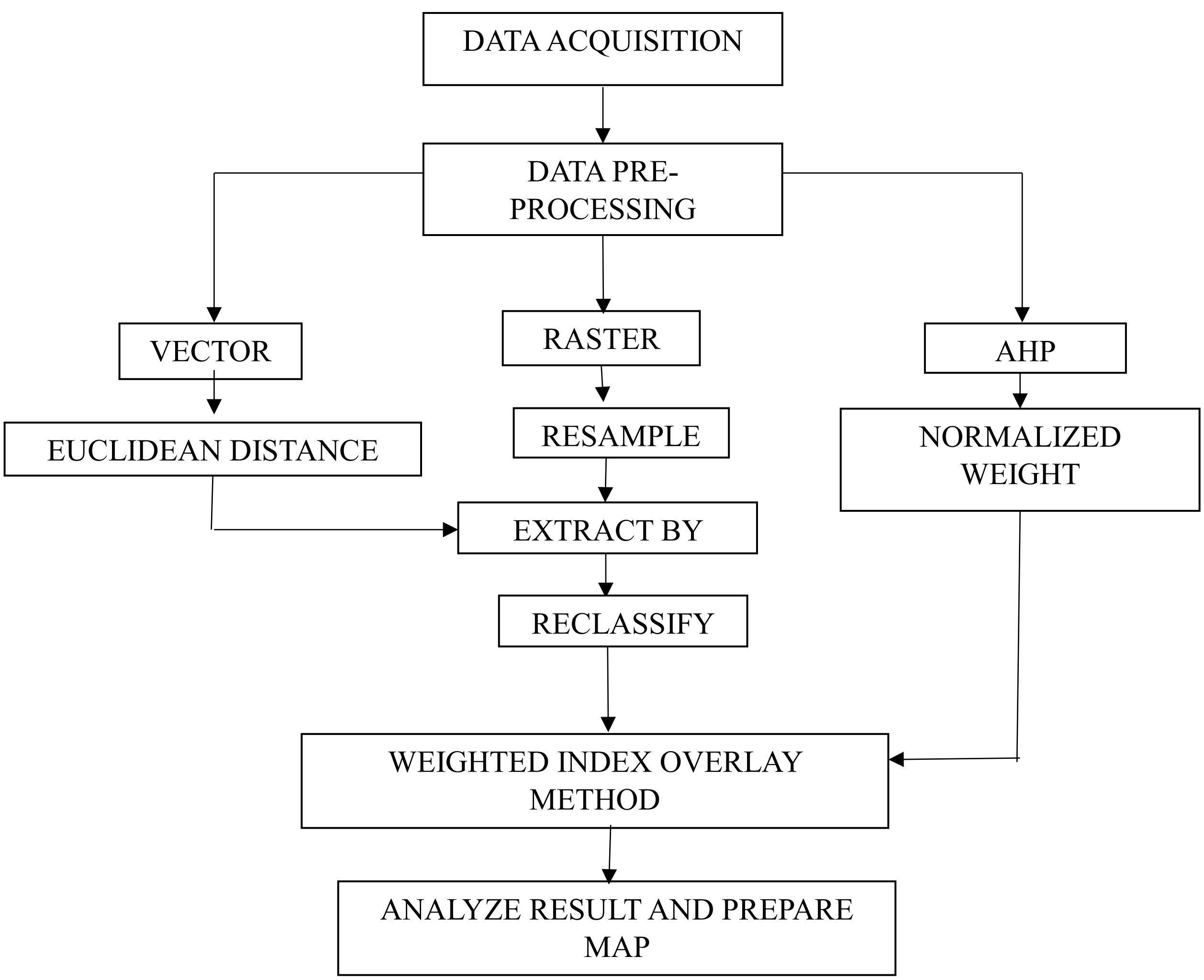

Figure ii: Work Flow

3.4 Data Preparation

Firstly, the criteria for determining suitable windmill site was established. This was accomplished by examining previous research on windmill selection criteria. The criteria included factors such as elevation, land use, power stations, roads, wind speed, and the specific data layers needed for analysis. To ensure consistency, the data was transformed into the same projection system ((WGS 1984 UTM zone 45N) and then limited to a defined area of interest i.e Manang.

3.5 Data Visualization

Different tools from ArcGis were used for data visualization. Euclidean distance, resample, and reclassify tools were used to create maps for visualization.

3.6 Data Analysis

3.6.1 Criteria Allocation

The evaluation criteria for selecting a windmill site in the Manang district were determined. Five parameters were taken into account for this study. They were wind speed, elevation, distance from roads, distance from power stations, and land use. Six classes were created and each class was allocated a value from 0 to 5, 0 representing unsuitable site, 1 representing very low suitable and 5 representing very highly suitable.

Table 2: Criteria allocation

S.N.	Assigned Numbers	Suitability
1	0	Unsuitable
2	1	Very low suitability
3	2	Low suitability
4	3	Moderate suitability
5	4	High suitability
6	5	Very high suitability

The following things were assumed while taking these factors into account:

3.6.1.1 Wind Speed

Wind speeds play a pivotal role in determining the optimal locations for establishing a wind power plant. This is due to the fundamental relationship between wind speed and the efficiency of wind turbines. Wind turbines initiate their operation when wind speeds reach around 3 m/s. For efficient energy generation, wind speeds of at least 3.5 m/s are considered favorable.

The suitability based on different wind speeds is classified as:

Table 3: Windspeed suitability

S.N.	Intervals (m/s)	Suitability	Assigned Number
1	0-3	Unsuitable	0
2	3-3.5	Very low suitability	1
3	3.5-4	Low suitability	2
4	4-5	Moderate suitability	3
5	5-6	High suitability	4
6	>6	Very high suitability	5

3.6.1.2 Elevation

Elevation of the site affects wind direction and speed. Typically, wind turbines are located on higher ground to catch winds at more powerful speeds. 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. There are fewer wind turbulences at higher elevations and wind speeds are more consistent. Construction costs go up, and maintenance becomes more difficult, because of this. As a result, careful consideration should be given to the location of windmills.

The suitability based on different elevations is classified as:

Table 4: Elevation suitability

S.N.	Interval (m)	Suitability	Assigned Number
1	0-3000	Very low suitability	1
2	3000-4000	Very high suitability	5
3	4000-5000	High suitability	4
4	5000-6000	Moderate suitability	3
5	6000-7000	Low suitability	2
6	>7000	Unsuitable	0

3.6.1.3 Distance from Roads

Ideally, wind farms should be located as close to major roads as possible, to reduce transportation costs and make access easier for various employees, and second, to minimize multiple discomforts, such as the detrimental impact on road mobility due to loud noises and changes in the visual scene due to the rotation of the wind turbines caused by wind turbine operation, which affects road mobility. Therefore, the minimum distance between windmill and major roads is set to 500 m.

The suitability based on distance from roads is as follow:

Table 5: Road suitability

S.N.	Intervals (m)	Suitability	Assigned Number
1	0-500	Unsuitable	0
2	500-5000	Very high suitability	5
3	5000-8000	High suitability	4
4	8000-15000	Moderate suitability	3
5	15000-20000	Low suitability	2
6	>20000	Very low suitability	1

3.6.1.4 Distance from Power Stations

The windmill's primary goal is to produce electricity and then feed it into the local grid via transmission lines. Therefore, the distance between the potential windmill location and existing transmission lines, and the power station is a critical consideration when selecting a windmill site. It should not be too close due to negative effects on power stations. The minimum distance between power stations and the windmill is set to 500m.

The suitability based on distance from power stations are as follows:

Table 6: Powerstation suitability

S.N.	Intervals (m)	Suitability	Assigned Number
1	0-500	Unsuitable	0
2	500-5000	Very high suitability	5
3	5000-8000	High suitability	4
4	8000-15000	Moderate suitability	3
5	15000-20000	Low suitability	2
6	>20000	Very low suitability	1

3.6.1.5 Land Use

Land use has an impact on the choice of a windmill because there are some locations where windmills cannot be built even though there is sufficient wind speed, like in a waterbody, glacier, forest, riverbed, and built-up areas. Therefore, it can be generally said that the most suitable types of land are grassland, barren land, and barren rock while forests, water bodies, and built-up areas are considered to be unsuitable.

The suitability based on land use is classified as follows:

Table 7: Landuse suitability

S.N.	Land use	Suitability	Assigned Number
1	Waterbody, Glacier, Forest, Built-up areas, Riverbed	Unsuitable	0
2	Snow, Other wooded land	Very low suitability	1
3	Cropland	Low suitability	2
4	Bare rock	Moderate suitability	3
5	Bare soil	High suitability	4
6	Grassland	Very high suitability	5

3.6.2 Determination of Criteria Weightage Using AHP

The weightage of the criteria was generated from the pairwise comparison technique of AHP. A total of 5 criteria were assigned by giving an input of numbers and names. On the sale of 1 to 9, the criterion importance is denoted concerning AHP priorities.

Table 8: Criteria priority based on AHP

S.N.	Importance intensity	Definition
1	1	Equal importance
2	3	Moderate importance
3	5	Strong importance
4	7	Very strong importance
5	9	Extreme importance

The pairwise comparison matrix was formed as follows:

Table 9: Pairwise comparison matrix

	Wind speed	LULC	Elevation	Road	Power station
Wind speed	1	0.5	4	2	2
LULC	2	1	5	3	1
Elevation	0.25	0.2	1	0.25	0.33
Road	0.5	0.33	4	1	1
Power station	0.5	1	3	1	1

The obtained weightage for each criteria from online AHP calculator is as follows:

Table 10: Criteria weight

Rank	Criteria	Percentage
1	LULC	34.3
2	Wind speed	25.7
3	Power station	18.9
4	Road	15.5
5	Elevation	5.6

Thus when selecting a suitable site for a windmill LULC is given the most priority while elevation is given least priority.

4 RESULTS AND DISCUSSION

4.1 Criteria maps

Five different criteria were used to find the suitable location for constructing the windmill. The percentage area covered based on suitability in all these criteria is as follow:

Table 11: Percentage area covered criteria-wise

Criteria	Unsuitable	Very low suitability	Low suitability	Moderate suitability	High suitability	Very high suitability
LULC	27.56	10.81	0.48	31.40	0.0004	29.74
Wind speed	22.22	7.33	7.72	15.99	14.87	31.86
Power station	0.07	33.53	17.29	32.32	10.12	6.66
Road	9.42	0.005	0.43	12.30	20.16	57.68
Elevation	0.56	3.70	8.40	38.26	34.42	14.65

The maps obtained from different criteria showing suitable site for windmill in Manang is as follows:

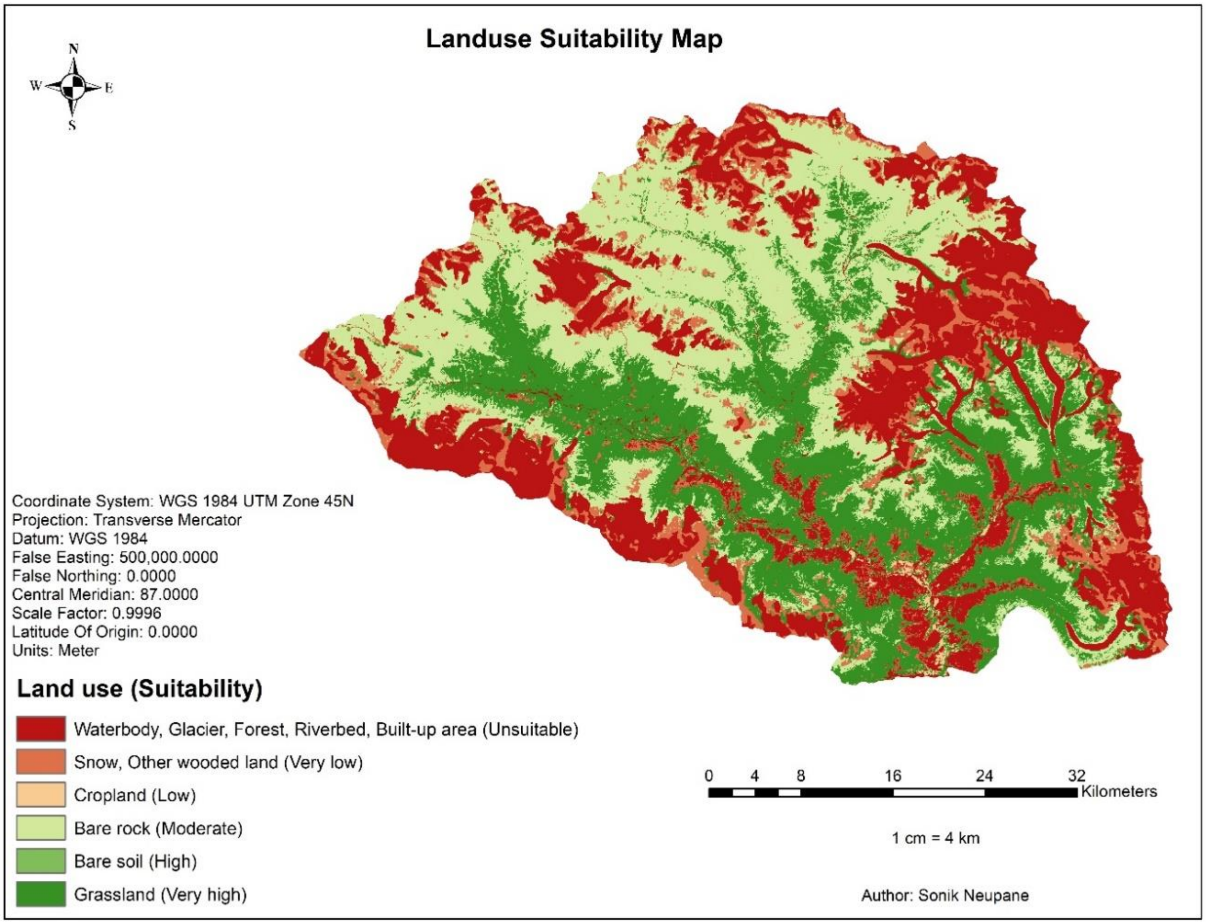

Figure iii: Landuse Suitability Map

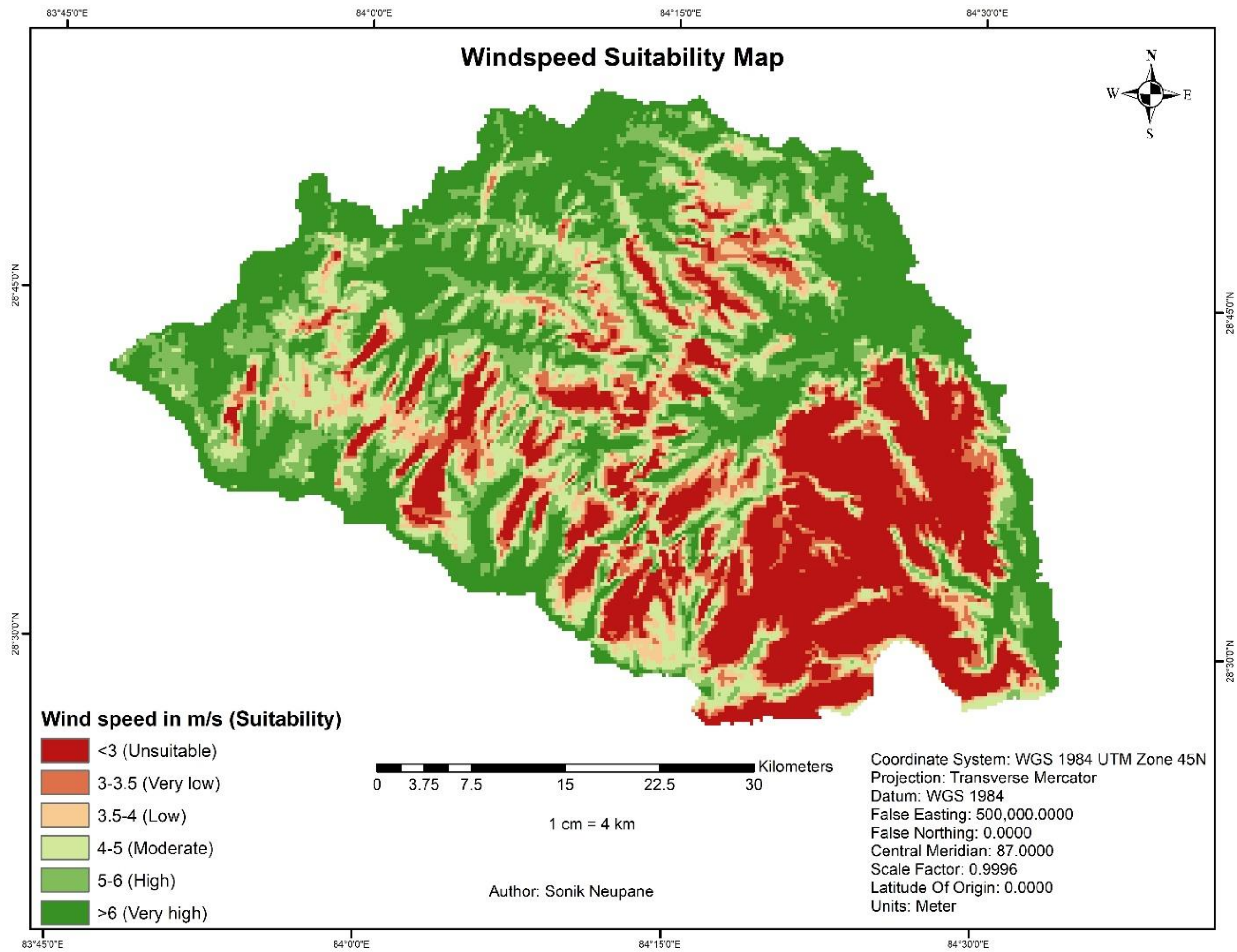

Figure iv: Windspeed Suitability Map

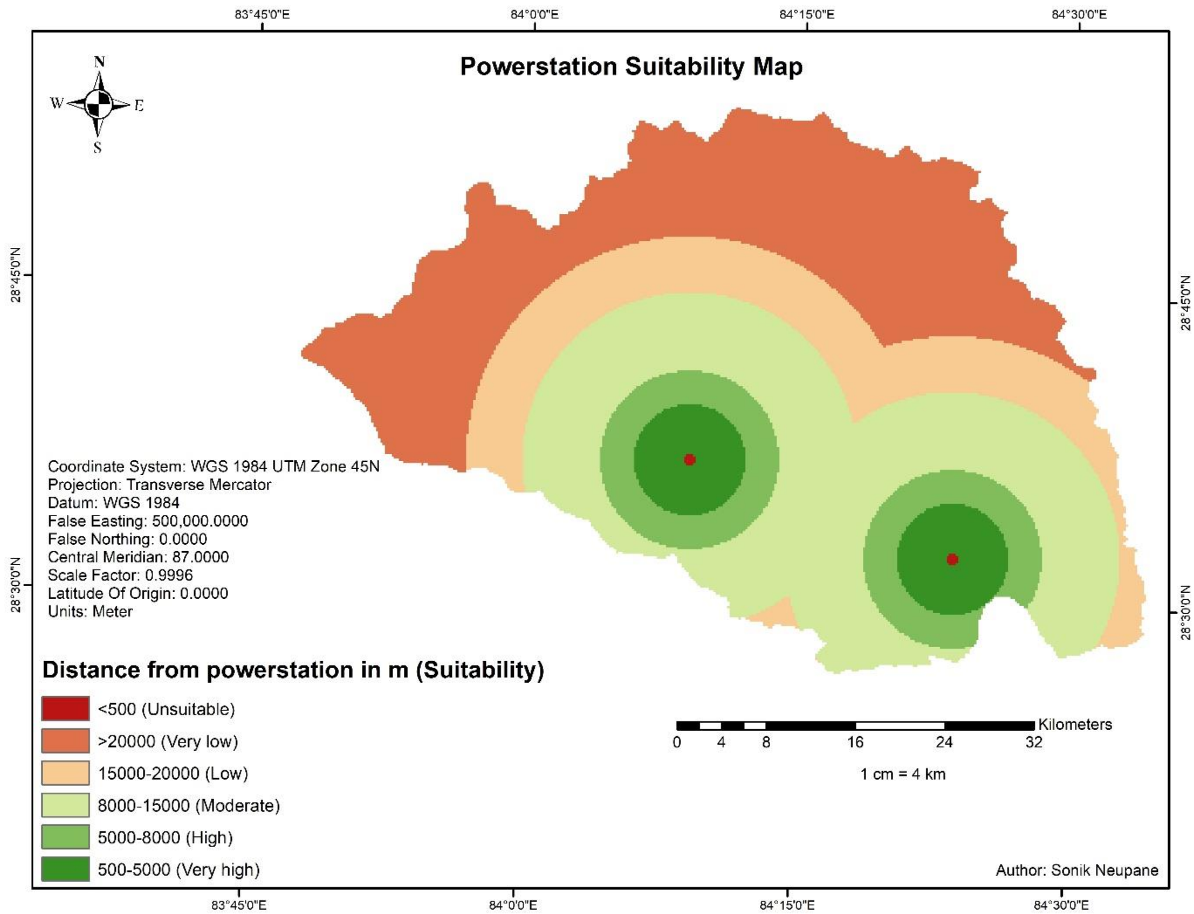

Figure v: Powerstation Suitability Map

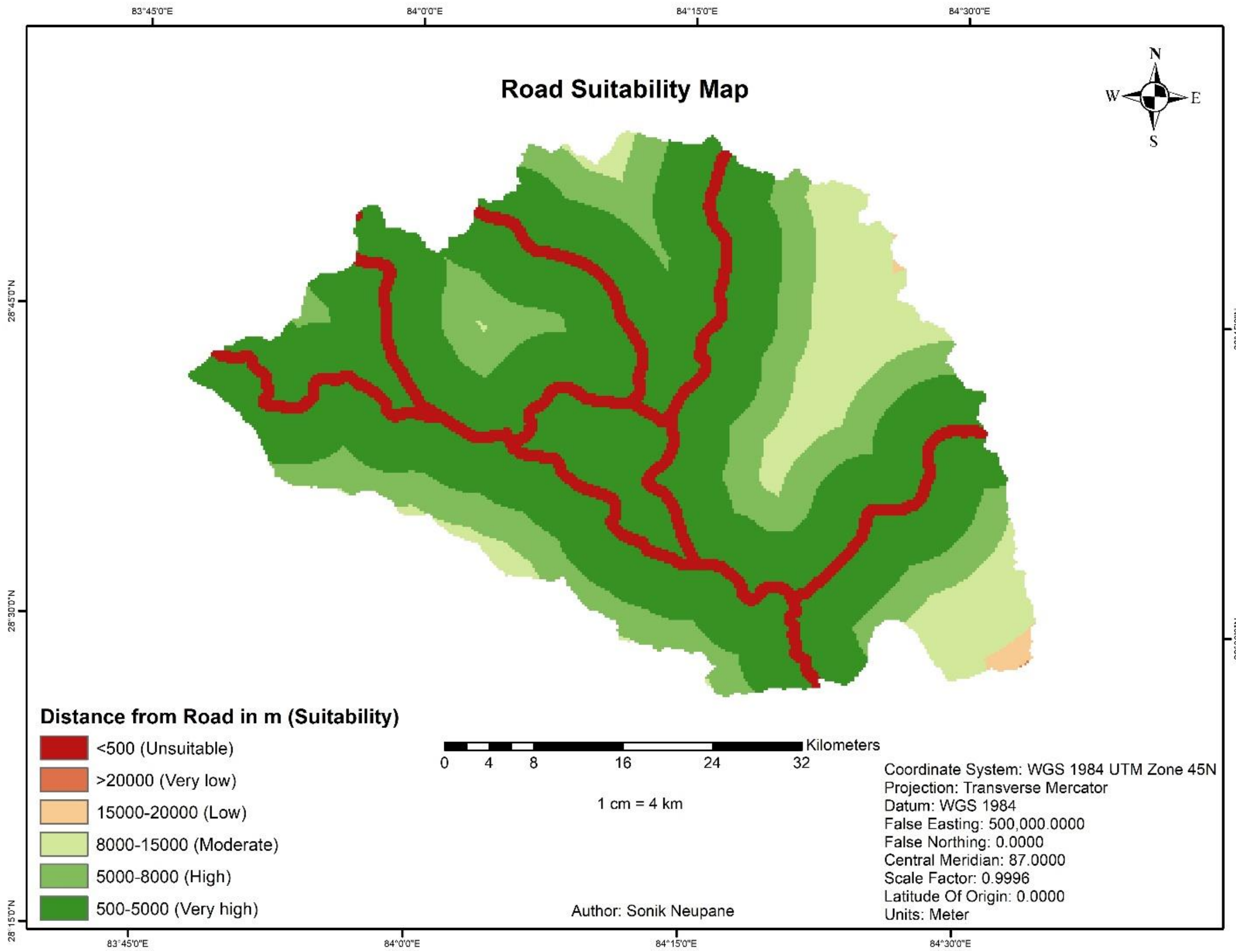

Figure vi: Road Suitability Map

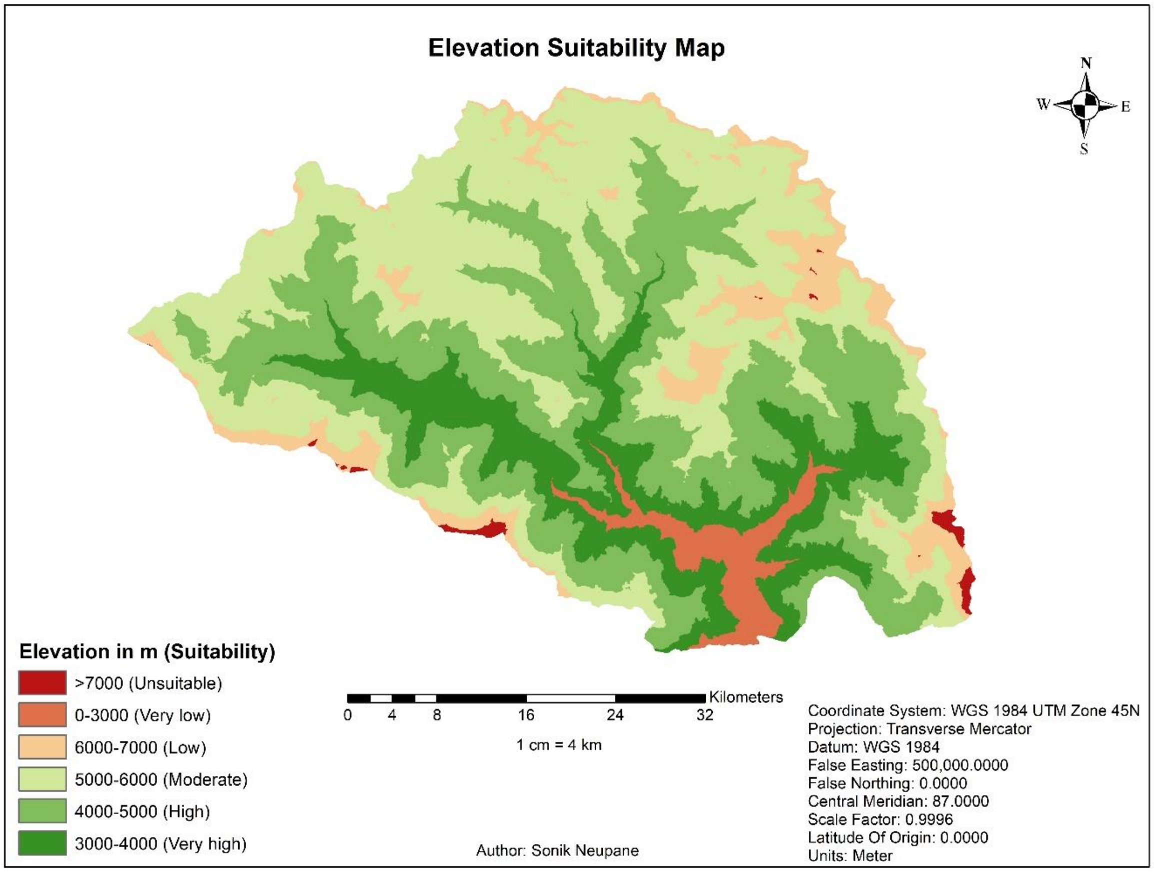

Figure vii: Elevation Suitability Map

4.2 Final Suitability Map of Manang

Weighted overlay tool was used to combine all the five criteria maps. The suitability map is as follow:

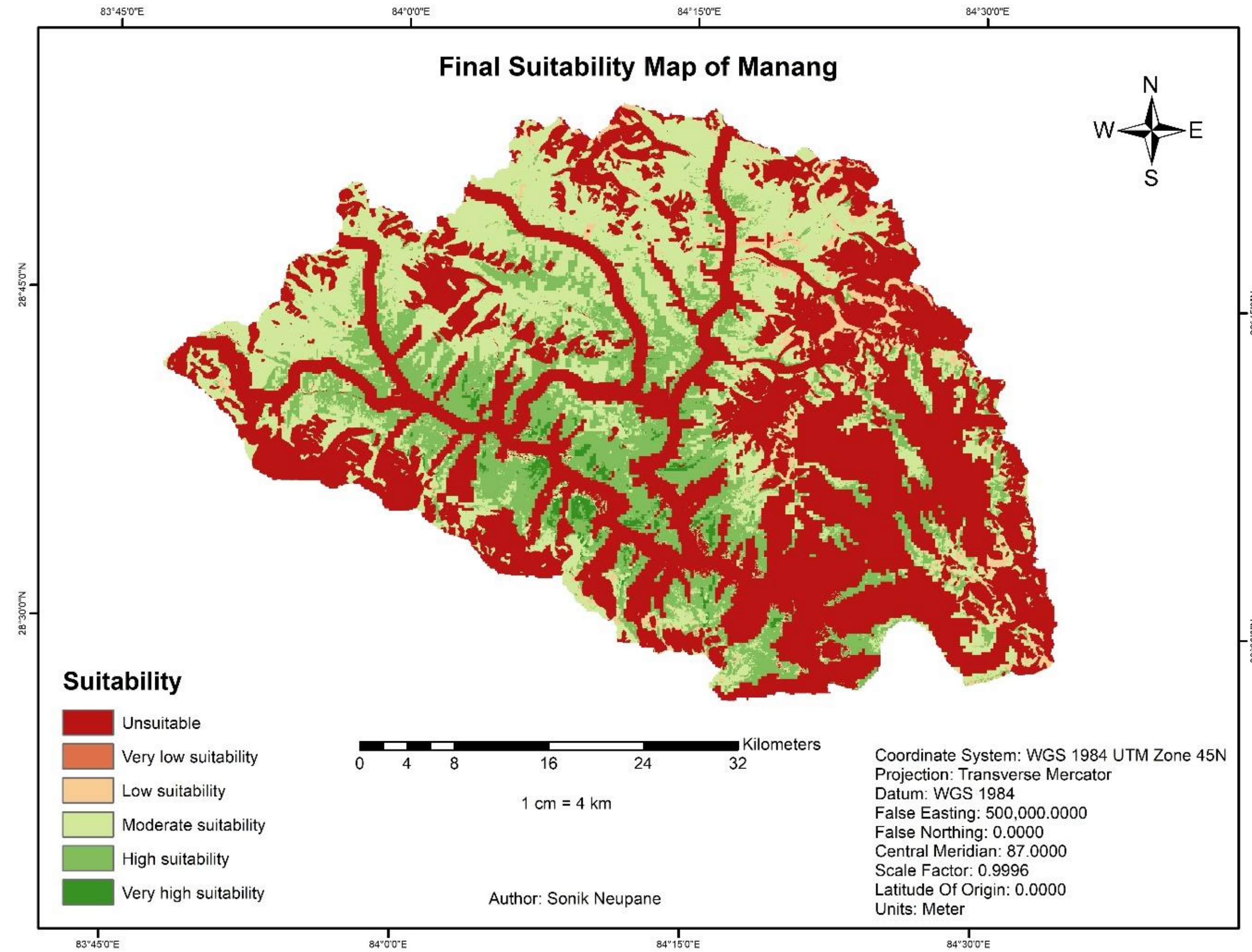

Figure viii: Final Windmill Suitability Map

The area coverage of different suitability is as follows:

Table 12: Area covered based on suitability

Suitability	Area (%)	Area (square km)
Unsuitable	51.04	1177.898
Very low	0.002	0.0476
Low	2.94	67.804
Moderate	28.17	649.669
High	16.82	388.001
Very high	1.03	23.741

5 CONCLUSION

Hence a total of 51.04% area of Manang is unsuitable for windmills. 1.03% of the area is very highly suitable. 16.82% area is of high suitability, 28.17% of the area has moderate suitability, 2.94 % of the area has low suitability and finally, 0.002% of Manang has very low suitability. This study introduced a GIS and AHP-based platform for identifying suitable sites for windmills in Manang district. The MCDM method efficiently resolves complex decision-making issues by utilizing the GIS platform. In this study, decision-supporting parameters were evaluated using prior research results and expert opinion. AHP was used to determine the weight and significance of the selected criteria for the decision to provide support. The final wind farm suitability map was generated by superimposing all the AHP-determined weight-based raster criteria layers.

This project provides a reliable site for windmill construction which can be used by future policy makers. Renewable energy like wind energy should be utilized to save our environment from the adverse effects of fossil fuels.

6 REFERENCES

Alizadeh, R., Soltanisehat, L., Lund, P. D. & Zamanisabzi, H., 2020. Improving renewable energy policy planning and decision-making through a hybrid MCDM method. *Energy Policy.*

Al-Shabeeb, . A. R., Al-Adamat, . R. & Mashagbah, A., 2016. AHP with GIS for a Preliminary Site Selection of Wind Turbines in the North West of Jordan. *International Journal of Geosciences,* pp. 1208-1221.

Aydin, N. Y., Kentel, E. & Duzgun, S., 2010. GIS-based environmental assessment of wind energy systems for spatial planning: A case study from Western Turkey. *Renewable and Sustainable Energy Reviews,* pp. 364-373.

Chedid, R. & Rahman, S., 1997. Unit sizing and control of hybrid wind-solar power systems. *IEEE Transactions on Energy Conversion,* pp. 79-85.

Keyhani, A., Ghasemi-Varnamkhasti, M., Khanali, M. & Abbaszadeh, R., 2010. An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. *Energy,* pp. 188-201.

Kwon, S.-D., 2010. Uncertainty analysis of wind energy potential assessment. *Applied Energy,* pp. 856-865.

Lee, A. H., Chen, . H. H. & Kang, H.-Y., 2009. Multi-criteria decision making on strategic selection of wind farms. *Renewable Energy,* pp. 120-126.

Mostafaeipour, A., 2010. Feasibility study of harnessing wind energy for turbine installation in province of Yazd in Iran. *Renewable and Sustainable Energy Reviews,* pp. 93-111.

Neupane, D., Kafle, S., Karki, R. K. & Pradhan, P., 2022. Solar and wind energy potential assessment at provincial level in Nepal: Geospatial and economic analysis. *Renewable Energy,* pp. 278-291.

Pechak, O., Mavrotas, G. & Diakoulaki, D., 2011. Role and contribution of the clean development mechanism to the development of wind energy. *Renewable and Sustainable Energy Reviews,* pp. 3380-3387.

Saaty, T. L., 1988. What is the Analytic Hierarchy Process?. In: *Mathematical Models for Decision Support.* Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 109-121.

Sisman, S. & Aydinoglu, A., 2020. USING GIS-BASED MULTI-CRITERIA DECISION ANALYSIS TECHNIQUES IN THE SMART CITIES. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* pp. 383-399.

Talinli, l., Topuz, E., Egemen & Kabakcl, S., 2011. A Holistic Approach for Wind Farm Site Selection by Using FAHP. In: *Wind Farm - Technical Regulations, Potential Estimation and Siting Assessmen.* s.l.:InTech.

Upreti, B. & Shakya, A., 2009. WIND ENERGY POTENTIAL ASSESSMENT IN NEPAL.