Suitability Analysis

Geoinformation Technology Program

Submitted under Geographical Information System 3 (GES711S)

SITE LOCATION SUITABILITY ANALYSIS FOR RENEWABALE ENERGY FARM FOR THE PRODUCTION OF GREEN HYDROGEN

Zambezi Region

Study done by:

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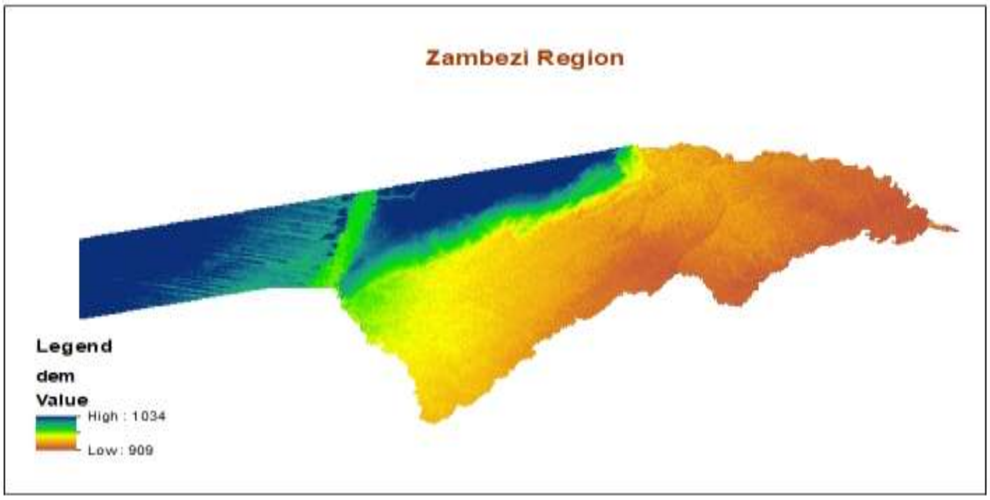


Abstract

The world is facing a climate problem. Huge amounts of Carbon emission in the atmosphere through fossil fuels such as oil, coal and natural gases, the greenhouse effect continues to deplete the climate. Not to speak about the demand in power consumption either by the population or industries all over the world. Practices to establish sustainable goals and green movements across the world can cause a significant impact on the climate problem. And using renewable resources as the main source of power is a huge step towards a better future.

This study aims to locate a suitable location for both a solar and wind farm in the Zambezi region of Namibia for the pursuit of the long-term development goal of vision 2030. Hence to help government incentives to attract multinationals to invest in clean energy sector. Considering, this analysis will showcase what Namibia has to offer, especially to several renewable energy producers who are interested in Namibia. With output maps depicting the suitable sites, they can potentially decide where to put their focus. As a result, the Namibian people will gain employment opportunities and hence contribute to the country's developing process.

The suitability analysis in this study was carried out on a regional level with Zambezi as the case study. And using GIS methods to conclude based on relevant environmental, technical, and socio-economic conditions. Moreover, an explicit methodology framework of how the potential areas has been outlined.

The solar farm was most suitable for Zambezi and could potentially be located around the northeastern part of the region down to the southwestern part. Whereas the wind farm was unsuitable for this area due to contributing factors determined in the analysis and will be further elaborated in the methodology.

Introduction

Namibia's transport sector makes use of the most energy followed by the fishing and manufacturing sector. Consequently, the most emission of Carbon dioxide comes from the transport sector (Munyayi et al., 2018). Energy statistics discovered that Namibia has a total Carbon dioxide emission from energy consumption in 2011 with an amount of 2800 kiloton

(Rama et al., 2013) as cited by (Munyayi et al., 2018). In retro fact, Namibia also imports power from other countries to cover for the supply gap of electricity between locally generated electricity and the required electricity for the country's economic activities (National Planning Commission, 2013) as cited by (Munyayi et al., 2018). Considering the above, it is important for Namibia to implement more renewable energy sources. This is not only vital for contributing to the sustainable development goals but to reduce importing power because soon the country will locally produce enough or close to enough power to keep the country afloat.

The current local main renewable source used in Namibia is hydropower from the Ruhakana Hydro Power Station. Clearly, there is more work to be done. The country has a great potential for solar, wind and biomass generation. In turn this allows for a large-scale bioenergy production based on capacity according to Meyer van den Berg in (Africa Energy Futures: Namibia, 2021). Subsequently, Namibia has shown an interest in green hydrogen as an alternative way for energy.

Green hydrogen is a clean fuel which allows for the use and storage of energy from renewable sources. It is considered to substitute for fossil fuels in industries that can't be decarbonize easily as well as aviation and heavy transport sectors like maritime transport. The best green hydrogen is one which is produced by electrolysis of water from renewable electricity. This is a decomposition method whereby water is broken down to oxygen (O_2) and hydrogen (H_2) through a direct electric current that travels across electrodes in water (electrodes are conductors or mediums in which electricity pass through). Green hydrogen is clean energy, it emits water as a waste product, 100% renewable (generated using natural resources that can be replenished for instance, solar and wind energy), can be stored (it can be compressed and kept in a special tank.) and it is transportable (hydrogen is light) isolated areas or villages can easily be supplied with power as mentioned by (acciona.com).

Most importantly green hydrogen helps to reduce negative climate change caused by end products of fossil fuels. For this reason, green hydrogen is skyrocketing across the world as many countries are aware of its benefits, with it being cost friendly, its market continues to rise, and many studies are centered around it. Similarly, Namibia is emerging into the hydrogen market with a goal of becoming the leading exporter of green hydrogen in Africa using wind and solar energy (GreenHydrogenNamibia.com).

Already Namibia is planning on choosing investors for green hydrogen projects. For instance, the government announced to choose German consortium Hyphen Hydrogen Energy as the bidder of choice in the Tsau Khee National Park. According to the economic advisor of the president and hydrogen commissioner, claimed that Karas region particularly is suitable because of the large solar and wind resources it contains as well as its closeness to the coast. Above is one of the few planning frameworks that are being implemented. Furthermore, it is speculated that by 2026, 300 000 tons of green hydrogen will be produced per year. That is to say that the country is set to be a major contributor to the project of green hydrogen as mentioned by (African Business) in the article *Namibia eyes green hydrogen future*.

(GIS) Geographical Information System is proving to be a powerful tool for answering relevant questions, analyze, edit data with a spatial component as well as display themes (Abdelrazek, 2017). Especially site analysis studies like this study are best fit.

Problem statement

The increase in energy consumption by economic sectors and the population at large evokes for a demand of alternative sources of energy to be applied to compensate for the supply gap in power of what locally the country can generate and the amount that is imported. Therefore, the production of green hydrogen using solar and wind energy is important to compact the power imbalance efficiently, as well as to reach the areas that currently do not have power.

Background:

Zambezi region has a total of 21 manufacturing Companies. Food manufacturing companies (such as Wholesalers & Mills, Poultry, Rice, and flour Mills), Aluminum & Glass Manufacturers, Construction, Electric Utility. Eight constituencies composed of a generous amount of people, with a count of over 90 000 today.

The region constructed 200 energy-saving cooking stoves and 200 solar distributed lamps to 200 houses in 2017 at the Miyako village lead by The Namibia Red Cross Society in partnership with the Spanish Red Cross and the European Union. (constructionreviewonline.com)

Relevance: The region only has one renewable energy plan implemented therefore more incentives need to arise to provide enough power to all the manufacturing companies in all the constituencies as well as the growing population.

Aim:

This study aims to conduct a suitability analysis to identify potential locations for a solar and wind farm in Zambezi region, to produce green hydrogen using GIS tools and algorithms to come to a concrete conclusion.

Objective:

Three suitable locations should be located with the following criteria:

Site A should have a suitability of low potential.

Site B should have a suitability of medium potential.

Site C should have a suitability of high potential.

With that in mind, for the solar farm each site should have the following suitability parameters:

Criteria	Site A	Site B	Site C
Global Irradiance	455130	455130 - 891040	891040 - 1042561
Temperature	<15°C	15°C	35°C
Days of fog per year			<75
Elevation	<500m	1500m – 2000m	>2000m
Slope	>40	7 - 40	<7
Aspect	N, NE, NW	E, W	S, SE, SW, Flat area
Protected Areas	500m	5000m	10000m
Water Bodies	500m	5000m	10000m
Distance from main roads	>1500m	500m – 1500m	<500m
Distance from power line	>1500m	500m – 1500m	<500m
Distance from built up areas	<500m	500m – 3000m	>3000m
Distance from airports	>1500m	500m – 1500m	<500m

Plot size	30000ha	35000ha	40000ha
Population	Less populated	Sparsely populated	Densely populated

Literature Review

A suitable site location analysis for a solar plant was carried out in Al-Qassim region, Saudi Arabia (Alhammad et al., 2022). Spatial GIS, Remote Sensing and MCDA (multi-criteria decision-analysis) framework was used, being mindful of the technical, environmental, and socio- economic characteristics to perform the analysis. The framework was composed of Random Forest raster classification, model builder. Output maps showing the results of suitable areas of the GIS processes that was deployed to achieve the desired results.

A master's thesis conducted a study in Sinai Peninsula, Egypt to find feasible locations for solar power stations. This study was specifically centered around GIS techniques to get the required objectives. Spatial analysis tools and multi criteria decision-making techniques was carried out (Abdelrazek, 2017).

(Messaoudi et al., 2019) This study took place in Adar province, Algeria for a wind-powered hydrogen production site. The methodology used to outline areas that are most feasible was using GIS and MCDM (multi-criteria decision-making) technique accompanied by LSI (land suitability index) and AHP (analytical hierarchy process) weight criteria evaluations. Moreover, this study rendered output maps showing the successful suitable sites after applying a series of algorithms.

According to the study in Erzurum province, Turkey by (Türk et al., 2021), used GIS and intuitionistic fuzzy set based multi-criteria decision-making methods to get the most suitable area for a solar energy power plant site. To determine the area, a site selection map was created with GIS program based on ecological criteria and other technical criteria. Two types of methods were used in this study to compare the consistency of the obtained results. And both approaches generated the same results, both delineated the same areas per suitability criteria.

In the study done in Macedonia for solar, wind farms across the country and hydro power in the vicinity of Prespa lake (Izeiroski et al., 2018). GIS-based approach, geospatial analysis for suitable locations for a potential renewable energy source has been executed. And the GIS based multi-criteria spatial analysis techniques efficiently produced the results of suitable sites as shown in the methodology of the study.

A GIS-based assignment took place in Kayseri, Turkey for solar-powered hydrogen fuel charged stations. Technical, accessibility and environmental criteria was assessed. This includes buffer tool techniques, Area Solar Radiation tool, Reclass tool and weighted value analysis (Akarsu, 2022).

Another study in Morocco to locate suitable PV(photovoltaic) plant and solar farms exploitation was carried out and the famous GIS, MCDM approach was implemented (Taoufik et al., 2021).

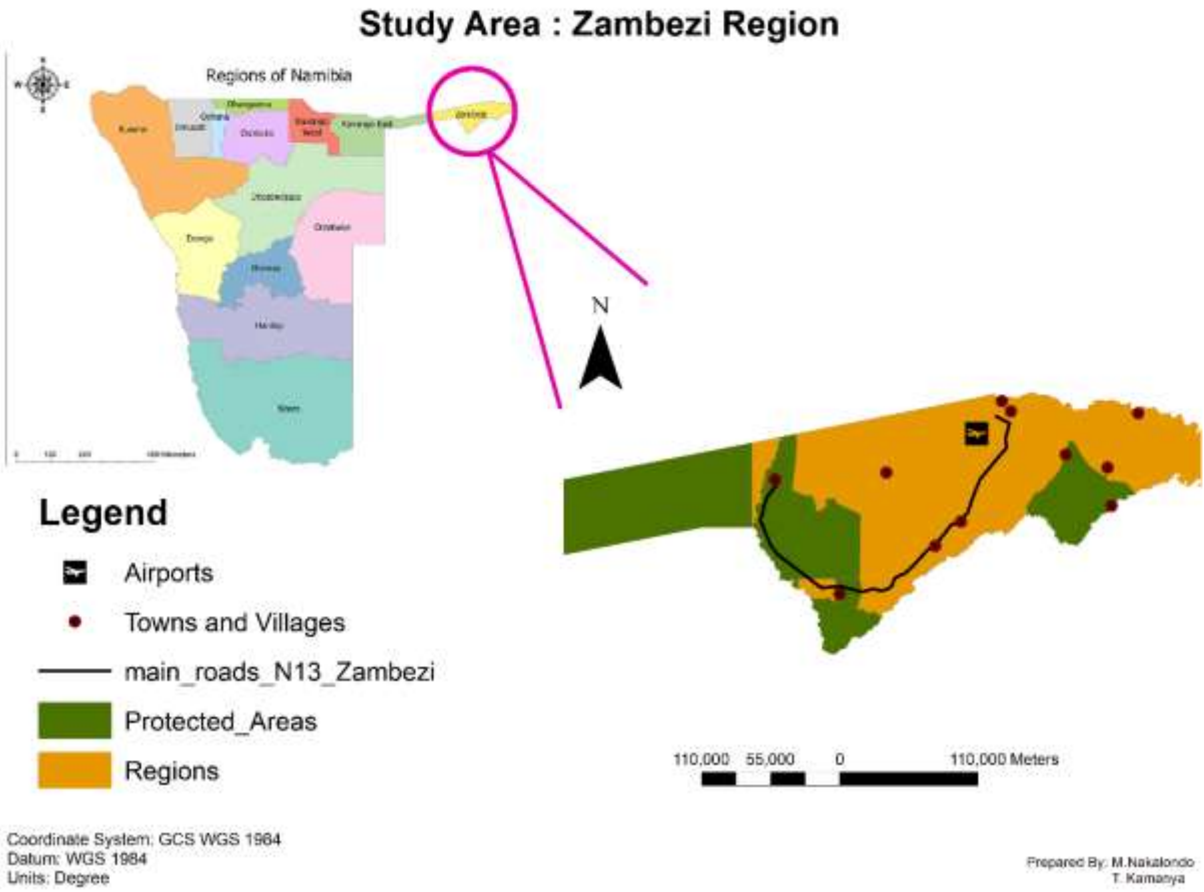
Based on all the previous studies mentioned above, it can be concluded that GIS based analysis can locate, calculate, and precisely estimate suitability analysis assessments.

Methodology

Optimally, this study aims to identify suitable locations for a wind and solar farm from collected data of Zambezi region using GIS techniques such as Buffers, Reclass, Area Solar radiation, clip, DEM, Rasterization, Slope, Aspect, Contour, Selection by attribute and cell statistics to get a resultant map depicting the suitable areas. And the platform used in this analysis is the ESRI ArcMap 10.8 desktop software.

Study Area and Data Collection

Zambezi is one of the 14 regions of Namibia. It adopted its name from the Zambezi River that flows along the border of the region. It is in the far north-east of Namibia. The region has a total population of 90 596 and population density of 6.1/km2 based on the 2011 census. It covers an area of 14 785 km2 and is positioned at a tropical side of the country. Composed of high temperatures and rainfall through summer and it is known as the most wet region in Namibia. Zambezi consists of terrain massively made up of wetlands, floodplains, woodlands, and swamps. And it only has one city and a few localities enclosed by 8 constituencies.



Methodology framework

Considering the objectives of this analysis; technical, accessibility and environmental factors guided the findings in this study. Thus, multiple sources were consulted for data acquisition. Contrary to this, the data that is used in this analysis influenced the overall results, in a sense that it was cumbersome to acquire latest data for some datasets.

The data collected and sources.

Data	Format	Source
Solar radiation	SHP	PolyDB
Days of Fog per year	SHP	Digital Namibia
Temperature	SHP	PolyDB
Wind Speed	TIF	Global Wind Atlas
Digital Elevation Model (DEM) 30m SRTM	GRID	http://dwtkns.com/srtm30m
Towns and Villages (Built up areas)	SHP	Digital Namibia
Airports	SHP	Digital Namibia

Protected Areas	SHP	PolyDB
Population	SHP	PolyDB
Powerlines	SHP	PolyDB
Main roads	SHP	Digital Namibia
Waterbodies	SHP	Digital Namibia

The datasets used in this analysis as per criterion.

Technical

This refers to the slope and climate criteria. Generally, factors such as solar radiation, sunshine per hour, fog, precipitation, temperatures and humidity affect the amount of radiation transmitted (Alhammad et al., 2022)

Elevation

This is significant for a wind farm because the higher the altitude above sea level the more the wind speed. In other words, winds over high altitudes blow more steadily than wind on low elevations. It could be to obstruction reason for instance on low laying land there is grass and trees.

A wind farm, high wind speed values are feasible as opposed to areas with low wind speed values.

Aspect

The differences in air direction influences the in wind and orientation. Prevailing winds are steadier.

For a solar farm, the flatter the area the more suitable it is. Because steep slopes increase the maintains and cost of the power plant as mentioned by Taoufik et al., 2021). High temperatures are optimum for solar radiation. High solar radiation results in GHI (global horizontal irradiation). GHI refers to the solar radiation energy per hour per square meters (Alhammad et al., 2022). Hence it is important for this analysis because the value of energy that can be produced in an area can be determined.

Socio-economic or accessibility

Both power plants should be near roads. This is important because of accessibility and connection between transport means and the power plant. For instance, transporting tanks of green hydrogen will be easier and faster. As well as building the power plant will be faster because the optimum area is within reach, and it won't take long distances to install handful equipment. The goal is to be efficient.

Subsequently, the power plants should be close to powerlines to cut costs. This way it won't be necessary to construct new powerlines which can be time consuming and not cost effective. Proximity to powerlines is essential to conserve power. If power lines are far from the power plant electricity will be lost due to resistance and the longer the cable the more the resistance, and this is not favorable.

And the power plants should not be too close to airports because airports are restricted areas.

Environmental: Protected areas

Based on previous studies, protected areas is a restricted area for nature conservation purposes (Taoufik et al., 2021).

Waterbodies

Both power plants should not be too close and too far from waterbodies. For electrolysis of green hydrogen water is an essential component therefore it should be accessible.

Built up areas.

A suitable power plant should not be built close to residential areas to avoid direct impacts on the population (Taoufik et al., 2021).

The power plant site selection parameters summarized.

Technical	Slope GHI (Global Horizontal Irradiation) Temperature Fog Wind Speed
Accessibility or Socio-economic	Main Roads Powerlines Airports
Environmental	Built up Areas. Protected Areas Waterbodies

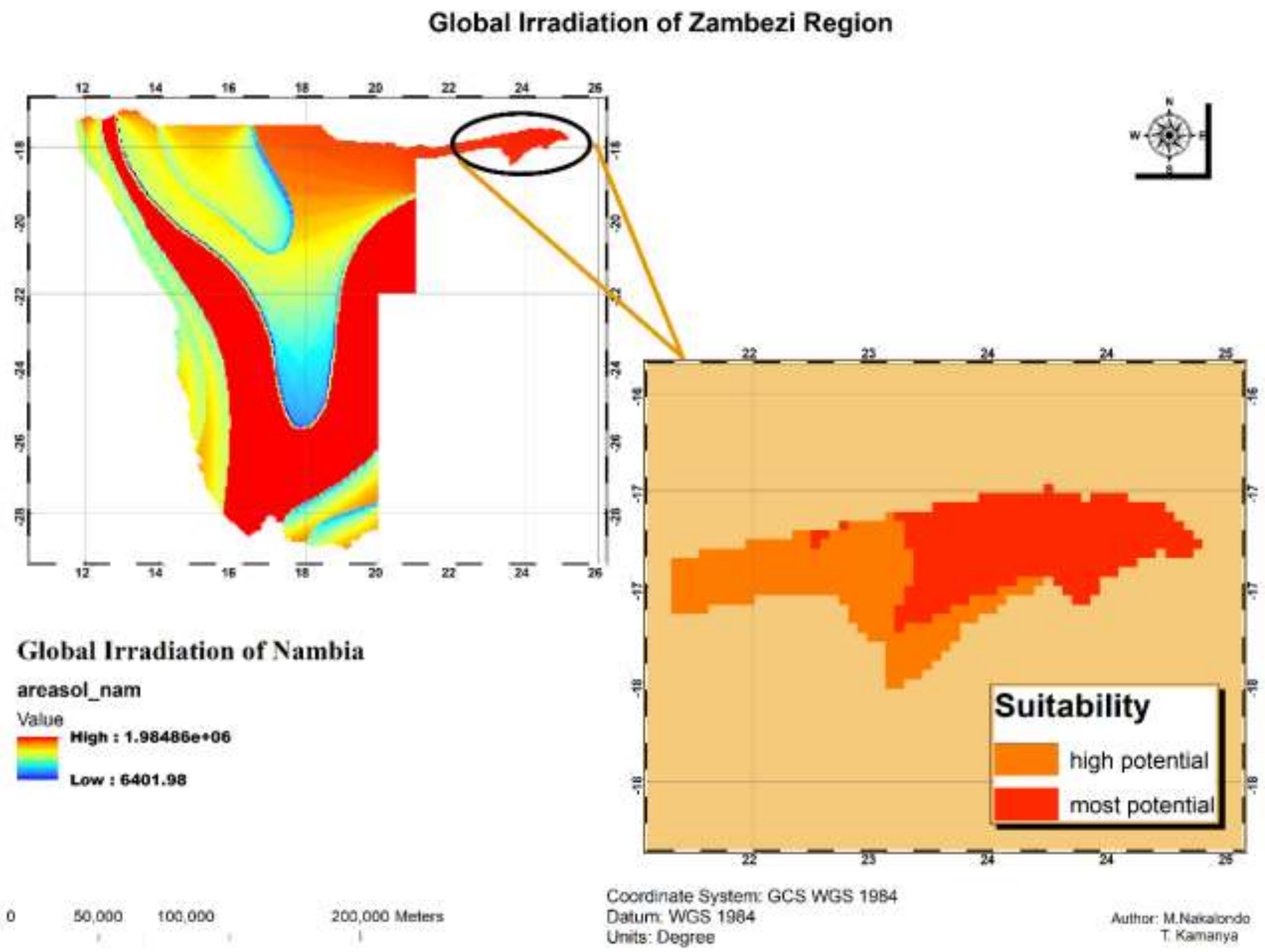
Processes that were carried out to determine a suitability for a both power farms.

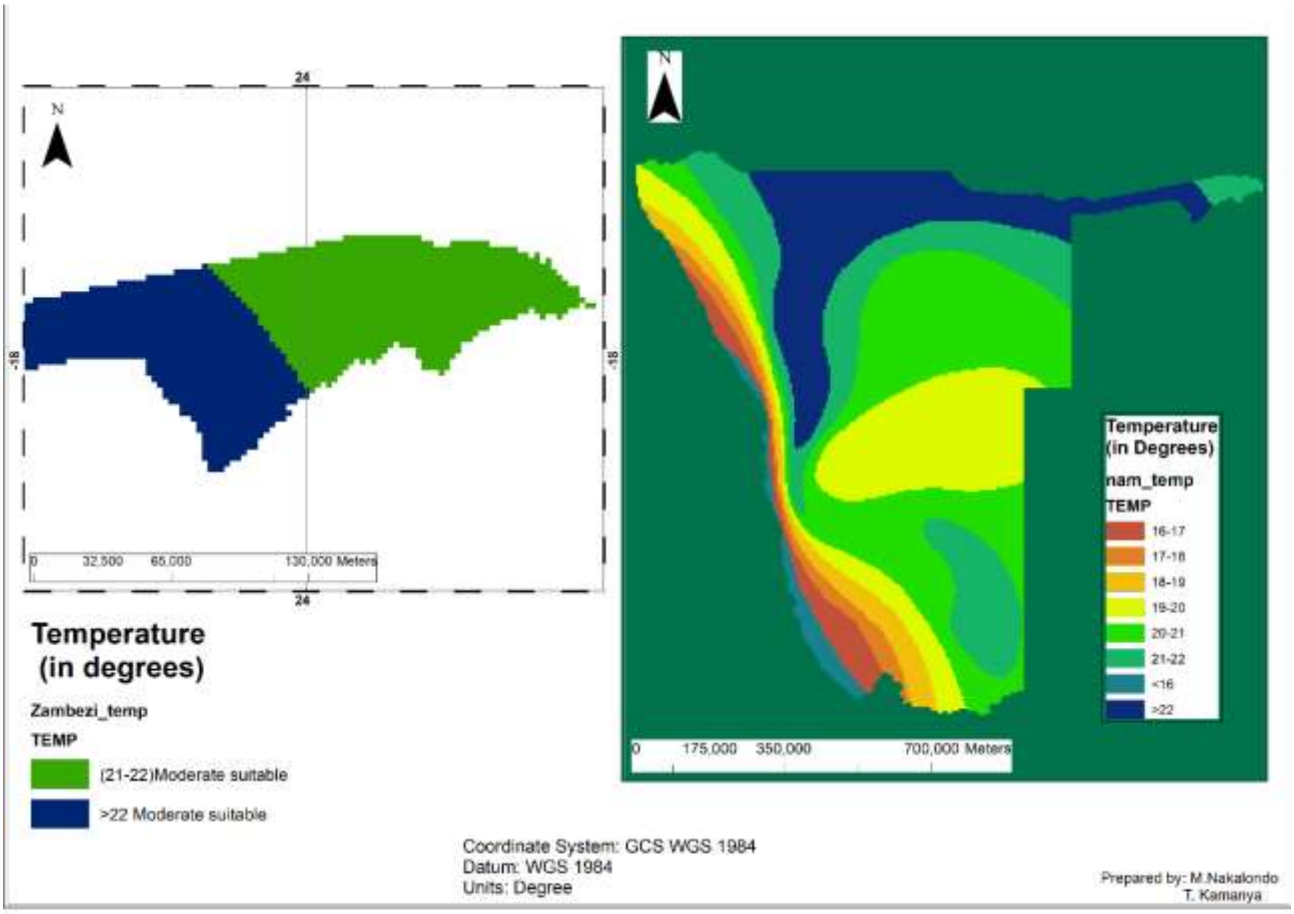
1. After loading all the layers in ArcMap, a thorough examination was done on the datasets. For instance, different values outlined in the attribute table for a better interpretation of the information contained by the datasets. Thus, to be able to apply the right criteria best fit with the available data. And to make sure the data is in the same projection.
2. Using the Area Solar Radiation, the GHI value was calculated with the Solar radiation shapefile as the input and the output layer has been reclassified as per criteria of Site A, Site B and Site C.
3. Using the reclass tool the wind speed has been reclassified.
4. In the 3D analyst tool, the surface contour was used to generate a contour layer to show elevation values of the area.
5. Again, with the 3D analyst tool, the slope tool created the slope layer.
6. With the spatial analyst tool aspect of the slope was produced.
7. Multiple ring buffer for protected Areas, waterbodies, main road, powerline, built up areas, airport, population, and plot size were created.

8. Further, the output layers at each step were reclassified and individual maps was produced to visually the results of each process and how the criteria have been executed for all the sites (Site A, Site B and Site C).
9. The union tool was used for merging the vector layers.
10. Run a cell statistics process, inserting all participating layers with distinct values of influence considering the criteria given.

Visual representations of each process deployed in this analysis.

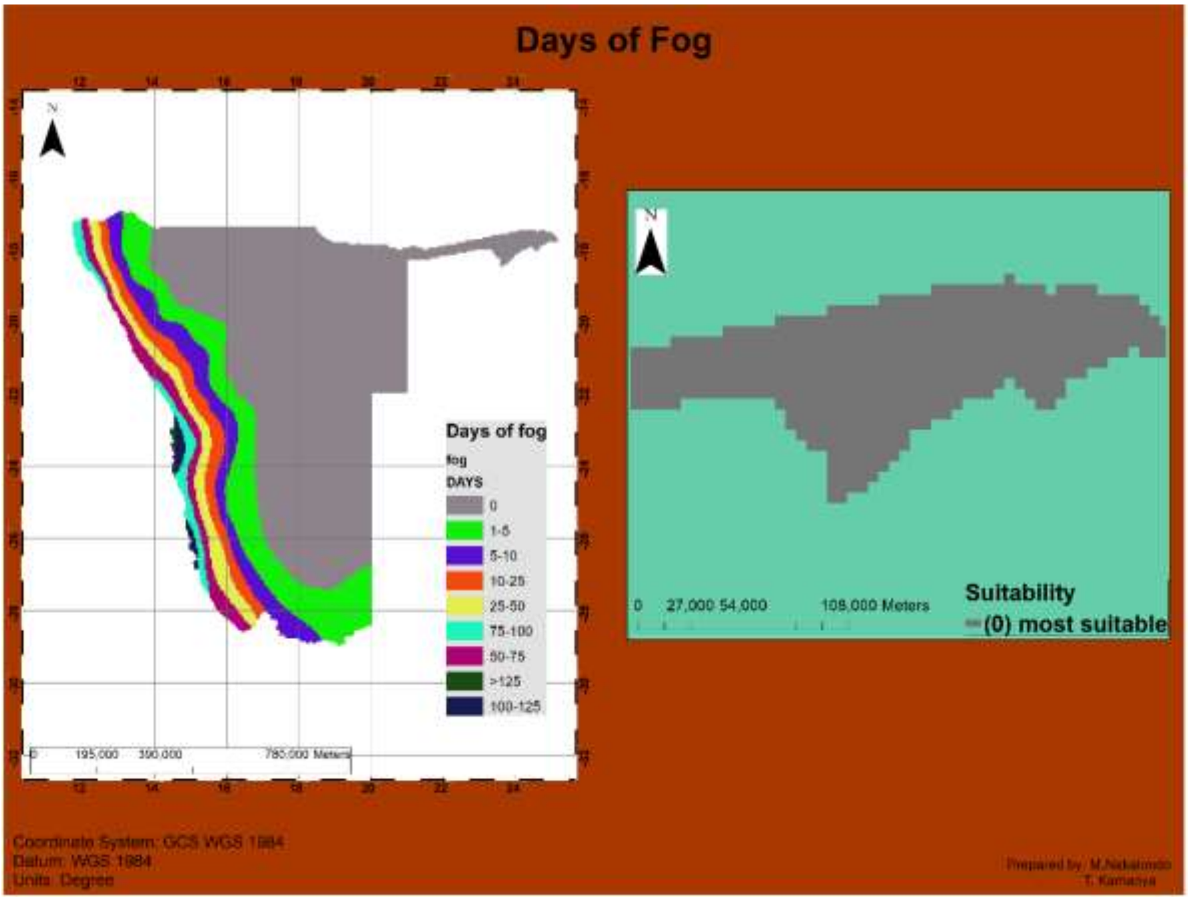
Below is a map showing the distribution of GHI of Namibia and of Zambezi specifically. The region has high solar radiation in turn the GHI calculated in the area will be high as well.



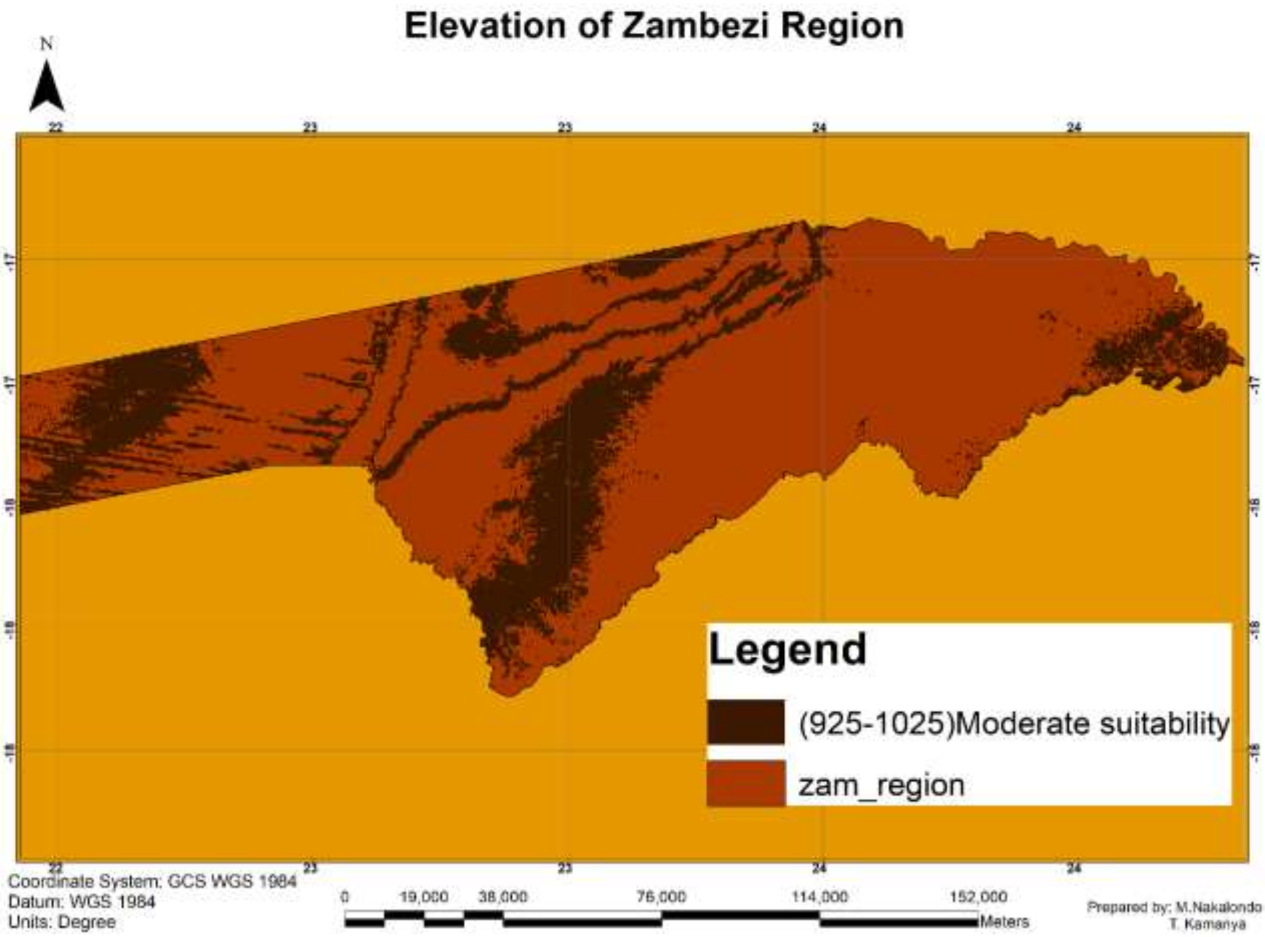


Suitability Map of Temperature in Zambezi Region and All over Namibia

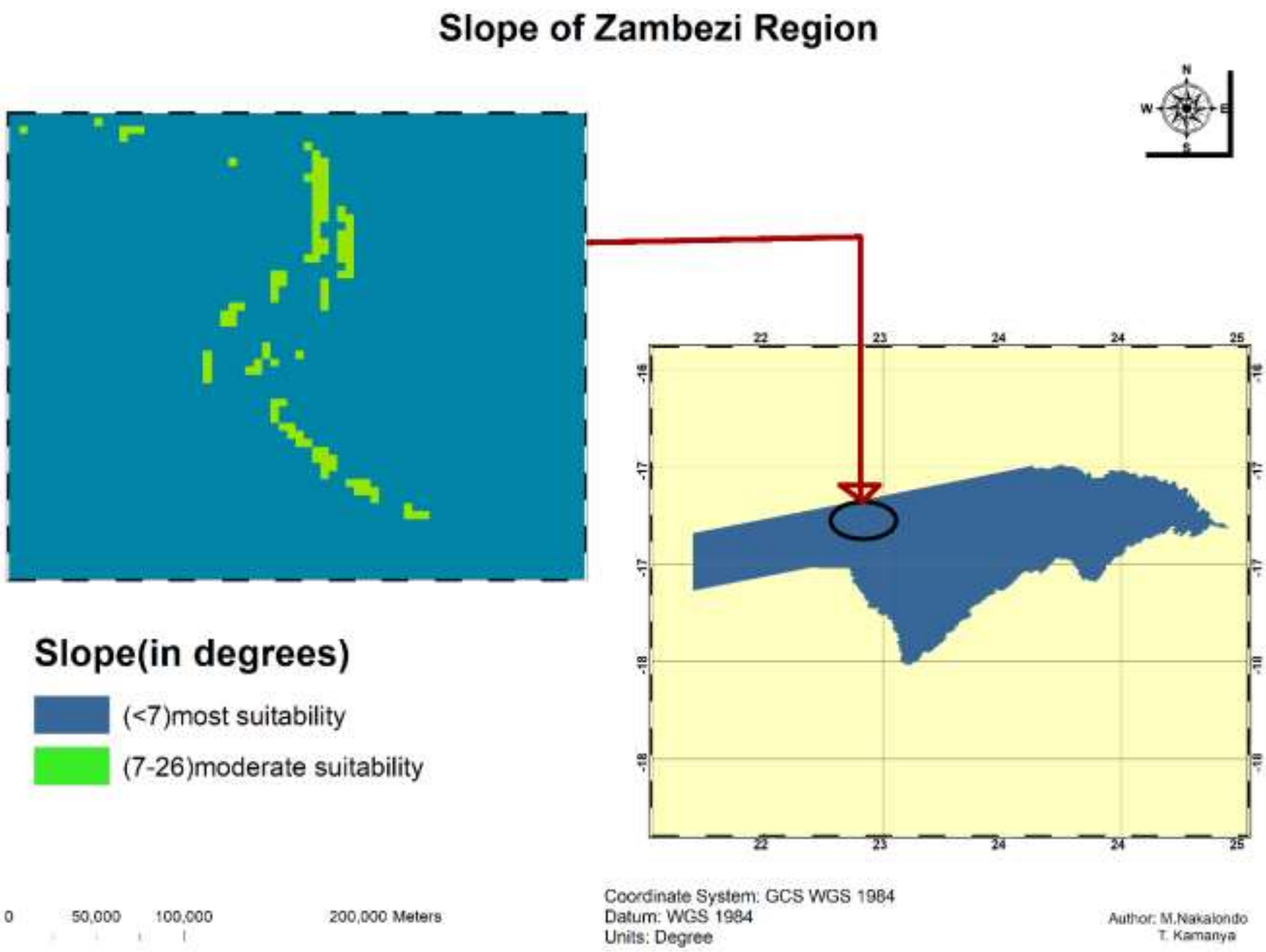
For Zambezi the highest temperature at the time was 22 degrees however for high suitability an optimum temperature of 35 is required.

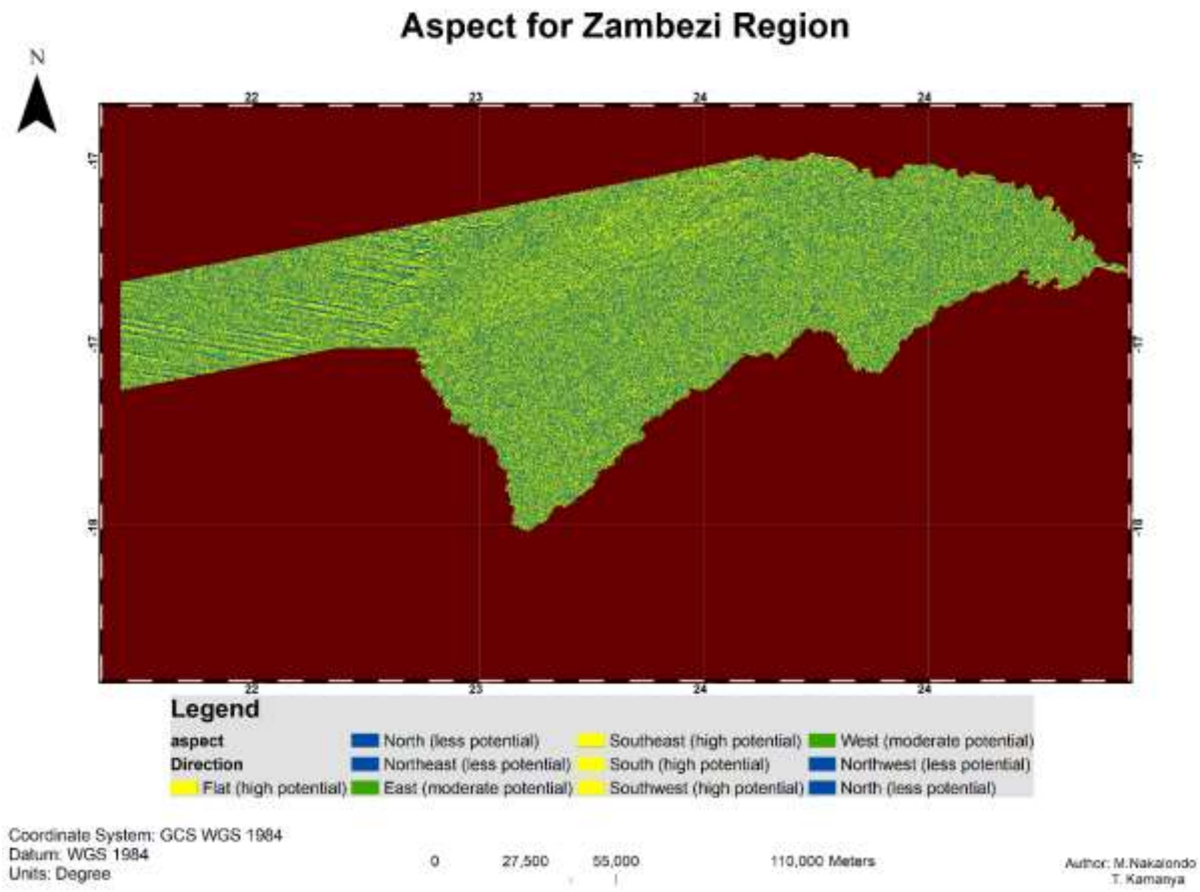


At the period of when the fog dataset was collected, the region had no fog. But it is comprehensive based on the geographic location of the area. And zero days of fog per year is optimal.

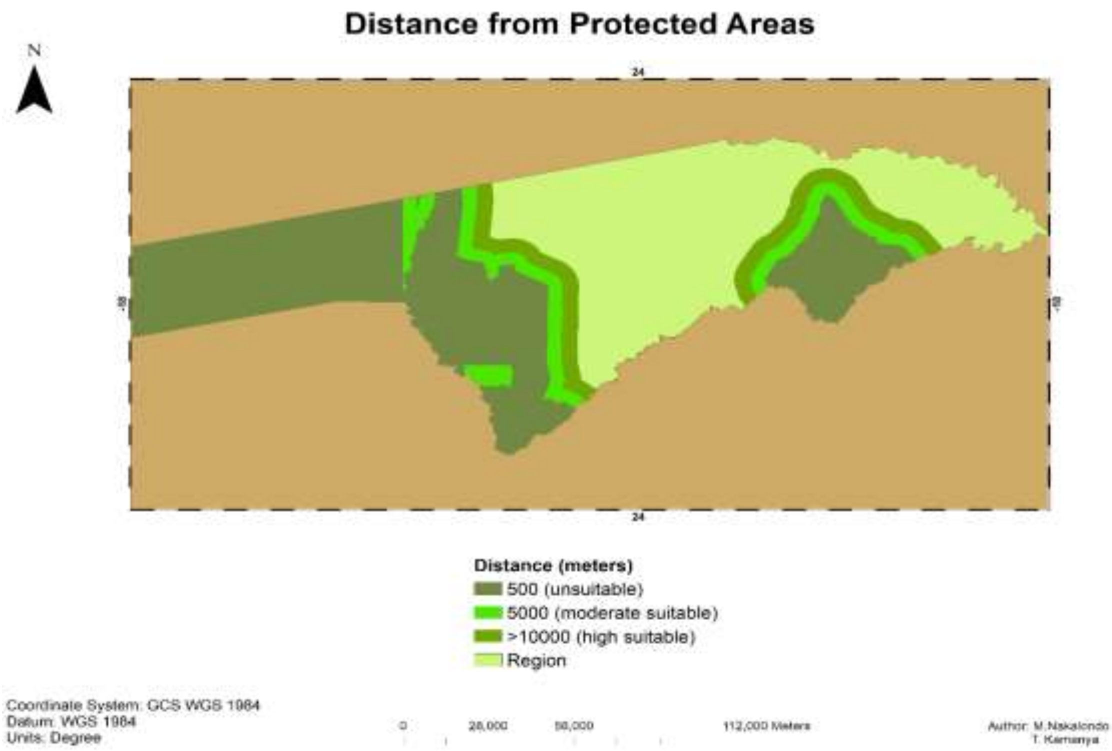


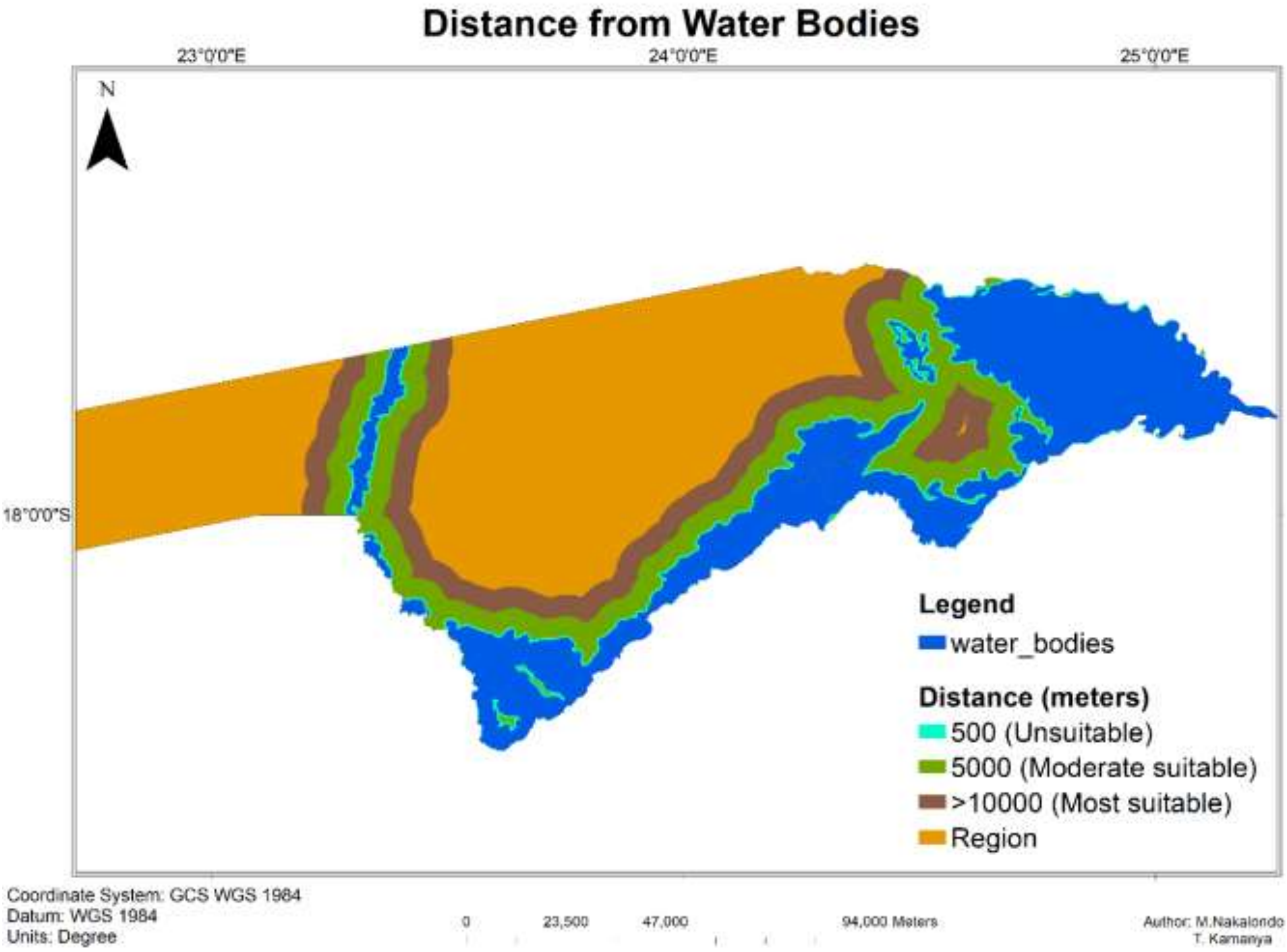
The elevation is required to be greater than 2000m. But the region had a minimum height value of 925 to a maximum of 1025 which is concluded to be moderately suitable because the height values are not drastically far from the desired elevation.


Slope of Zambezi Region
N
W
E
S
Slope(in degrees)
(<7)most suitability
(7-26)moderate suitability
0
50,000
100,000
200,000 Meters
Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree
Author: M.Nakalondo
T. Kamanya



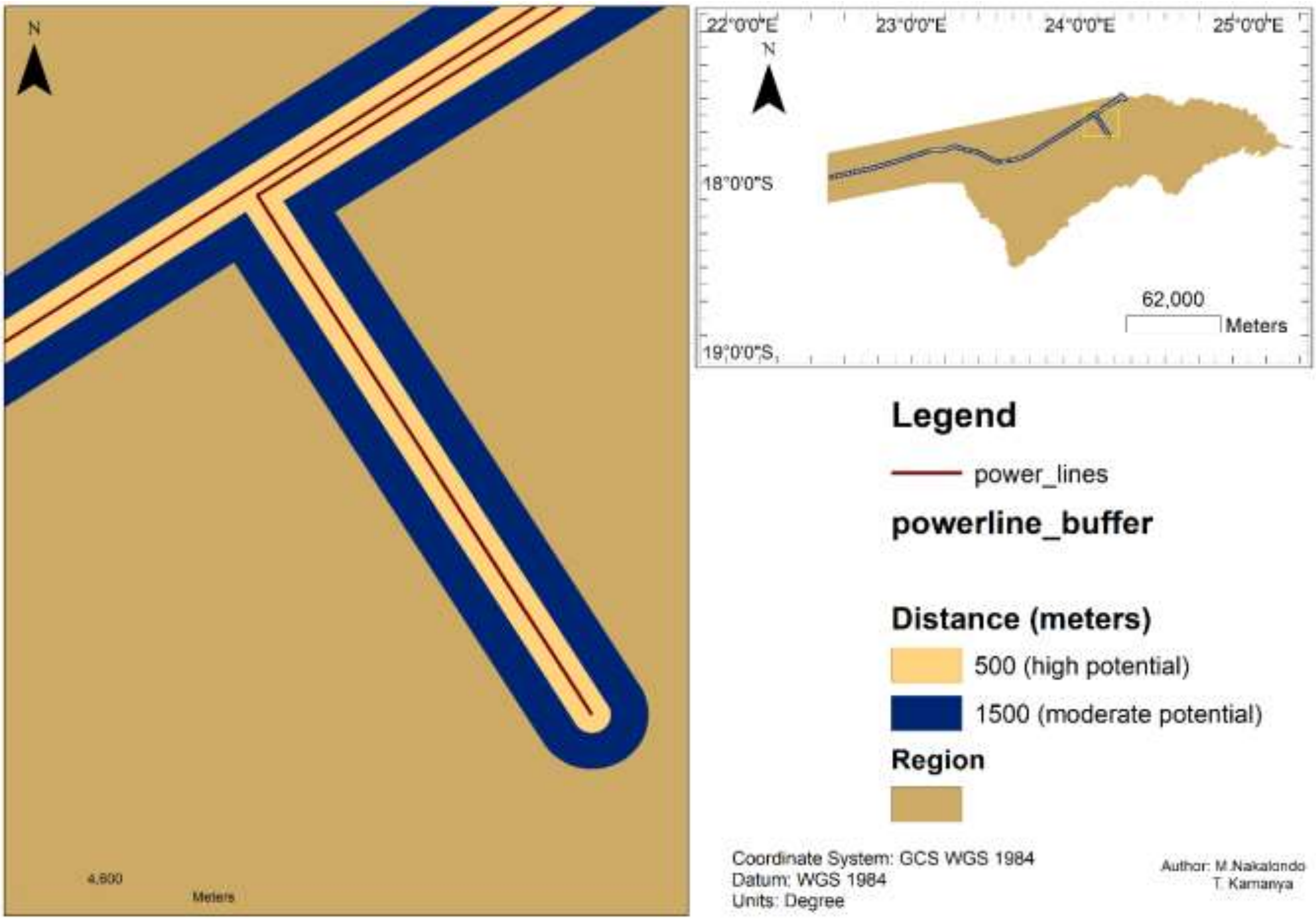
Desired aspect is concluded to be (Less suitable: N, NE, NW), (Moderate suitable: EW) and (most suitable: S, SE, SW, and flat area)





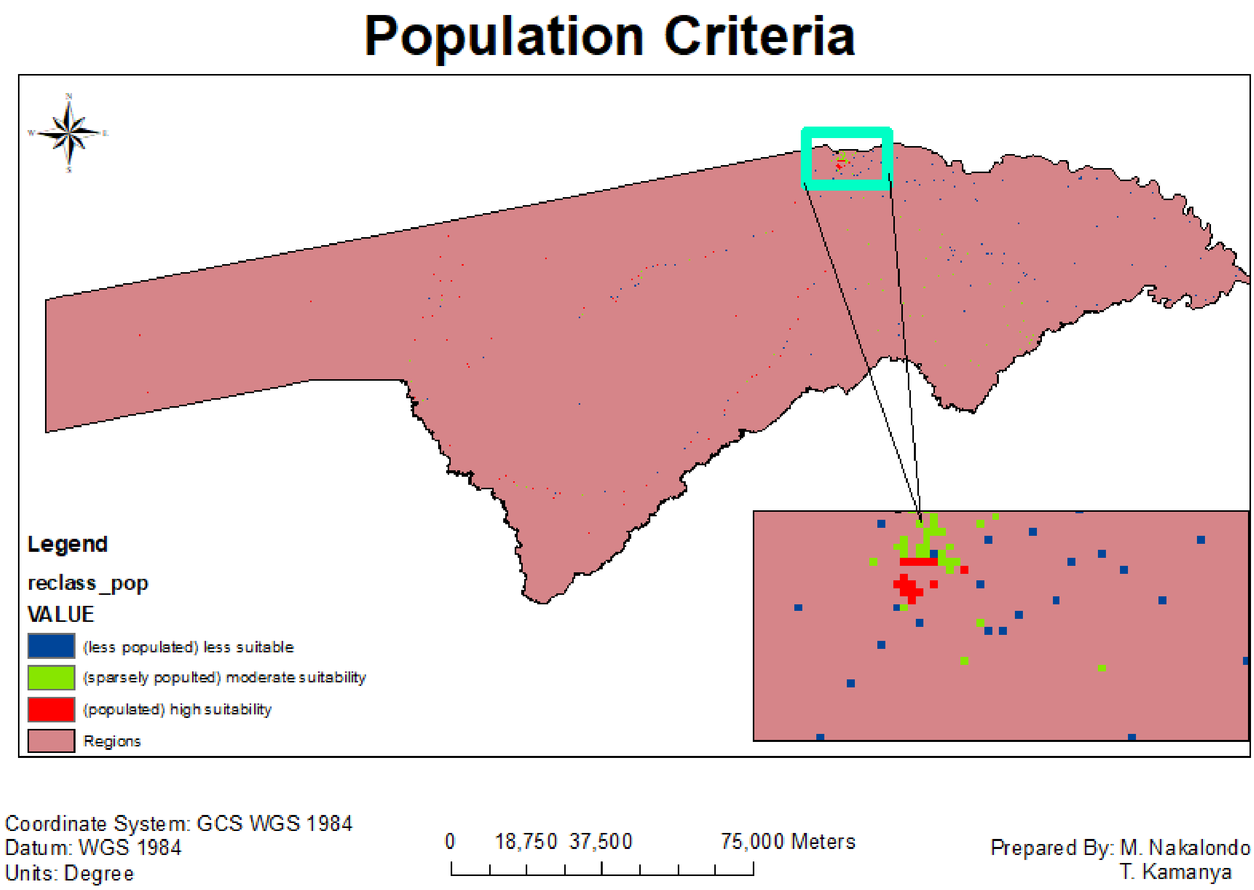
Distance from Water Bodies
23°0'0"E
24°0'0"E
25°0'0"E
N
18°0'0"S
Legend
water_bodies
Distance (meters)
500 (Unsuitable)
5000 (Moderate suitable)
>10000 (Most suitable)
Region
Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree
0
23,500
47,000
94,000 Meters
Author: M.Nakalondo
T. Kamanya

Distance from the Main Road

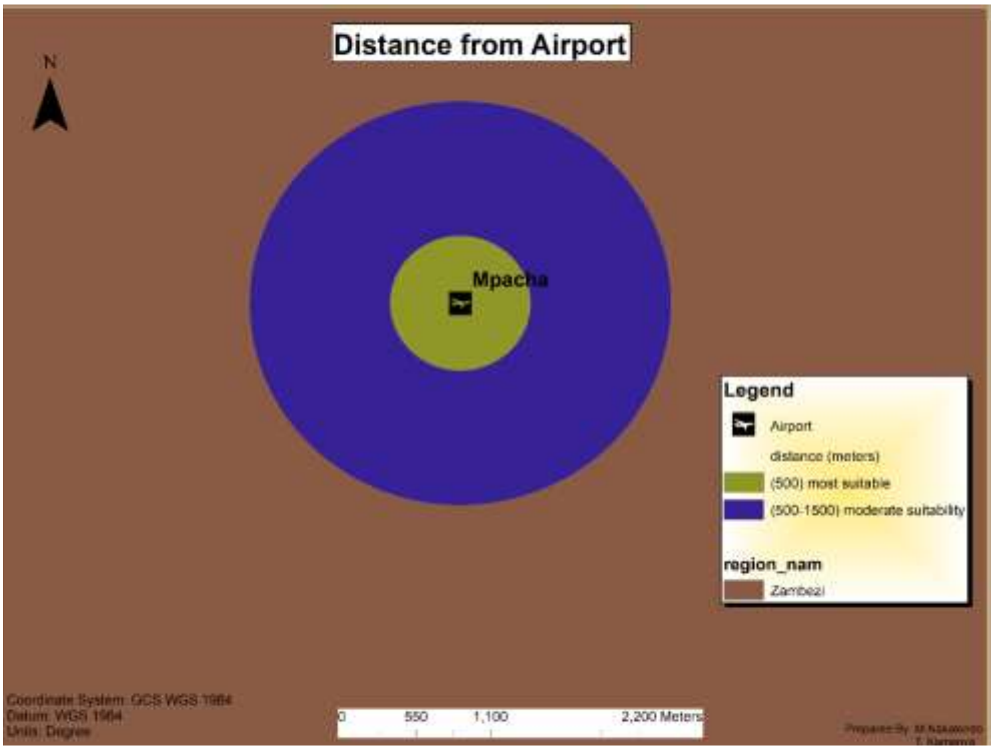


Distance from the Powerline

Distance from Built up Areas



As depicted in the map the area where the population is concentrated is optimal for both power plants because more people can get access to energy.



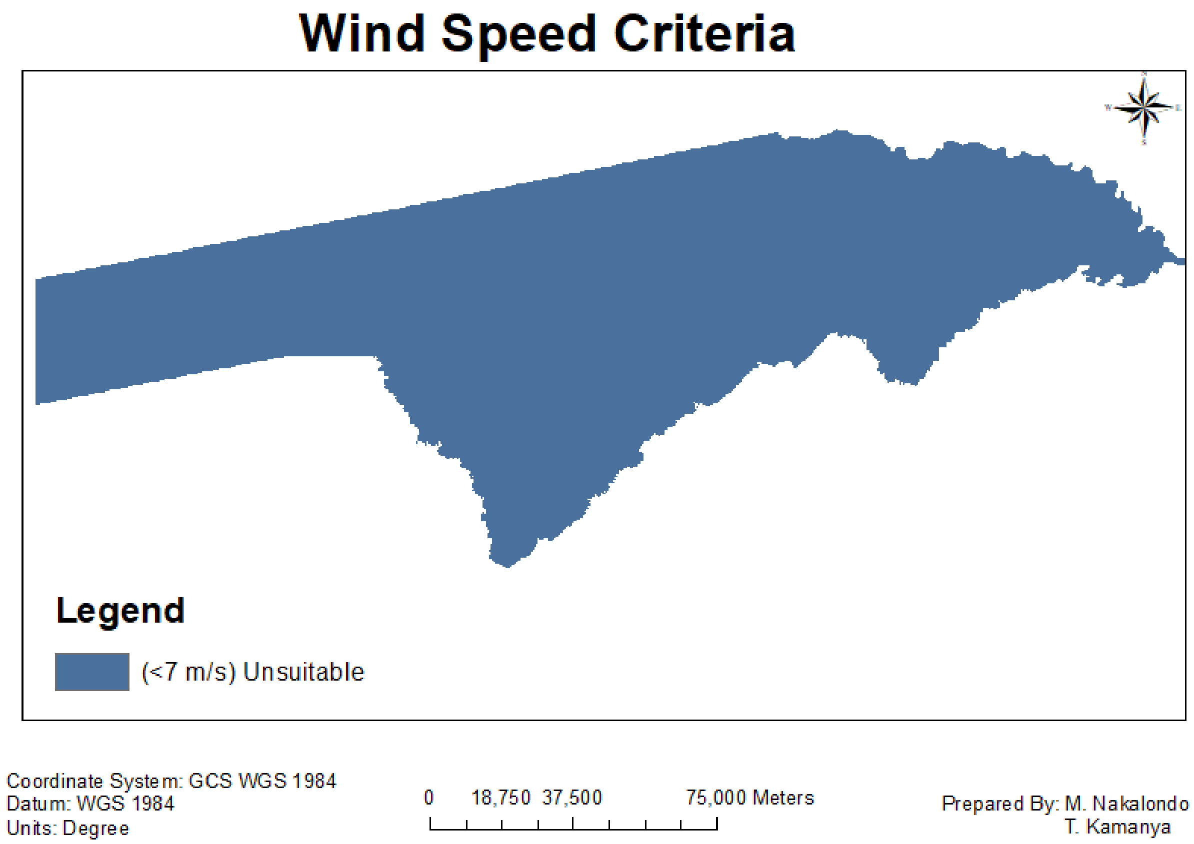
For the distance away from airports, distance outside the two buffer rings is unsuitable.

Wind Farm

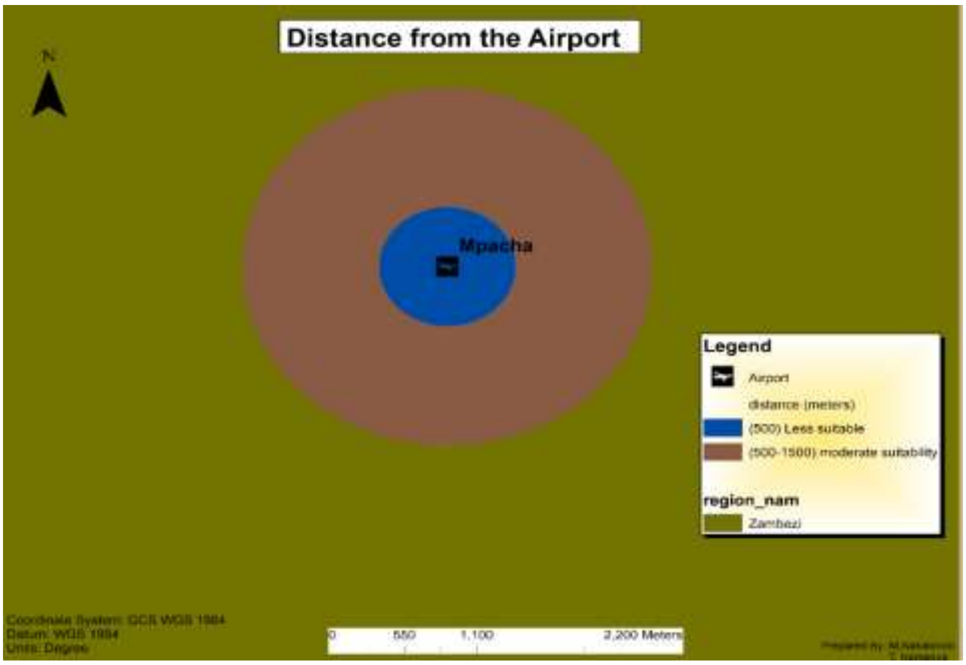
Certain criteria for the wind farm are the same for the solar farm such as, Elevation, Aspect, Slope, Protected areas, water bodies, distance from main roads, distance from powerline, plot size, population. The only difference is the wind speed in that area and the distance from airport. And fog doesn't significantly influence the speed at which the wind blows therefore that factor is not explored.

Wind Farm parameters.

Criteria	Site A	Site B	Site C
Wind Speed	<10	10 – 11.5	>11.5
Elevation	<500m	1500m – 2000m	>2000m
Slope	>40	7 - 40	<7
Aspect	N, NE, NW	E, W	S, SE, SW, Flat area
Protected Areas	500m	5000m	10000m
Water Bodies	500m	5000m	10000m
Distance from main roads	>1500m	500m – 1500m	<500m
Distance from power line	>1500m	500m – 1500m	<500m
Distance from built up areas	<500m	500m – 3000m	>3000m
Distance from airports	>1500m	500m – 1500m	<500m
Plot size	30000ha	35000ha	40000ha
Population	Less populated	Sparsely populated	Densely populated

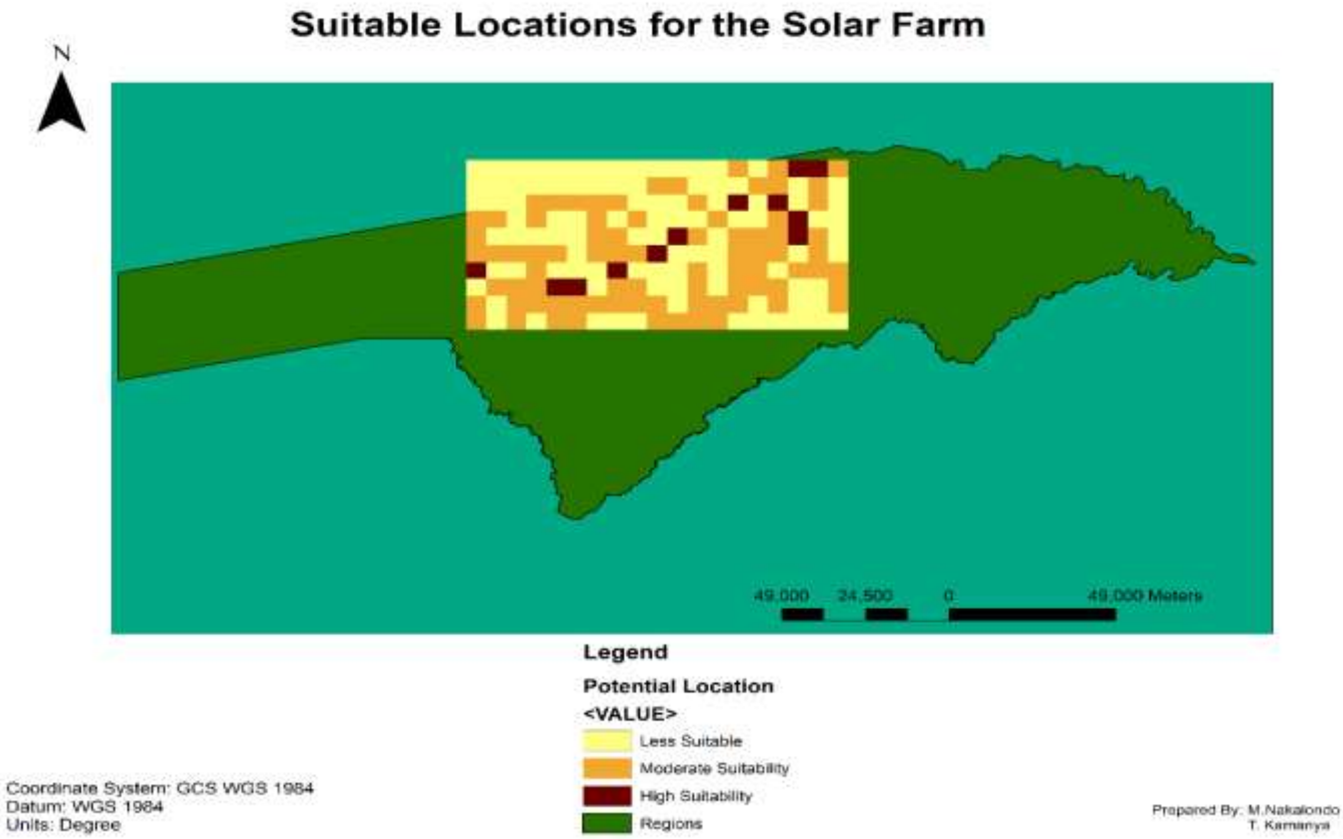


With the results shown in the map, a wind farm cannot be installed in Zambezi because the highest value of wind speed was 7m/s (knots) which in the criteria falls under less suitable. Again, these results could have been affected by the time of the data acquisition. But, Zambezi geographically is located on a tropical area as mentioned earlier in this study. Therefore, it explains why it has low wind values.



Results: The suitability map for a solar farm

The map shows the areas that are suitable after a series of algorithms have been applied. Like the Cell statistics tool produced the results shown by combining all the criteria together.

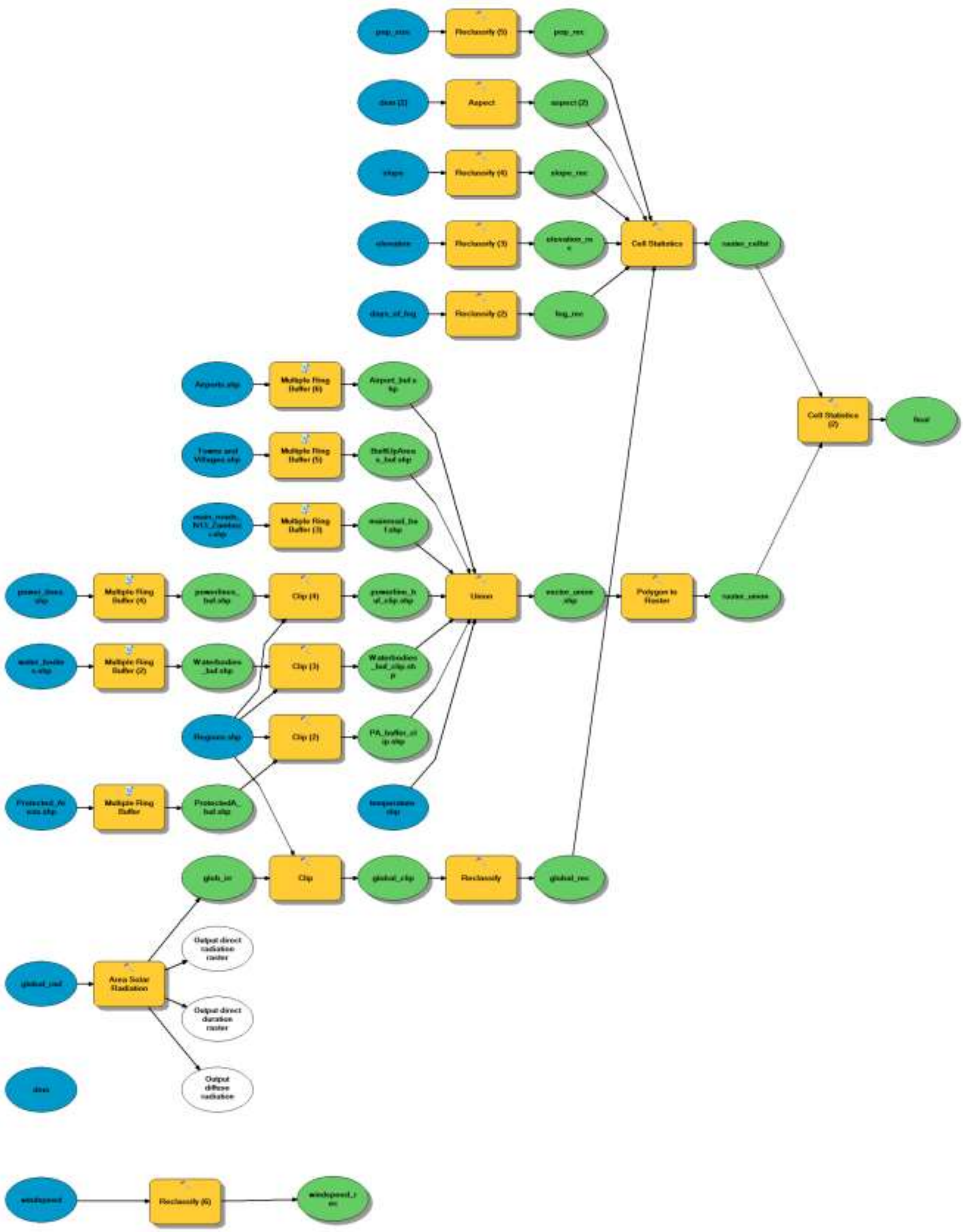


Conclusion:

This study aimed to conduct a site suitability analysis to determine a suitable location for both a solar and wind farm to produce green hydrogen and implement renewable energy resources as the main way to generate power as per goal of the sustainable developed goals and the vision 2030 framework of Namibia. Hence to supply enough power at a large scale, to manufacturing companies and cater for the whole population. Undoubtedly, this study used Zambezi region as a case study but with effort, findings in this paper can be used to conduct research and implement these methods to install power plants all over the country in the future.

Besides that, GIS tools and techniques proved to be a major platform to effectively answer questions for studies like this one. With a generous number of literatures mentioned in this study, one can confidently say site location analysis is best carried out using these techniques. And the output maps at each step of the methodology framework confirms this conclusion.

A figure showing the process carried out.



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