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Land Suitability For The Placement Of Green Hydrogen Infrastructure In South-Eastern Nigeria

Master thesis

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DECLARATION FOR THE MASTER'S THESIS

I confirm that this master's thesis is my own work including all maps, and I have documented all sources, citations and material used. This thesis was not previously presented to another examination board and has not been published.

ABSTRACT

In numerous settings, the emergence of renewable energy has sown the seeds of green energy for the future. The desired answer that is used to address the problems of rising energy demand, accessibility, availability, and renewable energy possibilities is recognized as being green energy. Without a doubt, population expansion has been a global phenomenon, and with development comes human needs, particularly those related to energy use and consumption. Due to the population's heavy reliance on fossil fuels and high daily energy use, other issues that have alarmed the populace include the expansion of the effects of human activities, energy demand, and supply. In order to maintain adequate supply and availability renewable energy that is sustainable for both the present and future generations, it is necessary to balance energy use and consumption with a decrease in dependency on carbon and fossil fuel.

In order to achieve its long-term objectives, a country like Nigeria must find a sustainable renewable energy source to replace fossil fuels due to the country's increased energy consumption and a variety of general concerns, such as the rising need for energy. With its abundance of renewable energy resources, including hydroelectric power plants, solar, wind, biomass, and hydrogen exploitation potential, as well as potential for ocean energy and geothermal progress, the country has a great potential for renewable energy, notably in the area of solar, wind, and other sources like green hydrogen, as a way to balance these deficits and satisfy the energy demand.

This study used GIS technologies to examine the viability of certain area in southeast Nigeria for the installation of solar hydrogen infrastructure. The multi-criteria decision model was used to weigh in the suitability of criteria such as elevation, slope, surface temperature, production potential, energy demand as well as distances to road, rail, powerlines and river. These were overlaid using the Weighted Overlay tool under Spatial Analysis. The constraints of land use were considered and AHP was used in deriving relative weights for each criterion. The results showed that about 45% of the region was unsuitable while 8.5% of the region was considered highly suitable with most parts located in the north and north eastern areas of the region. With 61 out of 95 communes being potential sites, through careful development and maintenance of the infrastructure, there is a good probability that green hydrogen can be established in the south-eastern Nigeria.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The dawn of renewable energy has frequently birthed the foundation of green energy for the future in different places. Green energy is acknowledged to be the 'wanted solution' that is deployed for curbing the issue of increasing energy demand, accessibility, availability and renewable energy prospects (Izeiroski et al., 2018). With no doubt, population increase has been an inevitable phenomenon around the world and with growth comes, human needs for daily living which centers around energy usage and consumption (Chrysochoidis-Antsos et al., 2020)

Also, the increase in impacts of human activities, energy demand and supply are issues that has concerned the population because of much reliance on fossil fuel and high energy consumption for daily use (Maestre et al., 2021). The need to balance energy use and consumption with a reduction in reliance on carbon and fossil fuel comes with the essentials to ensure proper provision and availability of green and renewable energy that is sustainable for present and future generations (Gül & Akyüz, 2020).

Holt & Pengelly (2008) described renewable energy as an energy that has its source and are continually replenished by nature (either sun, wind, water, or plants). Also, Prentiss (2015) explained renewable energy as 'energy that can be used without jeopardizing future availability' and it can include hydropower, solar, geothermal, wind and bioenergy. This is to point out that the essence of renewable energy is to ensure the sustainability and availability of energy from different sources without affecting future prospective use. Again, it is seen that its capacity to meet the needs of the future come first as an advantage. Today, fossil fuels are mostly used to heat and power modern houses, as well as to propel different automobiles. Coal, oil, and natural gas are convenient for providing daily energy demands, but there is a finite quantity of these fuels on the planet. They are consumed at a much faster rate than they are being generated and will eventually run out (Holt & Pengelly, 2008; Prentiss, 2015).

In most countries of the world, renewable energy capacities vary and with this knowledge, many of them have made efforts geared towards sustainable energy (see table 1.1)

Table 1.1: Installed Renewable Energy Capacity by Country (Madhumitha, 2021)

Rank Order	Country	Renewable Energy Installations (Gigawatts)
1	China	895
2	United States	292
3	Brazil	150
4	India	134
5	Germany	132
6	Canada	101
7	Japan	101
8	Italy	55
9	France	35

According to Madhumitha (2021), renewable energy capacity explains the maximum generating capacity of installations, that uses renewable resources to produce electricity i.e., how much installation can generate output from renewable resources. This is quite different from renewable energy consumption where China, USA and Germany are the top three countries with highest renewable energy consumption even though there have been increased production in renewable energy overtime (Madhumitha, 2021).

1.2 Green Hydrogen as a Renewable Energy Resource

With hydrogen-based fuels capable of transporting renewable energy over vast distances – from energy-rich areas to energy-scarce areas – hydrogen is quickly becoming one of the most popular solutions for storing renewable energy (Messaoudi et al., 2019). Green hydrogen was mentioned in the United Nations Climate Conference (COP26) as a solution to decarbonize heavy industries, long-haul freight, shipping, and aviation. Both governments and businesses have acknowledged hydrogen as a critical component of a net-zero economy (Kalbasi et al., 2021; Supapo et al., 2021).

Hydrogen is the simplest and smallest element in the periodic table. Regardless of how it is made, it produces the same carbon-free molecule (IRENA, 2019). However, the methods for producing it, as well as the emissions of greenhouse gases such as carbon dioxide (CO2) and methane (CH4), are quite wide. Green hydrogen is hydrogen generated by splitting water into hydrogen and oxygen using renewable energy (Fan et al., 2021). Solar energy, on the other hand, can be utilized to produce hydrogen in two ways: solar-powered water electrolysis and direct solar water splitting (US Department of Energy, 1995).

The ever-increasing amount of renewable energy sources in the electricity supply necessitates massive energy storage systems to handle resource uncertainties. Hydrogen generation technologies offer a clean and adaptable alternative for improving renewables penetration and energy independence in this environment (Maestre et al., 2021). Hydrogen generation has been studied as a method for decarbonizing the energy mix since the early 1990s (Abdurakhmanov et al., 2021). Furthermore, greenhouse gas (GHG) reduction has been a major concern since the turn of the century. As a result, an international effort is underway to cut global emissions while simultaneously limiting global average temperature rise to 2 degrees Celsius above pre-industrial levels (Maestre et al., 2021).

Hydrogen is a potential option for decreasing global warming and achieving the United Nations' Sustainable Development Goals (SDGs), which are 17 global goals adopted by United Nations as a list of actions geared towards ending poverty, protecting the planet and to create peace in the countries of the world (UNSDG, 2020). Creating an affordable and clean energy (SDG Goal 7) hinges on the need to create clean, affordable. sustainable as well as renewable energy sources that will benefit of the increasing population. It is also aimed at energy productivity through expanding infrastructures and upgrading technology to provide clean and more efficient energy.

Green hydrogen infrastructure falls within the precept of the SDG because it is technologically and infrastructure-oriented and is aimed towards providing efficient energy that would help to reduce the demand and reliance on fossil fuels, which are major contributors to climate change. Furthermore, its large-scale integration with Renewable Energy Sources (RES), such as the sun and wind, makes it a clean and long-term alternative for speeding up the clean energy transition (Adewuyi, 2020).

Apart from inefficiencies in the energy industry, conventional resources have other disadvantages, such as being nonrenewable and potentially contributing to environmental degradation. This has highlighted the importance of finding alternatives to Nigeria's traditional energy sources (Adewuyi, 2020). An 18% market penetration indicates that hydrogen resource is slowly gaining its way as a part of the renewable energy market that can be implemented (Chrysochoidis-Antsos et al., 2020; Fan et al., 2021; Newsom, 2012).

Renewable energy resources, such as solar hydrogen, might present diverse chances for optimizing consumption and creating an avenue for the development of renewable energy, which would help to reduce overdependence on fossil fuels in a location like the country's south-eastern region (Olanipekun & Adelakun, 2020). This will also usher in a new technological system that will improve livability and make the environment more open to opportunities for its residents' advancement. Because the region is recognized for its enterprises and industries, solar hydrogen infrastructure is a definite way to make energy accessible and available in a way that will help people with their daily activities. Finally, there will be a reduction in carbon and greenhouse gas emissions (Abdurakhmanov et al., 2021; Alhammad et al., 2022; Ezugwu, 2015; Olanipekun & Adelakun, 2020; Supapo et al., 2021).

1.3 Problem Statement

It is a difficulty in Nigeria and other regions of Africa to provide affordable clean energy in accordance with the Sustainable Development Goal (SDG) 7 as described above. The majority of current energy solutions are unsustainable or requires maintenance. Nigeria is a major exporter of fossil fuels, but it is currently suffering from a serious energy deficit, forcing the search for a sustainable renewable energy source to replace fossil fuels in order to meet its long-term goals (Adewuyi, 2020).

The need for energy in African countries has risen throughout time as a result of fast population growth, a boom in small-scale businesses, and indigenous technology breakthroughs. Nigeria, the world's most populous black country, has a huge demand for this product, with a population of about 200 million people (Igbinovia, 2014). Unfortunately, because Nigeria's access to renewable energy and energy efficiency is restricted, this demand is rarely met. Poverty, insufficient health care, a drop in economic growth, poor research development, and socio-economic inequities are all outcomes of this lack of energy availability (Kehinde et al., 2018).

The domestic, industrial, agricultural, transportation, and commercial sectors all consume energy in the south east as well as the country (Adewuyi, 2020). The constant fluctuation in supply and market price of power and petroleum products in country's energy industry reveals inefficiency in meeting demand and exposes the problem. Crude oil, coal, and natural gas are only a few of the country's basic energy resources (Igbinovia, 2014). The country as a whole, is faced with challenge of energy supply, which is often linked with the failure of energy and urban planners to effectively estimate the effect of numerous socio-economic and physical aspects that influences the electricity consumption rate throughout the geopolitical zones (Ubani et al., 2013). This is to say that energy supply problems are not limited to the south east zone alone. Nigeria has abundant oil and gas, hydropower, and solar resources, and existing facilities have the capacity to produce 16,384 Megawatts of electricity. However, most times, it can only generate energy that is lesser than half of the capacity, which is inadequate for a country with a rapidly increasing population (USAID, 2020).

Also, the Nigerian power sector has a number of broad issues, including policy enforcement, regulatory uncertainty, gas supply, transmission system limits, and severe power sector planning shortages, all of which have prevented the sector from attaining commercial and economic potential. Presently, demand for electricity continues to exceed capacity, resulting in the deployment of substandard and inadequate services, as indicated by continuous power outages (Ubani et al., 2013).

Furthermore, over the decades, Nigeria's electricity consumption has increased at a breakneck pace. Electricity usage in the country went from 752 million kwh to 8576.3 million kwh between

1970 and 2004. Electricity consumption have also been predicted to rise significantly in the upcoming decades, owing to existing trends in population growth, industrialization, urbanization, modernization, and income development (Ubani et al., 2013). All of this necessitates an equal supply of infrastructure and public services to ensure long-term viability. The provision and distribution of adequate power is a critical development problem that cannot be overstated.

In general, the country has high potential for renewable energy especially in the aspect of solar, wind energy and others as it has abundant renewable energy resources, such as large and small hydroelectric power plants, solar energy, biomass, wind, hydrogen exploitation potential, as well as potential for ocean energy and geothermal advancement (Igbinovia, 2014). In this way, it can be inferred that the country's affinity to development of renewable energy infrastructure, especially in the line of green hydrogen is high. A major challenge here, according to Igbinovia (2018) is that the resources are not fully exploited yet.

Currently, the energy supply for the country is almost exclusively reliant on fossil fuels and wood fuel and due to an inability to harvest and utilize other energy supplies, these two are becoming exhausted and insufficient. Even with access to fossil energy for use and untapped renewable energy resources, energy capacity and production is lowest in comparison with other African countries, which is a major challenge in the area of energy production and consumption in the country (Igbinovia, 2014; Olanipekun & Adelakun, 2020).

In a good way of harnessing potentials like green hydrogen, Igbinovia (2014) pointed that wind, which is largely available in the northern portions of the country, solar, which has an average of 5.5 hours of insolation daily, and geothermal resources are all available renewable hydrogen resources in Nigeria. With these resources and available technology, the prospects of solar hydrogen infrastructures can be huge with projects that will impact lives of people mostly in the rural areas. This will also encourage community participation in planning and sustainability and in general, reduce dependency on fossil, which is a major source of energy in those areas (Ezugwu, 2015; Igbinovia, 2014; Newsom, 2012).

1.4 Aim and Objectives

This research is centered on land suitability for the placement of solar hydrogen infrastructure in south-eastern Nigeria using GIS tools. This study looks into best sites for the infrastructure in states of the south east Nigeria.

Objectives for the study include to:

- Assess and understand the potentials of the geographical site
- Examine contributing factors and constraints or limitations for infrastructure placement
- Derive an ideal site within the southeastern region for installing solar hydrogen using GIS techniques
- Determine the prospects or gains of such infrastructure within the given region

1.5 Solar Hydrogen Infrastructure and Its Components

Hydrogen can be produced from renewable energy sources in different ways. Thermolysis, radiolysis, photocatalytic water splitting, electrolysis, thermochemical cycle, to name a few, are some of the prevalent methods of creating hydrogen from water (Messaoudi et al., 2019). However, using renewable energy resources to produce hydrogen through water electrolysis is advantageous because it reduces pollution (Supapo et al., 2021). Solar hydrogen infrastructure requires structures for its production such as renewable energy source like solar energy or photovoltaic outputs, fuel cells, electrolyzers, and storage platforms (see Figure 1.1) as well as points of delivery such as industry facilities, power generators, or fueling stations with the use of infrastructures like pipelines, plants, storage facilities, compressors to name a few (U.S

Department of Energy, 2022). The use of solar energy source also gives n opportunity for implementing solar renewables alongside green hydrogen to create potential options for a renewable resource.

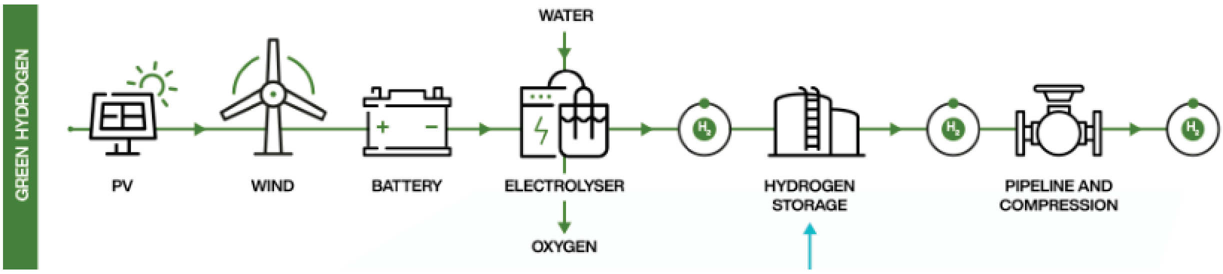


Figure 1. 1: Structures for producing and storing green hydrogen (Source: Petrofac, 2022)

1.6 Expected Contribution

As indicated, Nigeria, especially the south eastern region, is an area with potentials for establishing green hydrogen infrastructure. There is no doubt that the concept of renewable energy, particularly the production of hydrogen from solar, is a relatively new form of technology concept for the region and the country as a whole. The study will help to develop the concept of a renewable form of hydrogen, particularly for an area that has experienced various forms of energy deficiency.

Also, the study is expected to improve the forehand detailed understanding and use of renewable energy in Nigeria, as well as protect the environment from coal emissions, save money and conserve resources. Using the study, the goal of decarbonization of industry will be achieved and, in every way, provide a pathway for more research about renewable energy infrastructures that would help put the region on the map as a region known for renewable energy exploits.

CHAPTER TWO

OVERVIEW OF THE SOUTH-EASTERN REGION OF NIGERIA

2.1 Geopolitical Regions in Nigeria

Nigeria is divided into six geopolitical regions which include North-Central, North-West, North-East, South-South, South-East and South-West (see table 2.1 and figure 2.1)

Table 2.1: States in Geopolitical region (ECOWAS Workshop, 2008)

Regions	States
North-Central	Benue, Kogi, Kwara, Nasarawa, Niger, Plateau
North-West	Kano, Kaduna, Katsina, Kebbi, Sokoto, Jigawa, Zamfara
North-East	Adamawa, Bauchi, Borno, Gombe, Taraba, Yobe
South-South	Akwa-Ibom, Bayelsa, Cross-River, Delta, Edo, Rivers
South-East	**Abia, Anambra, Ebonyi, Enugu, Imo**
South-West	Ekiti, Lagos, Osun, Ondo, Ogun, Oyo

Nigeria sits in West Africa, between Benin and Cameroon, on the Gulf of Guinea, with a total size of 923,768 km^2, including around 13,000 km^2 of water. Cameroon (1,690 kilometers) to the east, Chad (87 kilometers) to the northeast, Niger (1,497 kilometers) to the north, and Benin (773 kilometers) to the west form the country's boundaries (Epron et al., 2019). The Niger–Benue river basin; a massive stepped plateau running to the northern border with elevations higher than 1,200 meters; and a hilly zone along the eastern border, which features the country's highest point i.e., Chappal Waddi which is 2,419 meters in height, are among the country's geomorphologic features, together with a low coastal zone along the Gulf of Guinea and hills and low plateaus north of the coastal zone (Epron et al., 2019).

Nigeria has a dry climate in the north, a tropical climate in the central, and an equatorial climate in the south. The interaction of the moist southwest monsoon and the dry northeast winds determines the fluctuations (Epron et al., 2019). In the south, average maximum temperature ranges from 30°C to 32°C, while in the north, peak temperatures range from 33°C to 35°C. From February to November in the south, and June to September in the north, high humidity is the norm. The dry season is attributed to low humidity. Rainfall ranges from roughly 2,000 millimeters in the coastal region (totaling more than 3,550 millimeters in the Niger Delta) to 500–750 millimeters in the north (Epron et al., 2019).

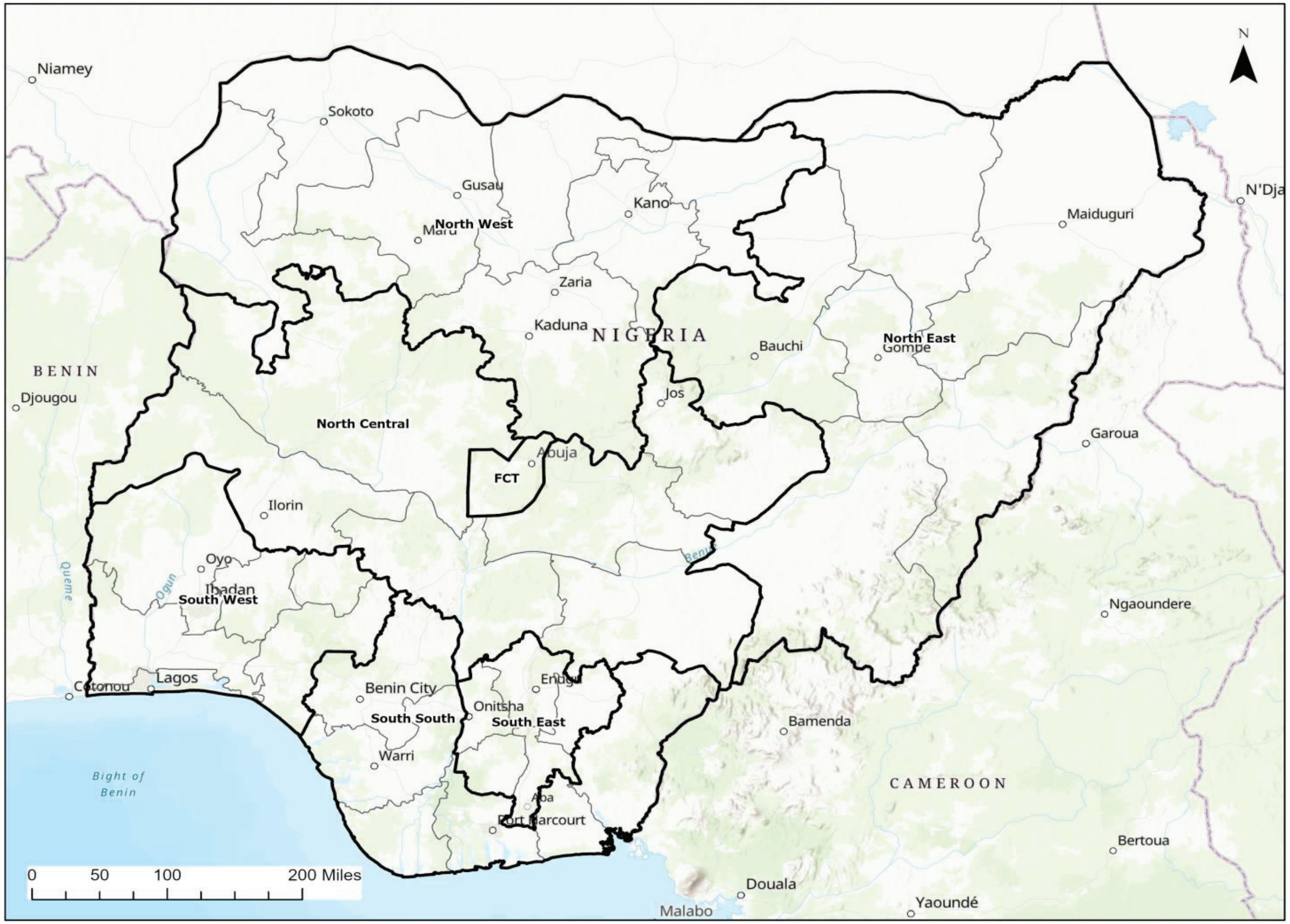


Figure 2.1: Map of Nigeria showing states and geopolitical zones (Source: Africa Open Data, 2018)

2.2 Study Area – South Eastern Nigeria

The region is made up of 5 states (see table 2.1). South-eastern Nigeria consists of Anambra, Enugu, Imo, Ebonyi, and Abia states (figure 2.2). It consists of the Igbo-speaking tribe of Nigeria and is one of the six geopolitical zones of the country. The region has a total of eighty-five Local Government Areas (LGAs) and a population of over twenty million people living in over ten commercial cities and significant towns (CIRDDOC, 2016).

Apart from agriculture, which is the primary source of income for the majority of rural residents, the zone is also noted for its commerce and trading activities, with a large number of micro, small, and medium indigenous companies engaged in manufacturing, fabrication, and agro-allied products (CIRDDOC, 2016; Ubani et al., 2013). Solid minerals and natural resources such as crude oil, natural gas, bauxite, iron ore, sandstone, lignite, kaolin, clay, coal, tin, columbite, and others are abundant in the zone and the region has great potential for investment in agro-allied industries, textiles, industrial minerals and quarrying, plastics industry and chemical industry (CIRDDOC, 2016).

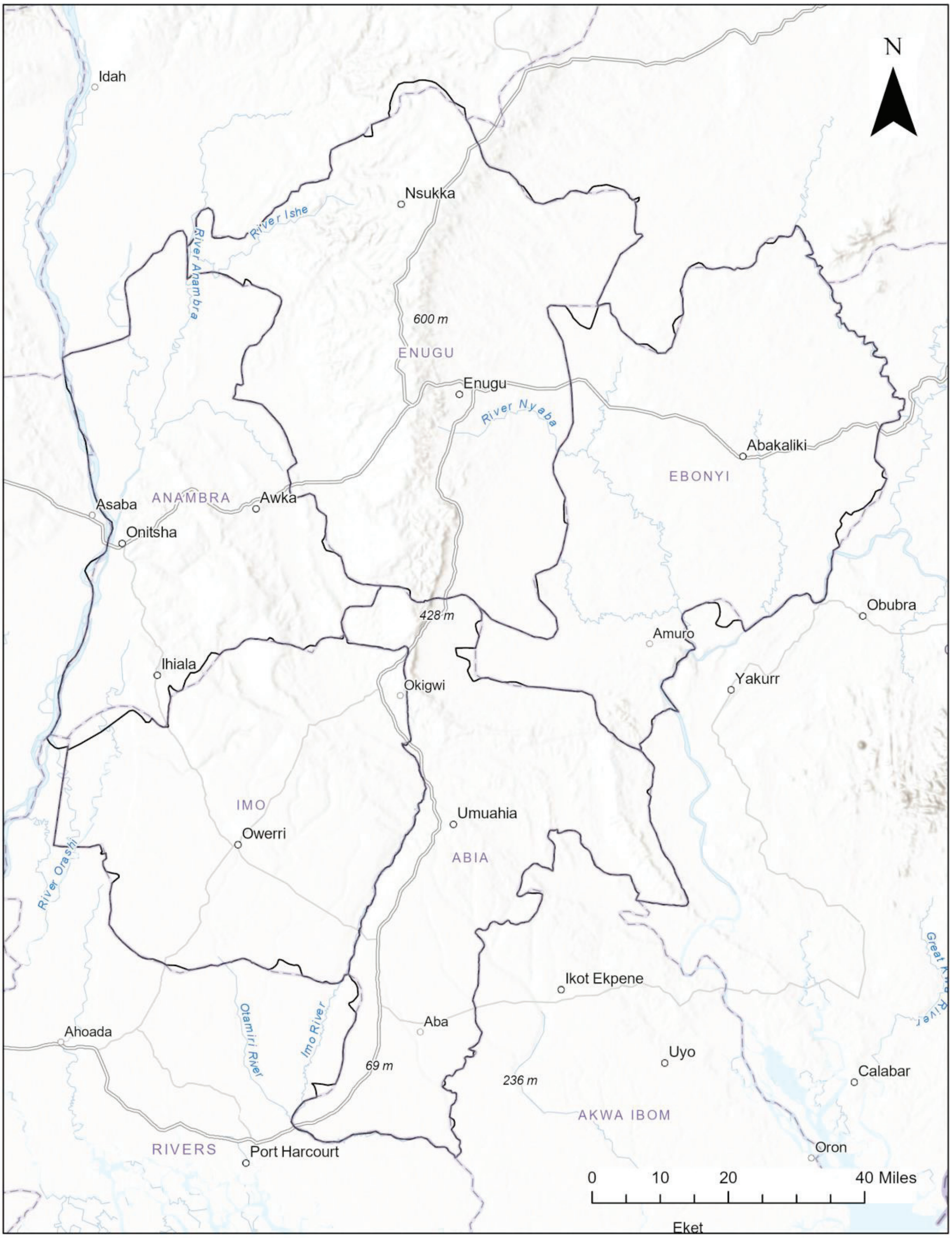


Figure 2.2: Map showing South East Nigeria (Source: Africa Open Data, 2018; ESRI Base Map)

2.2.1 Anambra State

The state consists of 21 local governments and has a total area of 4,844 km^2 (see figure 2.3). According to 2006 population census, the state recorded a total population of 4,182,032 with male population to be 2,174,641 while female counts 2,007,391 of the total population (Udo et al., 2021). Notable cities in the state include Awka and Onitsha, which are known as important center of commerce for the state. As at 2020, the population was estimated to be over 11 million, making it to be among the most populous states in the country (Udo et al., 2021).

The state is home to mineral resources such as clay, iron stone, natural gas, petroleum, sand stone, kaolin, pyrite, lignite (Ikechukwu, 2020). The state is located within the Anambra Basin which is mostly made up of sedimentary deposits, which makes it home to energy rich resources (Okoyeh et al., 2014). Although anthropogenic activities such as lumbering, urbanization, road construction, and other sorts of deforestation-induced activities have resulted in the loss of the natural forests, it is located inside West Africa's humid tropical rainforest belt. The research area has two major weather patterns: a wet season (April – October) and a dry season (November – March) (Okoyeh et al., 2014) .

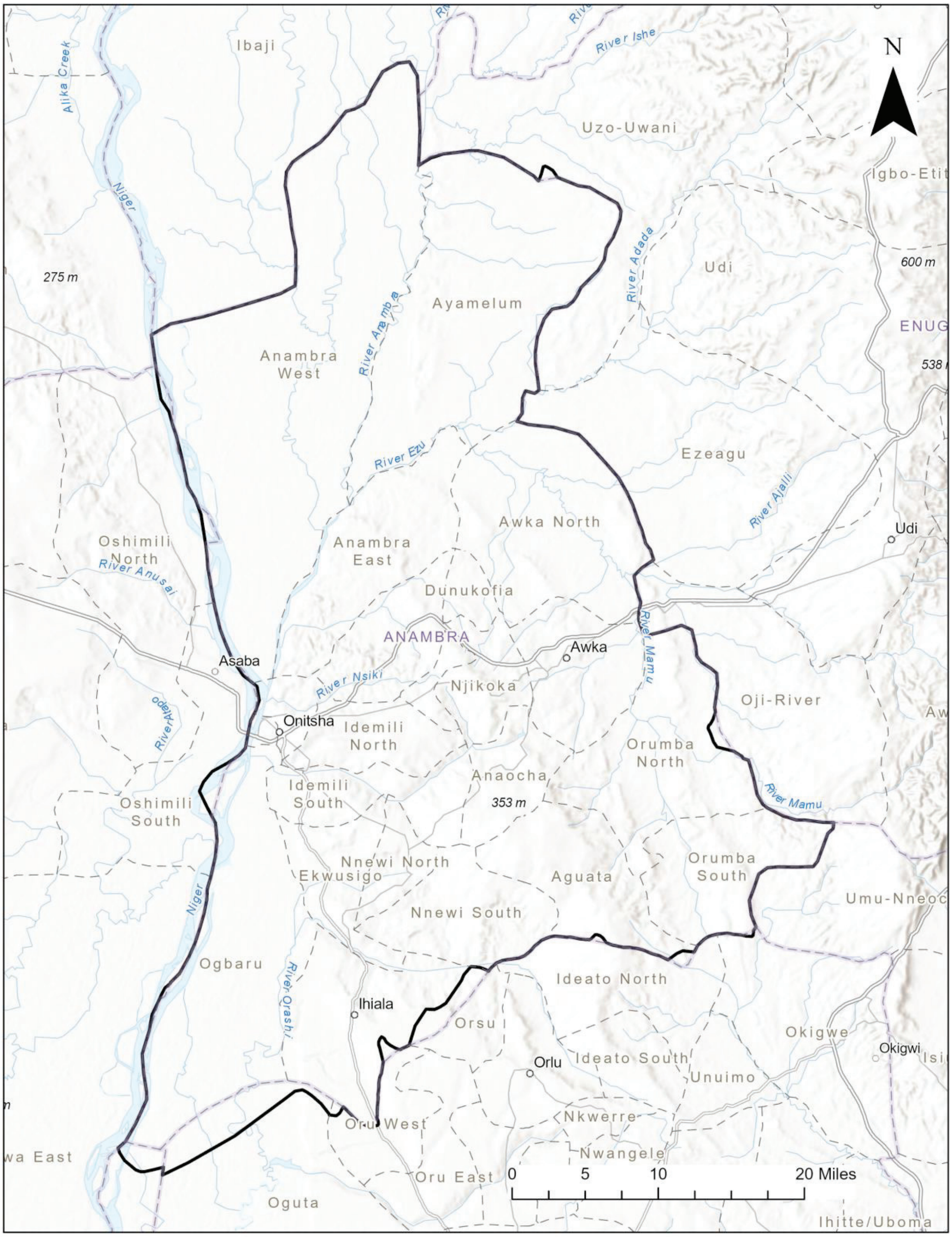


Figure 2.3: Map showing Anambra State (Source: Africa Open Data, 2018; ESRI Base Map)

2.2.2 Abia State

The state is located in southern Nigeria and contains 17 local government areas (LGAs) (see figure 2.4) spread across a total area of 6320 km^2 (Ogbuewu et al., 2016). According to 1991 census, there were about 2.29 million people. Population of the state as at 2006, was about 4,.1 million while a 2016 estimate showed that the population reduced to 3.7million (Ogbuewu et al., 2016).

Abia State has an equatorial climate with two distinct seasons: the rainy season (March - October) and the dry season (November - February). The seasonal variations of Abia state's climate are caused by the north east trade wind from the Sahara Desert and the southerly humid marine air mass from the Atlantic Ocean (Igboekwe & Nwankwo, 2011). Also, in terms of topography, the mean elevation for the state is about 152 meters above mean sea level while most southern parts of the area are located in low-lying terrain.

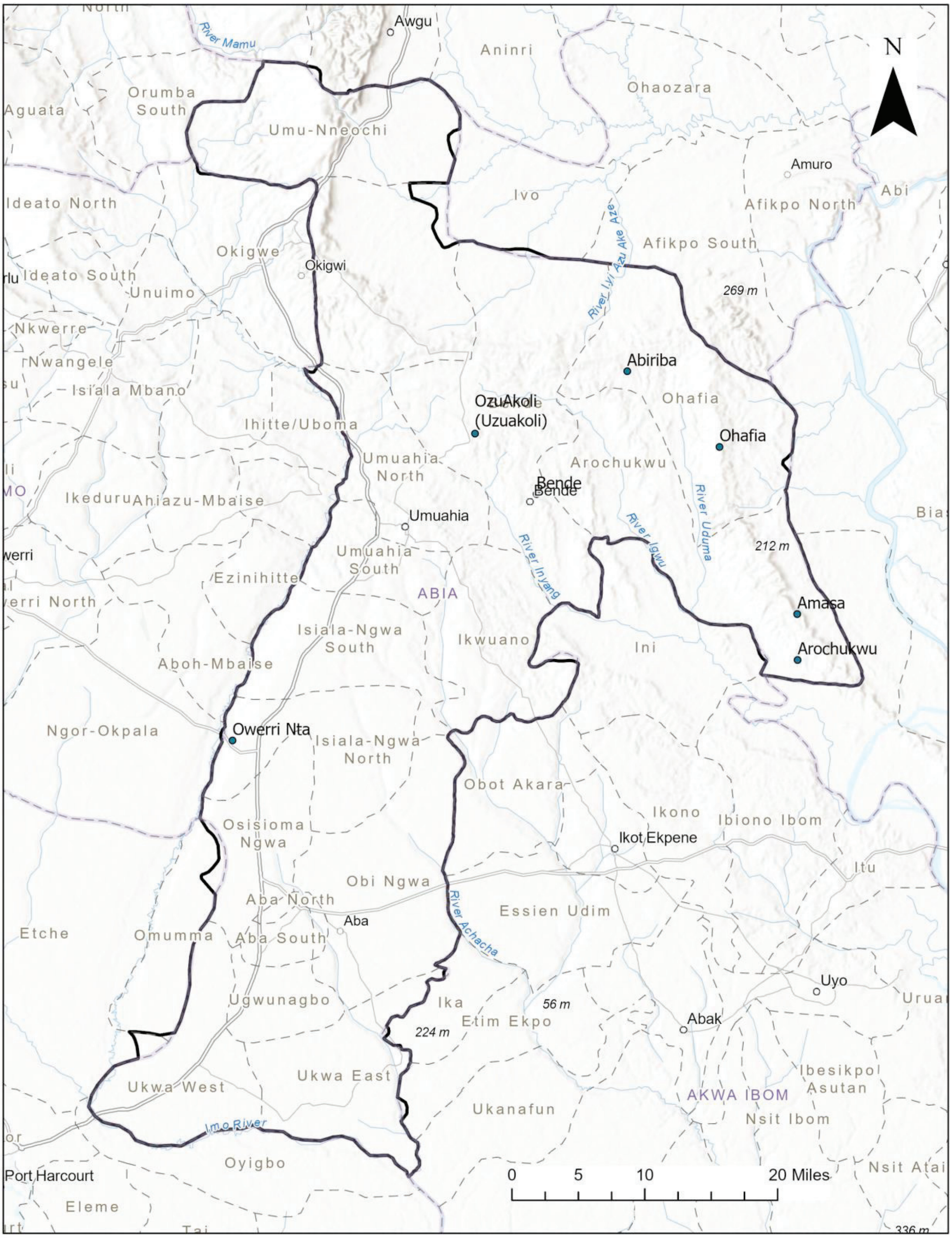


Figure 2.4: Map of Abia State (Source: Africa Open Data, 2018; ESRI Base Map)

2.2.3 Ebonyi State

The state has a land mass of about 5,950 km^2 (see figure 2.5). The state was created in October 1996 (Obasi et al., 2019). According to the National Bureau of Statistics, the state is regarded as one of the smallest states in the country. The estimated population as at 2011 was 2.1million but increased to 2.9 million in 2016 (Obasi et al., 2019). The state has only 13 local governments.

Plains and lowlands dominate the landscape, which has a rather homogeneous low relief landform. These plains and lowlands have a gently rolling topography with a distinctive landform heterogeneity of steeped slopes that are usually below or just about 100 meters above sea level (Obasi et al., 2019). This indicates that the state is located in a low-lying region. Rainfall occurs primarily from April to November, with the highest intensity occurring between June and September. The zone receives an average annual rainfall of between 2250mm in the south and 1500mm in the north, with an average annual temperature of around 27°C and relative humidity of 85 percent (Obasi et al., 2019).

In the area, there are two main seasons: the rainy season, which lasts from late April to early November, with two peaks in July and September. During the month of August, there is normally a short dry period (August break). From late November until early April, the dry season is in effect (Obasi et al., 2019).

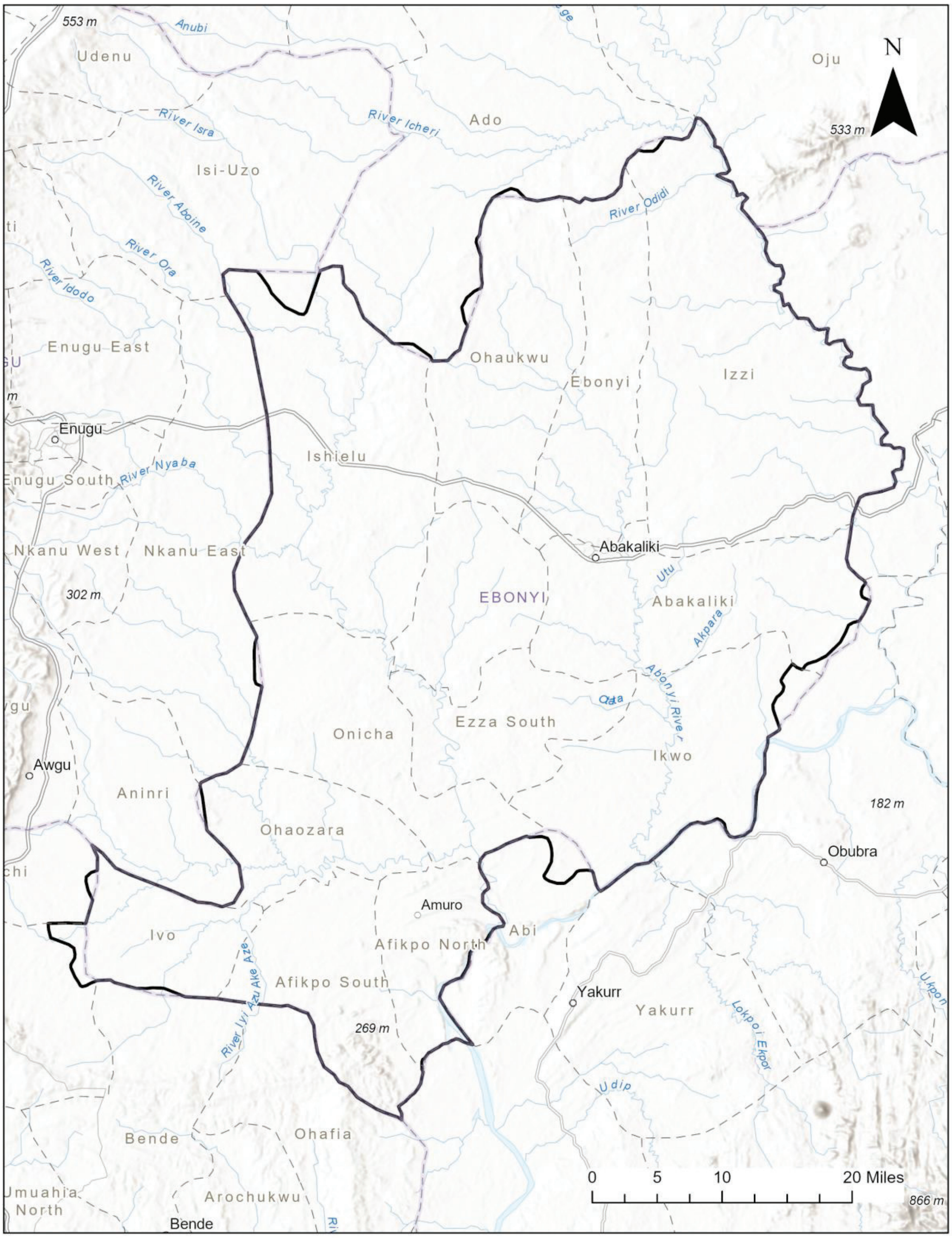


Figure 2.5: Topographic Map of Ebonyi state (Source: Africa Open Data, 2018; ESRI Base Map)

2.2.4 Enugu State

The state occupies a landmass of about 7,000 km^2 (see figure 2.6). It is also home to over 3.2 million people and contains 17 local government. it lies within the tropical rainforest zone (Omar et al., 2021) and is about 223 meters above sea level. The state was created in August 1991 alongside Abia and Anambra states (Vincent-Akpu, 2012)

The soil, like that of the rest of southern Nigeria, is among the poorest in the country owing to its poor natural fertility. They are light and easy to cultivate, but they are incapable of supporting high-density rural and urban populations using rudimentary agricultural practices. There are two main seasons, same like in the other states – dry and rainy seasons. The North-East Trade Winds are responsible for the dry season. This wind carried dust from the Sahara Desert, which is naturally dry. The season starts from November and ends in March. On the other hand, the rainy season lasts from April to October, and is caused by moisture-laden southwest winds blowing in through the Atlantic (UNN Publications, 2010).

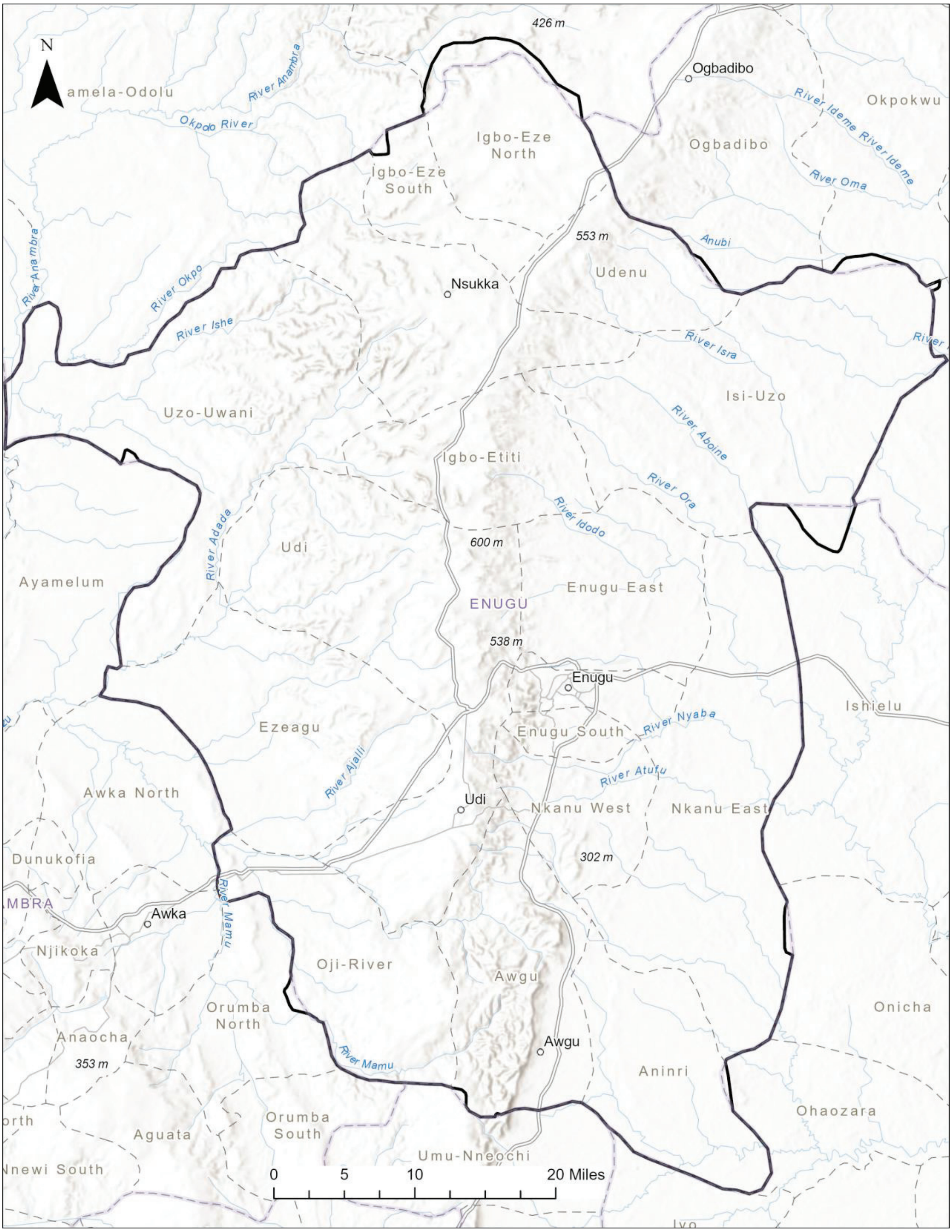


Figure 2.6: Map showing Enugu state (Source: Africa Open Data, 2018; ESRI Base Map)

2.2.5 Imo State

The state was created in February, 1976 alongside some other states like Benue and Bauchi as well as some south western states like Ogun and Ondo. The state is the third smallest in area but is home to about 5.4million people, according to population estimate of 2016. As at 2006, the population was about 3.9million (Onyenweaku et al., 2011). The state constitutes 27 local government in total (see figure 2.7).

The state is located in a tropical rainforest zone. Agriculture is the most common occupation among the population, and it is the primary or secondary occupation for practically all farm families. Tree crops, roots and tubers, grains, vegetables, and nuts thrive in this ecological zone (Onyenweaku et al., 2011). Crude oil, natural gas, lead, calcium carbonate, solar and wind power, and zinc are among the state's natural resources.

Oil and gas investigation, chemical and brewery plants, hydroelectric power plant, gas power plants, grain mills, starch production, cashews, fruit and vegetable juice concentrate production, integrated multi-oil seed processing plants, ceramics, inland waterway transport, and the palm industry are all profitable investment opportunities in the state (Oguzor, 2011).

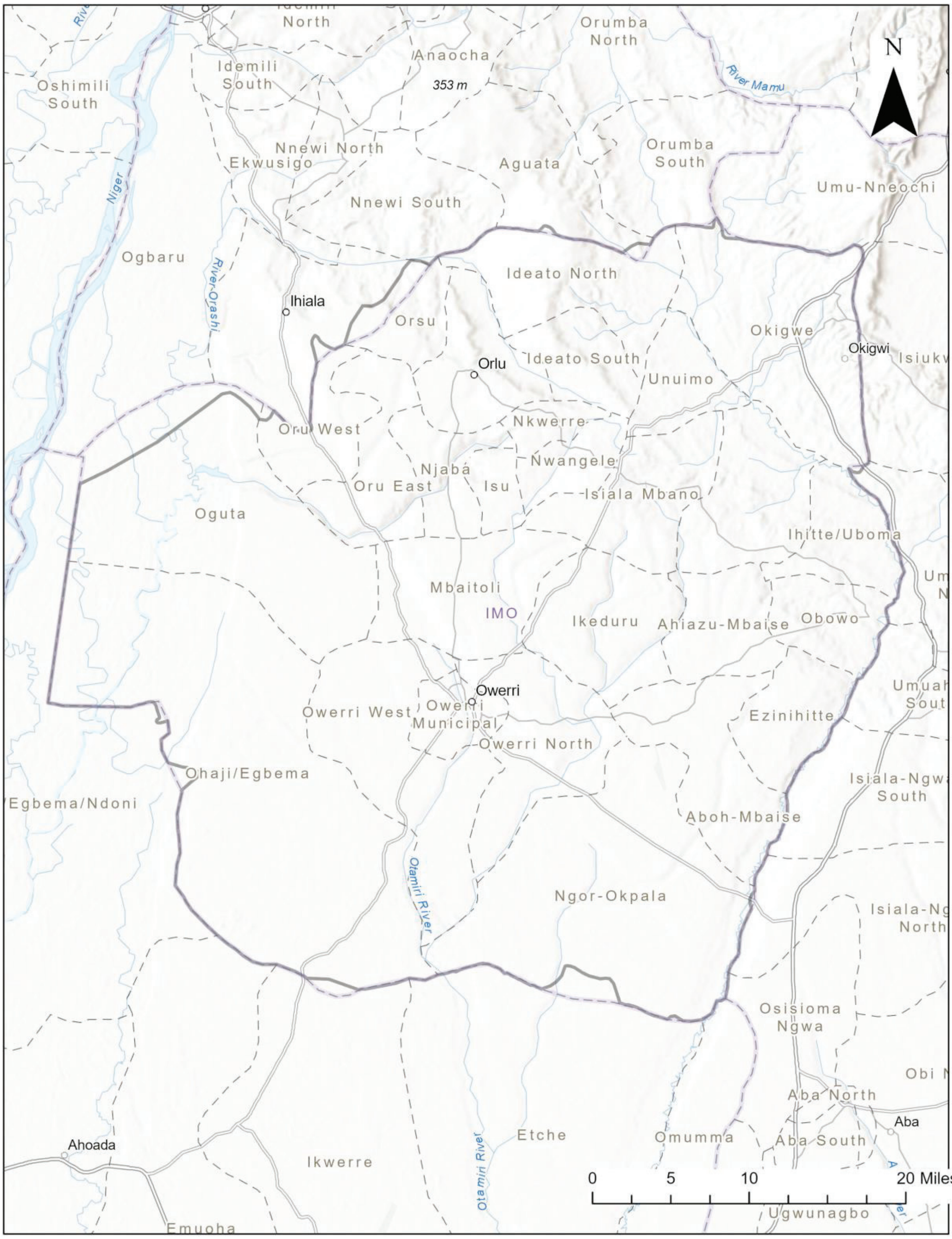


Figure 2.7: Map showing Imo state and towns (Source: Africa Open Data, 2018; ESRI Base Map)

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

This section explains the pre-processing and processing methods applied in the determination of suitable sites for solar hydrogen infrastructure in the southwestern region of Nigeria. According to the aim of the study, varying factors are considered as criteria to be looked at. Criteria include solar irradiation, land surface temperature (LST), land use, slope and elevation, population, photovoltaic output, distance or proximity to the road, rails, transmission, or power lines, and water (river and water bodies) (Messaoudi et. al, 2019).

Data types considered in this analysis include rasters and vector datasets as shown in the methodology workflow (figure 3.1). The methodology adopted in this study (Messaoudi et al., 2019) entails a category of criteria mostly economical and technical as well as restraints (excluded areas). Data used in this study are depicted in Table 3.1 below. In the first instance, the datasets are preprocessed to make them accurate and suitable for analysis in deriving suitable sites for hydrogen infrastructure.

For instance, all data are projected to a common projection (WGS 1984 UTM Zone 32N) while DEM tiles are merged using the Merge tool in QGIS. Also, satellite images of scenes covering the area are merged as well. Also, datasets in vector format are converted to raster through direct conversion as done with the population data and through raster proximity analysis (Euclidean Distance).

The project employs the multi-criteria evaluation method (MCE). In this case, multi criterion decision analysis is used in conjunction with spatial data to describe the causative aspects of a problem. The factors or criteria are quantitatively processed and produced in this study, and then converted to integers through the reclassification method (Groenewegen, 2021; Messaoudi et al., 2019).

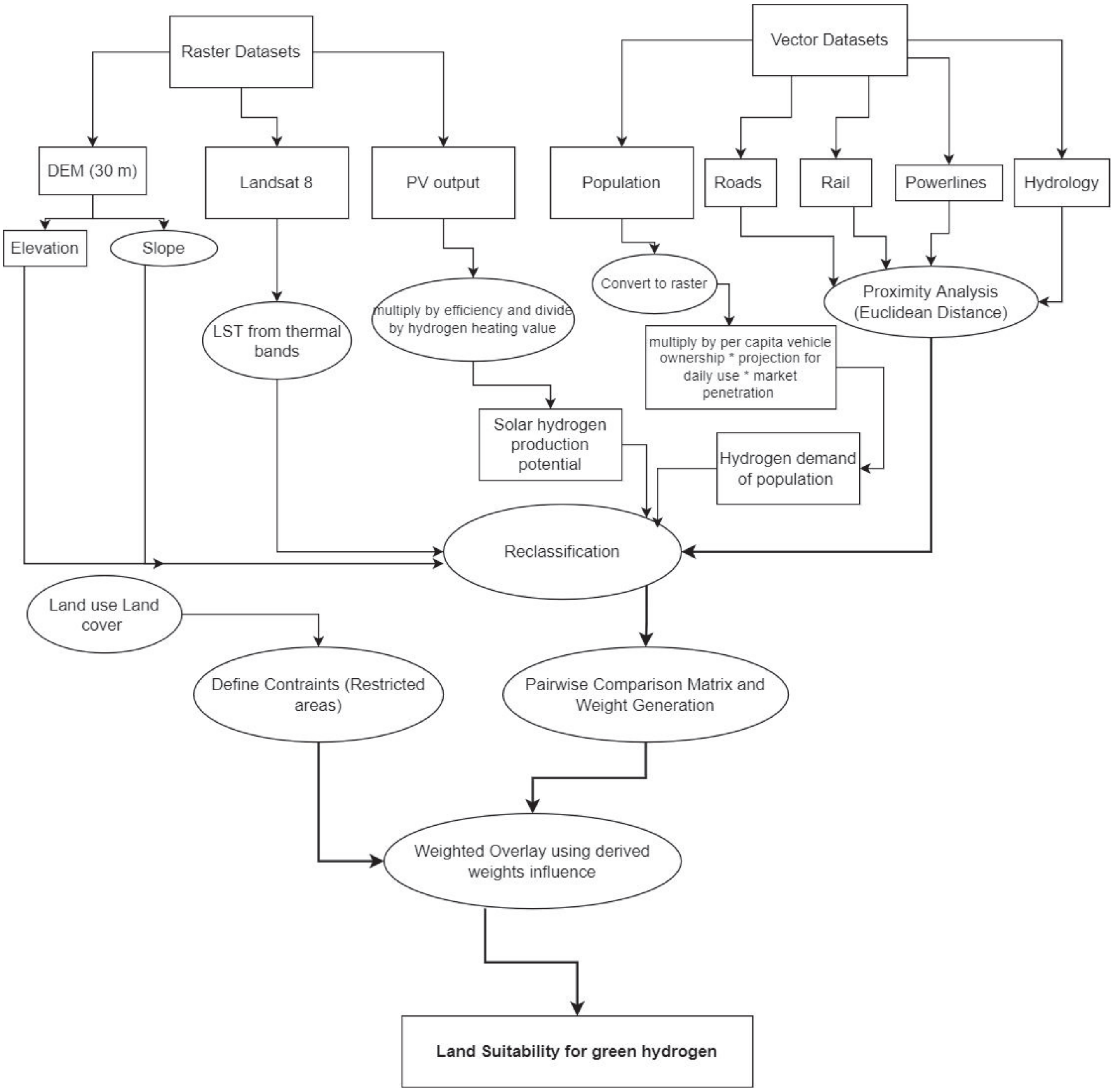


Figure 3.1: Methodology Workflow

Table 3. 1: Data type and Sources

Data	Type	Source
Nigeria States and LGA boundaries	Vector	Africa Open Data (2018) (https://africaopendata.org/dataset/shape-file-of-nigeria) The World Bank Data Catalog (2018) (https://datacatalog.worldbank.org/search/dataset/0039368)
Roads	Vector	OpenStreet Map
Railway and Powerlines	Vector	OpenStreet Map
Waterbody	Vector	UN Humanitarian Data Exchange Catalog (https://data.humdata.org/dataset/nigeria-water-courses)
SRTM DEM	Raster (30 meters)	NASA (https://earthexplorer.usgs.gov/)
Photovoltaic or Solar Output (2018)	Raster	Global Solar Atlas (https://globalsolaratlas.info)
Landsat OLI/TIRS	Raster	NASA (https://earthexplorer.usgs.gov/)
Population (2020)	Table	UN Humanitarian Data Exchange Catalog (https://data.humdata.org/dataset/cod-ps-nga)

3.1 Criteria and Constraints for Siting Solar Hydrogen Infrastructure

3.1.1 Elevation

This is an important criterion that helps to look at areas with increasing temperature with respect to height which is useful for the placement of PV or solar panels that would be used for production. According to Messaoudi et al., (2019), areas with increased elevation have higher efficiency than lower areas for the production of solar energy that is essential for electrolysis.

3.1.2 Slope

This is a factor that embodies construction and accessibility cost in total. Areas with high or steep slopes contributes to low accessibility and increase in costs. This is why gentle or flat slopes are preferred in this case

3.1.3 Temperature

This factor looks at land temperature ranges that would be helpful in the production of the renewable energy (Groenewegen, 2021). Here, high temperature areas are more preferable because they help in quicker production and efficiency of electrolyzers for production (Vincent-Akpu, 2012).

3.1.4 Land use land cover

This is majorly used in determining unsuitable areas such as built ups or natural environments like forests, water or farmland or even preserved areas like zoos or forest reserves. These places are considered as constraints and are restricted and excluded in the analysis.

3.1.5 Distance to Roads

For minimized costs of construction and quicker accessibility, areas closer to road i.e., in close proximity are more preferred than areas far away. Even in maintenance, the cost would be lower because such infrastructure should be closer to roads.

3.1.6 Distance to rail and power line

In the same vein, closer proximity to rail and powerlines is important for accessibility, connection and increased efficiency. A close distance to powerlines would help in delivering the additional energy from photovoltaic or solar panels to the grid and supply stable power to the other electrical equipment (Messaoudi et al., 2019). The river, roads, railway and powerline data were converted to raster data to create a distance or proximity raster.

3.1.7 Estimated Production Potential

This explains the capacity to produce solar hydrogen with respect to available solar energy output, efficiency of infrastructure and overall energy content of hydrogen (known as hydrogen higher, which is a constant of 39.4 kWh/kg) (Messaoudi et al., 2019). Efficiency of infrastructure such as hydrogen electrolyzers depicts the level of productivity and competence in production and ranges from 75% to 80%, depending on the product (Abdurakhmanov et al., 2021; Reed et al., 2020; Zhang, 2015). A good infrastructure such as the electrolyzer and solar energy source can increase production potential, which is an important criterion. This is explained in the subsequent sections.

3.1.8 Energy Demand

As an important renewable infrastructure, there is need to also consider the population's demand for its implementation. This is derived by multiplying population data and constants such as per capita vehicle ownership (which represents largest demand and use), market penetration (degree of acceptance in the markets) and projected daily use (Messaoudi et al., 2019). In Nigeria, the per capital vehicle ownership is about 59.7 (Naira metrics, 2021) while the projected daily use is estimated to be 380 kg H_2/ hydrogen vehicle/year (Messaoudi et al., 2019) with a 18% market penetration (Adebayo, 2021).

3.1.9 Distance to River

Areas closer to river areas are considered to be non-viable or unsuitable while areas far away are suitable This is to reduce the impacts of these strucures on natural areas,mostly rivers and lakes,since the region is blessed with many of these resources.

3.2 Data Processing and Analysis

3.2.1 Solar Hydrogen Potential and Demand from PV Output

Derivation of PV Output for South Eastern Nigeria

The solar energy output of the area is long term yearly average of potential photovoltaic electricity production, in kilowatt-peak or kilowatt-hour (kW_h/kW_p), covering the period 1994-2018. It is assessment of PV power production potential for a free-standing PV power plant with modules mounted at optimum tilt to maximize monthly PV production (World Bank, n.d) and it ranges from 1213.73 to 1793.74 kW_h. Using the geographic boundary of the region, the PV output is extracted using the Clip Raster by Mask Layer tool. The figure 3.2 below shows the PV output for the country while figure 3.3. indicate PV output for the south east.

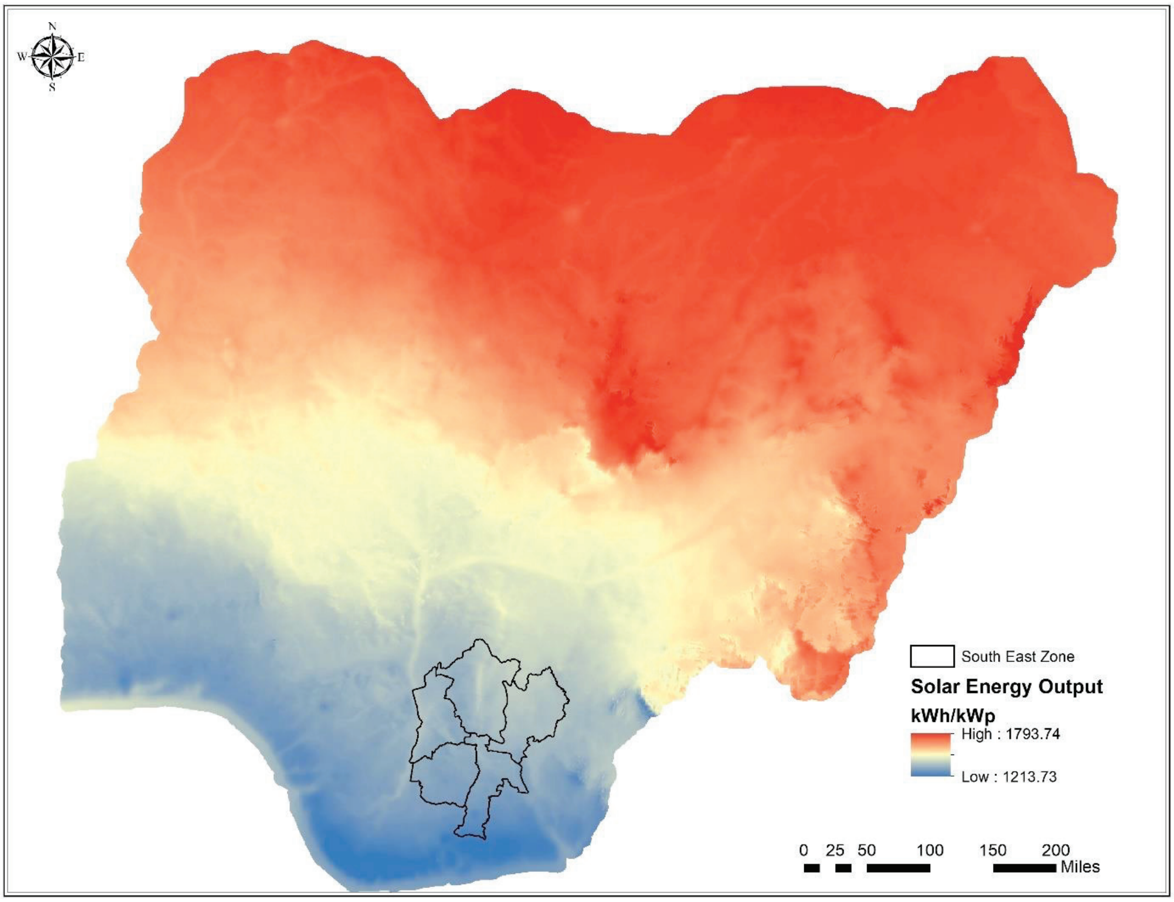


Figure 3.2: Photovoltaic output for the country (Source: Global Solar Atlas, 2018)

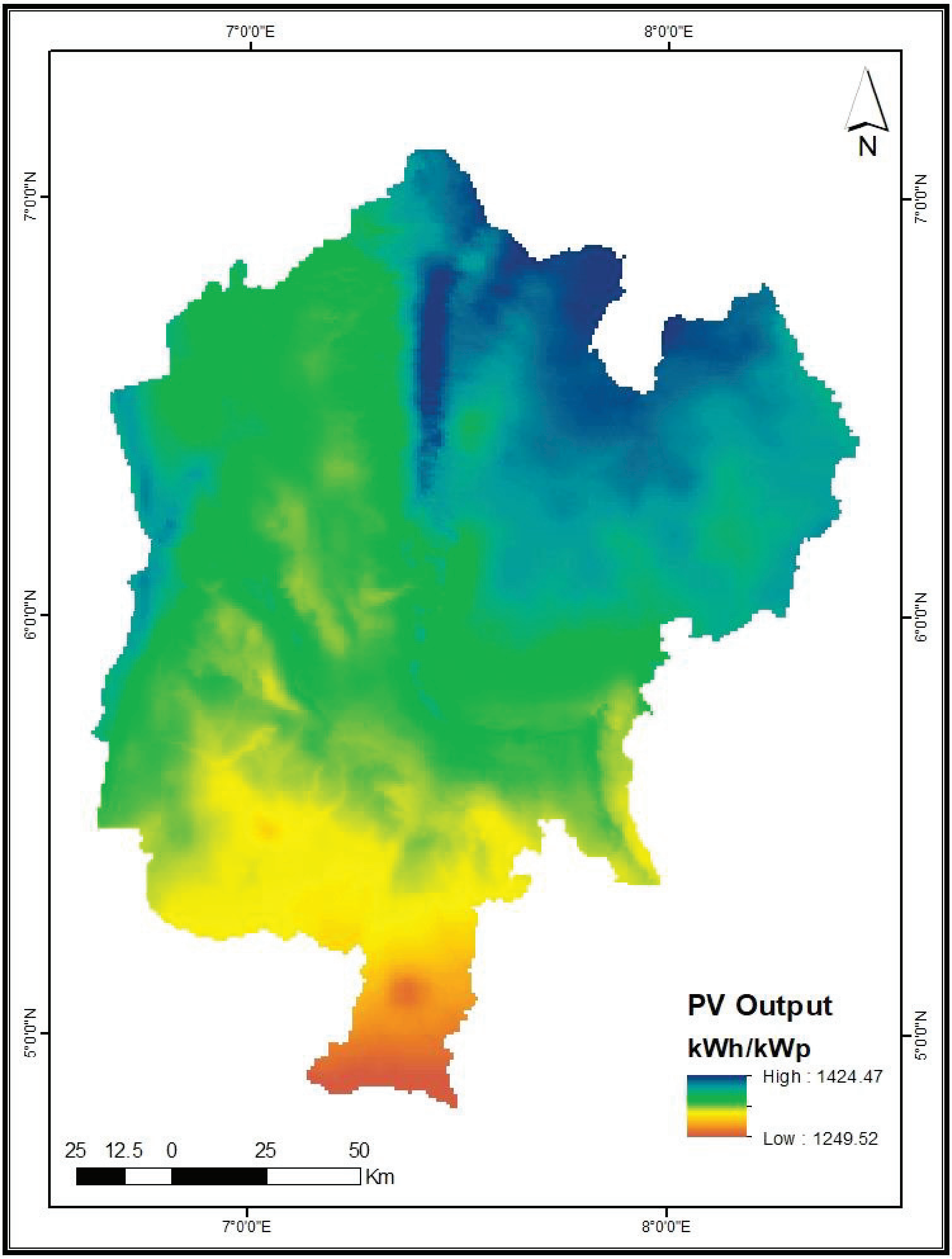


Figure 3.3: Solar output for the south east (Source: Global Solar Atlas, 2018)

Derivation of Solar Hydrogen Production Potential

Solar hydrogen potential explains the extent and capacity for the production of hydrogen from renewable energy with respect to efficiency of electrolyzers and heating capacity. According to Messaoudi et al., (2019), hydrogen production focuses more on the ability to have more yield for power and it is important to derive areas that have more potential to produce hydrogen from solar or PV output. In definition, hydrogen electrolyzer efficiency refers to how well an electrolyzer converts electricity into hydrogen. It is equal to the energy content of the hydrogen produced (based on the heating value) divided by the quantity of power consumed (Messaoudi et al., 2019).

Carbon Commentary (2017) depicted that the efficiency of an electrolyzer that is often used in the production of hydrogen is around 80%. It would be recalled that sun energy can be used to manufacture hydrogen in two ways - water electrolysis with solar-generated power or PV output and direct solar water splitting(Abdurakhmanov et al., 2021). For a good system of hydrogen production from solar energy, there would be need for PV panels (used for deriving photovoltaic or solar energy from the sun), AC/DC converter (useful as source for electricity regulation) and an electrolyzer (used in the electrolysis of water) (Abdurakhmanov et al., 2021; Maestre et al., 2021; Zhang, 2015).

Therefore, in order to derive the degree of potential to produce hydrogen using solar energy, the PV output is multiplied by electrolyzer efficiency and hydrogen higher heating value (which represents energy content of hydrogen) which is given by 39.4 kWh/kg (Georgia Forestry Commission, 2022) using Raster Calculator (figure 3.4).

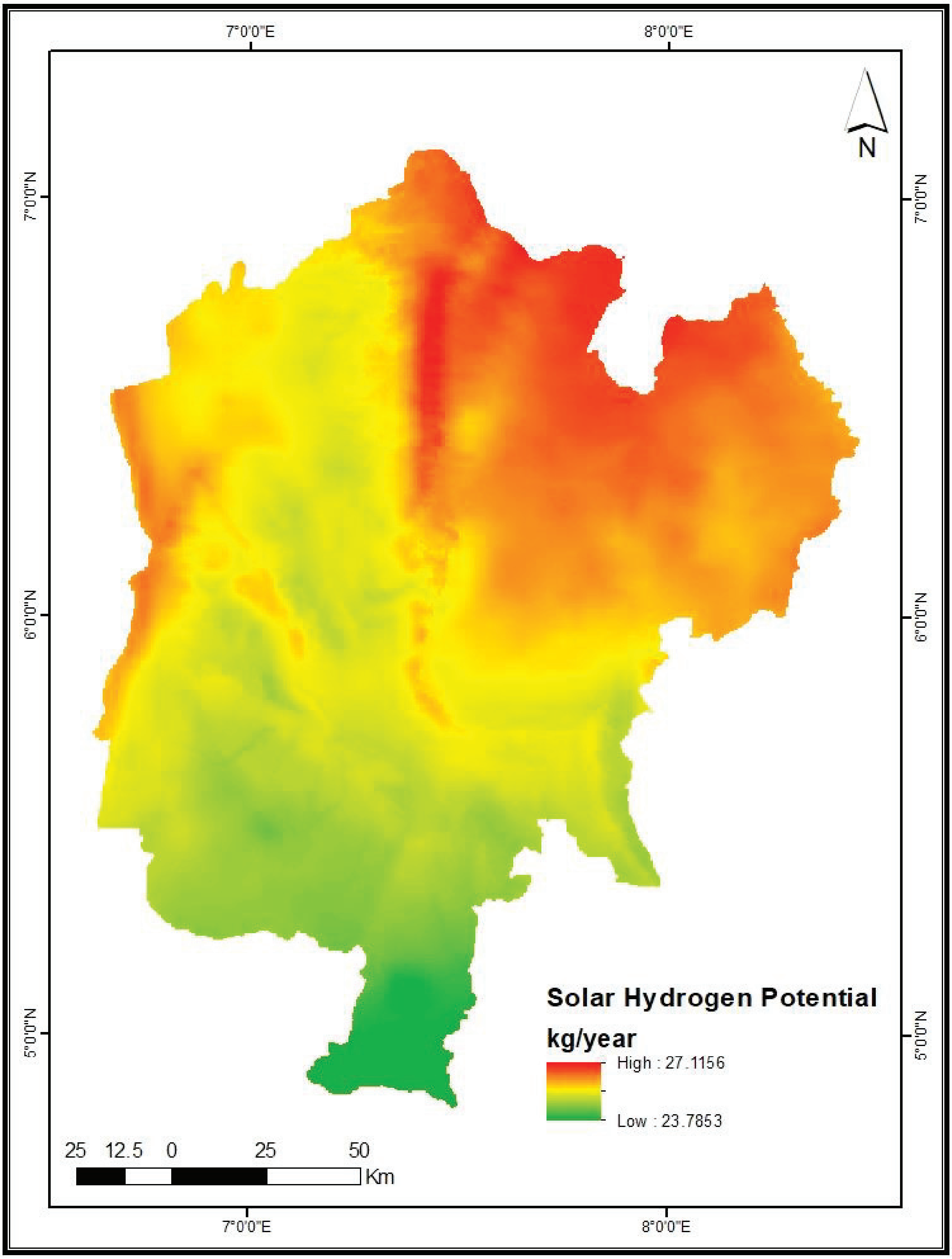


Figure 3.4: Solar Hydrogen Production Potential (Source: Author's Analysis, 2022)

Energy Demand in South Eastern Nigeria

This explains estimation of how much hydrogen would be needed in terms of location. The demand is derived by multiplying population, projection for use (380 kg H_2/ hydrogen vehicle/year), market penetration (18%) and rate of vehicle ownership (59.7) as explained in section 3.1.8. figure 3.5 depicts the hydrogen demand potential according to each local government area. the demand range between 2,500 to 16,000 tonnes per year – this shows that there is tendency for higher demand, if the market penetration level is increased in the future. According to criteria definition, areas with high demand would have a higher need and use than other areas and would be more preferred.

3.2.2 DEM Processing and Derivation of Slope

The SRTM DEM has a resolution of 30 meters. The elevation of the region ranges from -10 meter to 597 meters in general, with a mean of 114 meters (figure 3.6). This indicates that the area generally is within a low elevation region, which means that the region has suitable areas in terms of elevation and slope. The slope is derived using the Raster Terrain Analysis tool (figure 3.7). Elevation showed that mostly areas within Enugu have high elevation than other areas. This is also reflected in the slope derived from DEM. This showed that most of the area is located in a relatively flat area.

In terms of criteria, areas that are extensively flat are deemed unsuitable because of the vulnerability to flood hazards (Messaoudi et al., 2019). Also, areas of steep slopes are unsuitable because of high cost of construction as well as difficulty in accessibility. This is why slightly flat to moderately flat slope are deemed suitable (Guaita-Pradas et al., 2019; Udo et al., 2021)

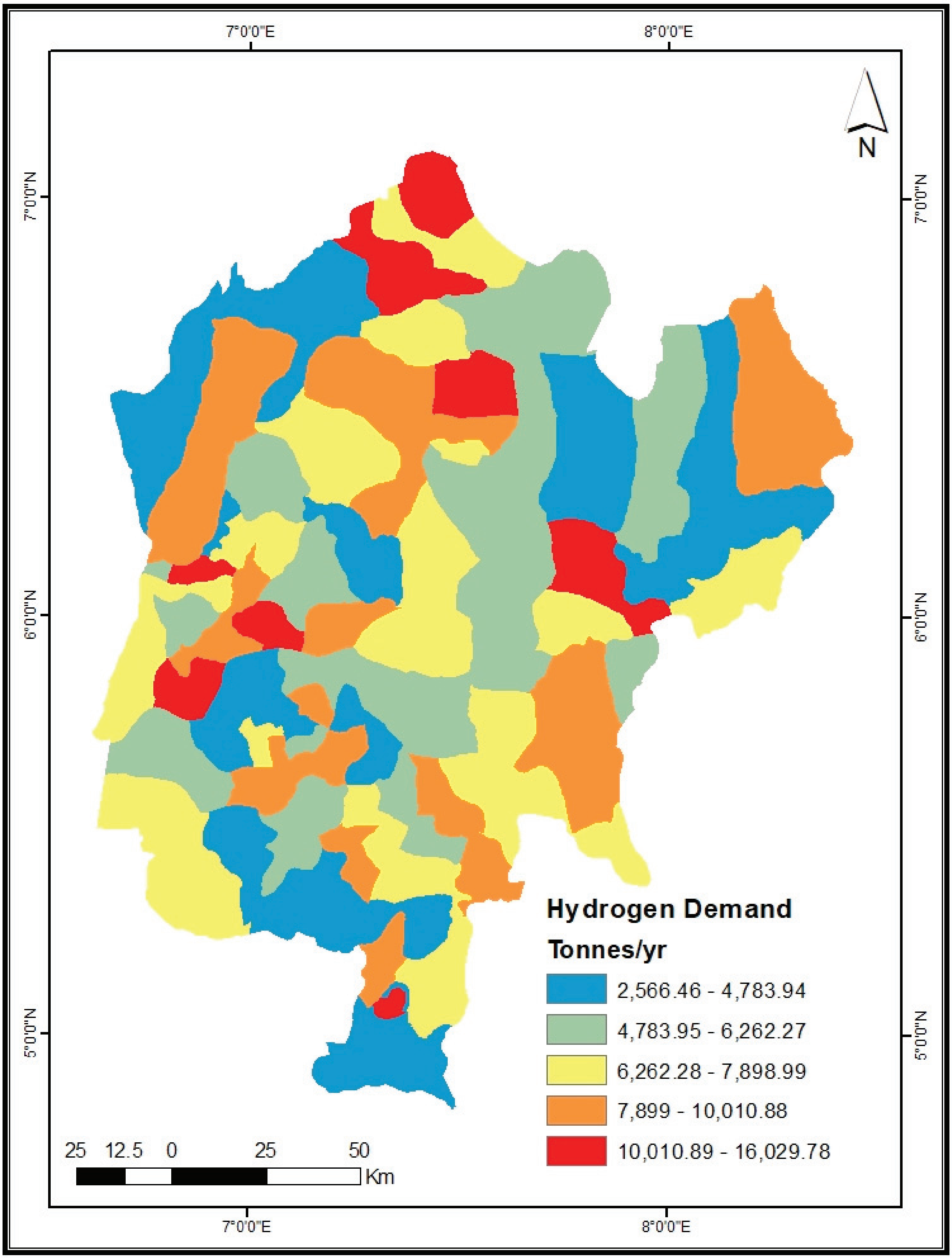


Figure 3. 5: Energy Demand for South East Nigeria (Source: HDX, 2020)

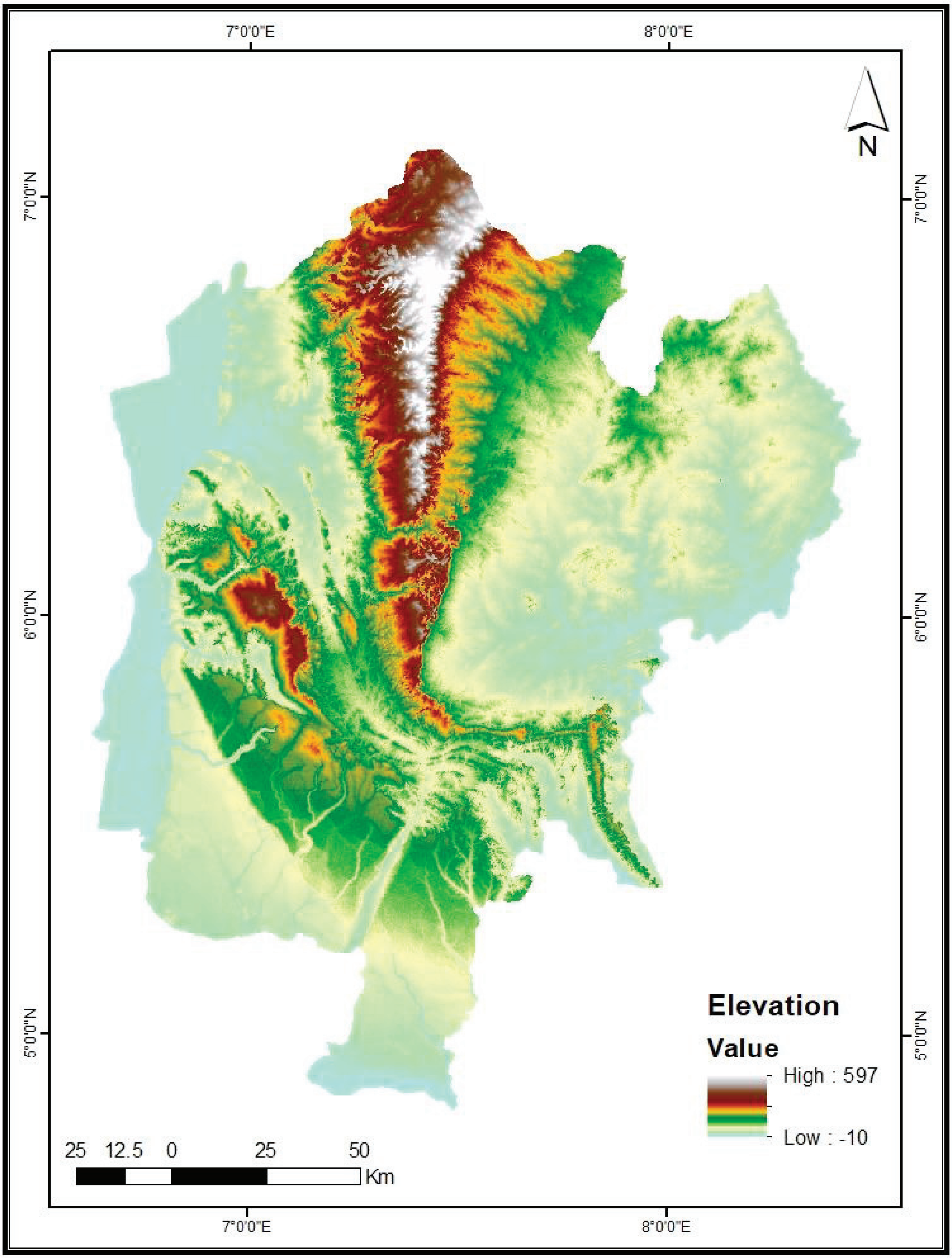


Figure 3.6: Digital Elevation Model of South Eastern Nigeria (Source: NASA)

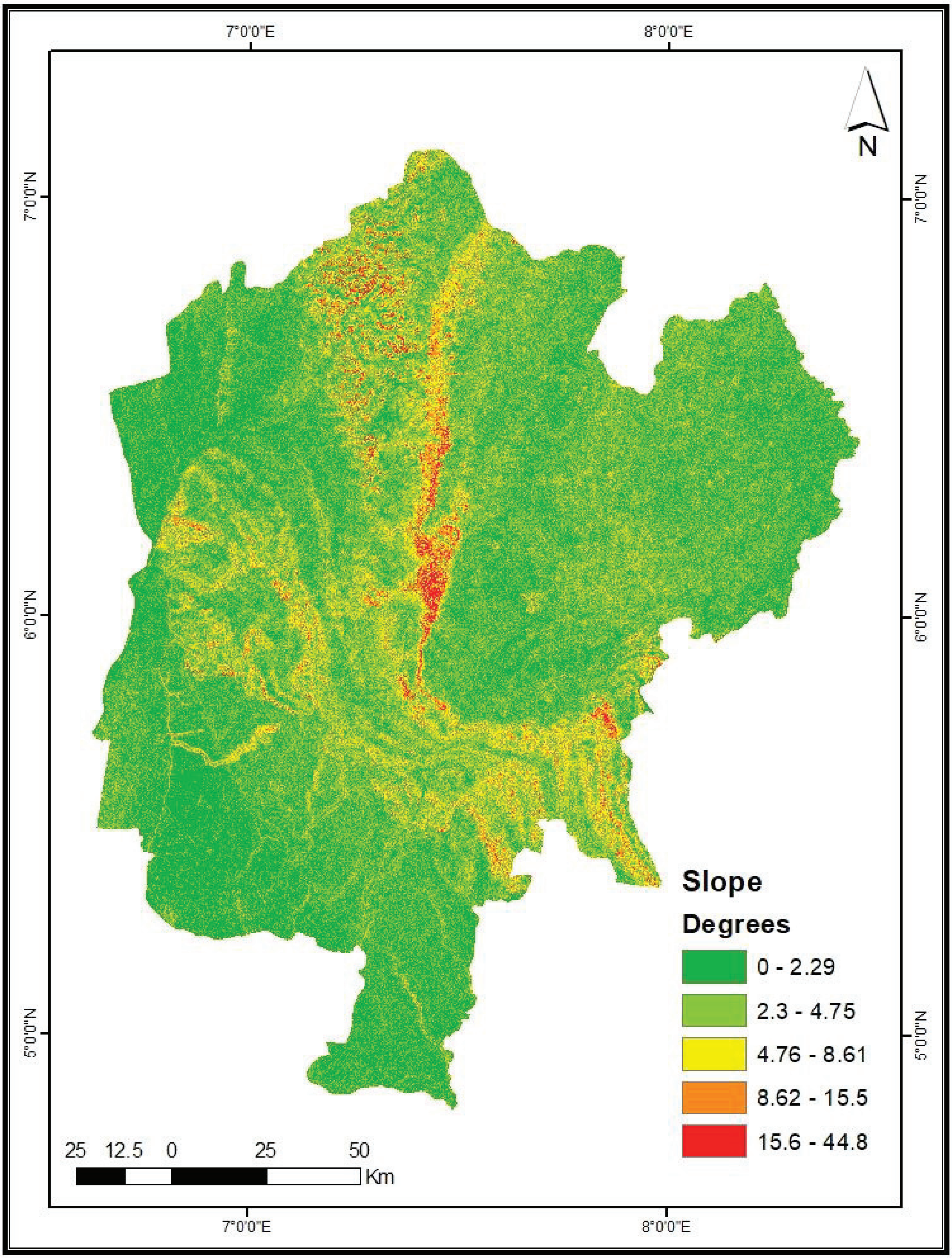


Figure 3.7: Slope Derived from DEM (Source: Author's Analysis, 2022)

3.2.3 Land Use Land Cover Classification

Supervised classification type is applied where training fields are selected to be signature file to be used in classifying the image. Features identified include built ups, waterbody, light vegetation, dense vegetation, rock outcrops and bareland (table 3.2). This made it easy to determine land uses that were not suitable (constraints) for the infrastructure which include built ups, conserved forest areas, farmlands and water features (figure 3.8).

Table 3.2: Land use and their descriptions (Source: Anderson et al, 1976)

Land use/land cover	Description
Built-up	Lands used for residential, industrial, commercial, etc.
Waterbody	Areas with lakes, rivers, streams.
Light vegetation	Lands used for farming (plantation, cropland orchard) and natural grassland
Dense vegetation	Lands covered with natural vegetation (any plant species) and forests
Rock outcrops	Areas cover with exposed rock surfaces
Bare land	Lands devoid of vegetation, exposed soil

3.2.4 Deriving Land Surface Temperature from Thermal Band

The DN of the thermal band is first converted to radiance using the expression below. The values are derived from the metadata file of image (table 3.3)

$$L\lambda = \frac{(L_{max} - L_{min}) \times Qcal}{Qcal_{max} - Qcal_{min}} + L_{min} \quad \text{(Source: Jeevalakshmi et al., 2017)}$$

Where:

$L\lambda$ = spectral radiance

L_{max} = maximum radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)

L_{min} = minimum radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)

Qcal = thermal band

$Qcal_{max}$ = maximum DN value of pixels

$Qcal_{min}$ = minimum DN value of pixels

Table 3.3: Variables from Metadata (Source: USGS)

Variables	Values	Description
L_{max}	22.00180	Maximum and Minimum values of
L_{min}	0.10033	Radiance, Band 10
$Qcal_{max}$	65535	Maximum and Minimum values of
$Qcal_{min}$	1	Quantize Calibration, Band 10
K1 Constant	774.8853	Thermal constants (used to compute
K2 Constant	1321.0789	brightness temperature)

In the same vein, the spectral radiance is then converted to brightness temperature using the thermal constants given above from the metadata file using the expression –

$$BT = \frac{K2}{\ln[\left(\frac{k1}{L\lambda}\right)+1]} - 273.15 \text{ (Source: Jeevalakshmi et al., 2017)}$$

Where L_λ = spectral radiance

BT = Brightness Temperature (°C)

Furthermore, another parameter that is important in deriving the LST, is the Normalized Difference Vegetation Index (NDVI). This is used to represent different land cover types of the area and ranges from -1 (water, builtups, rock surface, bare land) to +1 (vegetation and forests) (Jeevalakshmi et al., 2017). Calculation of NDVI is also essential to further compute proportional vegetation (P_v) and emissivity (ε) which are other components of LST (expressions below).

$$NDVI = \frac{NIR-R}{NIR+R} \text{ (Source: Jeevalakshmi et al., 2017)}$$

Where NIR is Near infrared band (band 5) and R represents red band of the image (band 4)

$$Pv = Square\left(\frac{(NDVI-NDVI\ minimum)}{(NDVI\ maximum-NDVI\ minimum)}\right) \text{ (Source: Jeevalakshmi et al., 2017)}$$

P_v = Proportional vegetation

NDVI = Vegetation index image

NDVI minimum = minimum value of NDVI

NDVI maximum = maximum value of NDVI

In the same way, emissivity (ε) is given as –

$$\varepsilon = 0.004 * Pv + 0.986 \text{ (Source: Jeevalakshmi et al., 2017)}$$

P_v = Proportion of Vegetation which is derived from NDVI

Therefore, the land surface temperature (figure 3.9) is given as -

$$LST = \left(\frac{BT}{1 + (\frac{\lambda \times BT}{\rho}) * ln(\varepsilon)} \right) \text{ (Source: Jeevalakshmi et al., 2017)}$$

Where;

BT = Brightness Temperature in Celsius

ε = Emissivity

λ = wavelength of band 10 (10.6 μm)

ρ = constant ($1.438 * 10^{-2}$ mK)

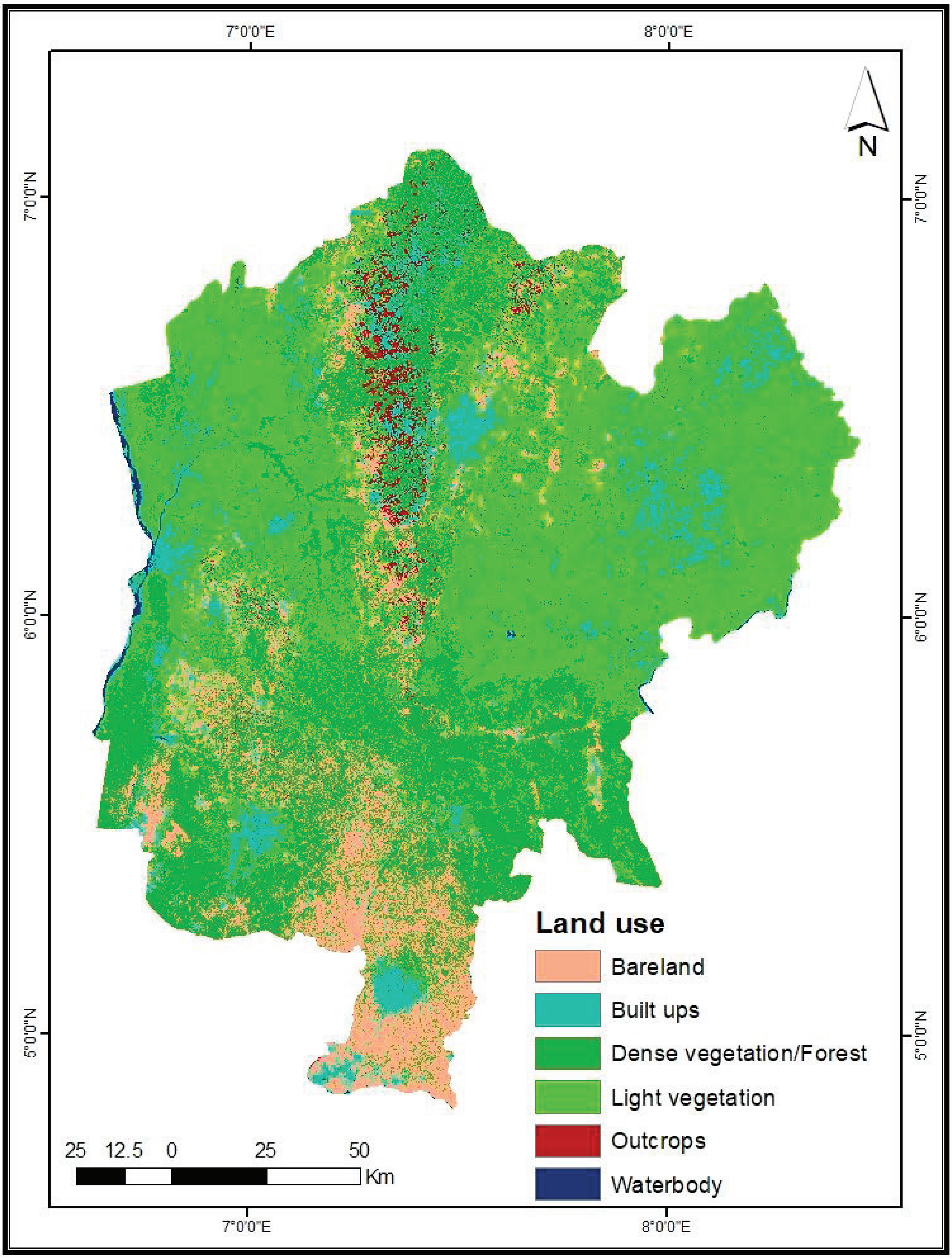


figure 3.8: Land use/land cover image (Source: Author’s Analysis, 2022)

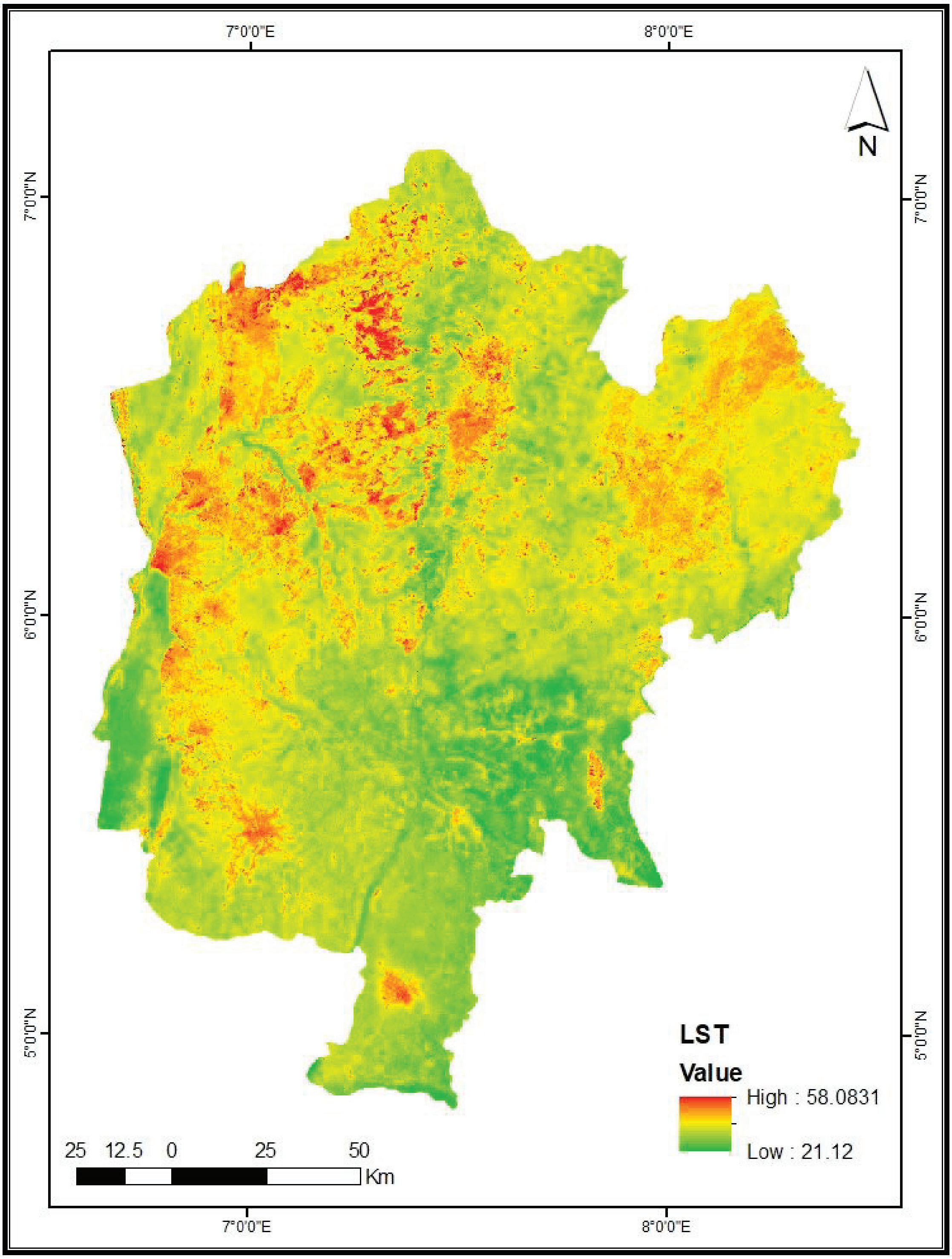


Figure 3.9: Land Surface Temperature in Celsius (Source; Author's Analysis, 2022)

3.2.5 Proximity Analysis for Solar Hydrogen Infrastructure

Figure 3.10 indicates the map that depicts location of the transmission lines, roads, railways and river. Euclidean distance is used to derive proximity rasters for the criteria. For easier accessibility and reduction of construction costs, areas closer to railway, roads and powerline are considered suitable (figure 3.11).

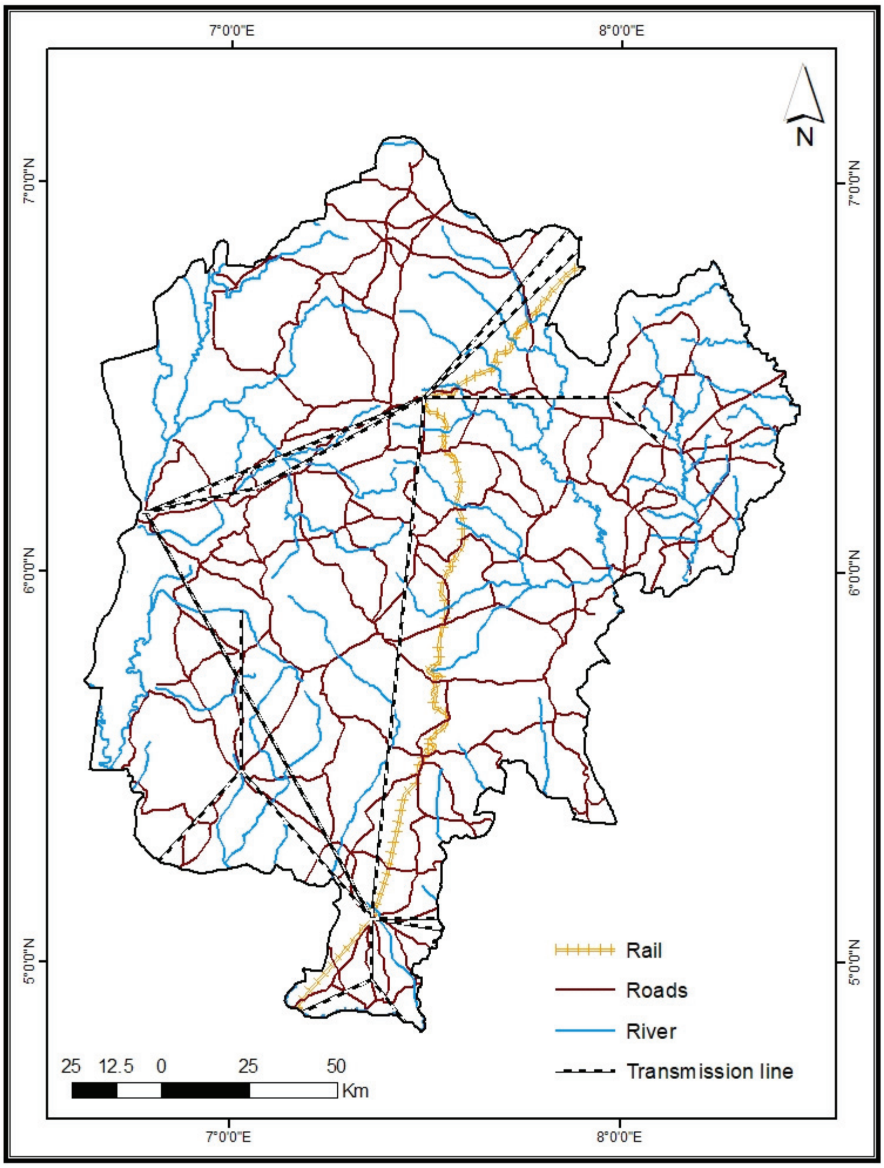
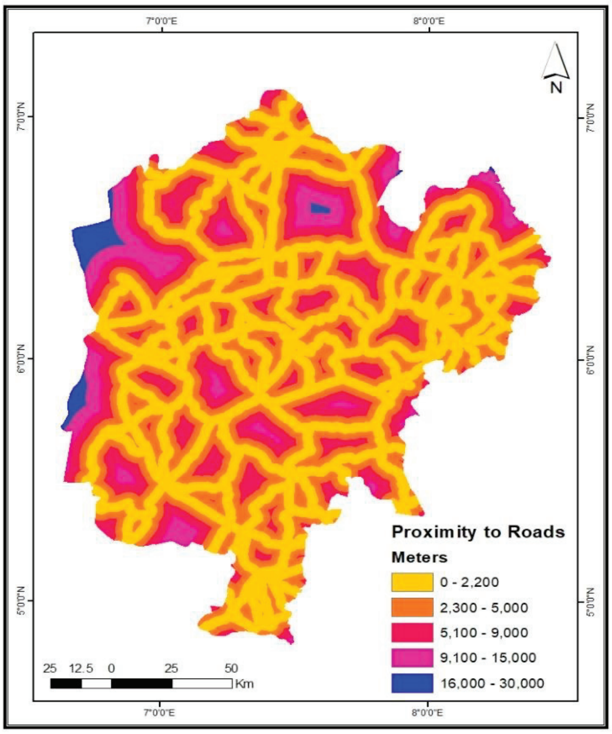
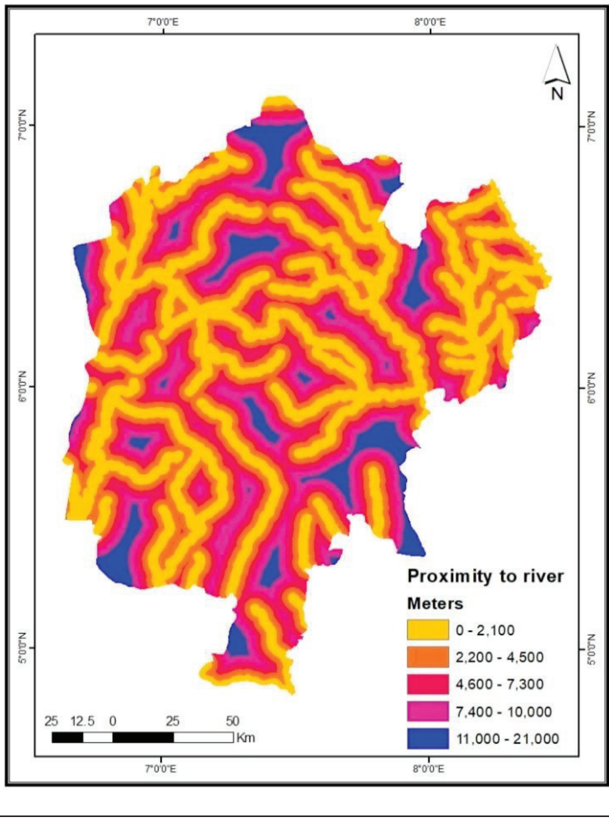


Figure 3.10: Roads, Rivers, Rail and Powerlines in South East Nigeria (Source: Openstreet Map)

Proximity Criteria	Map
Road	
River	

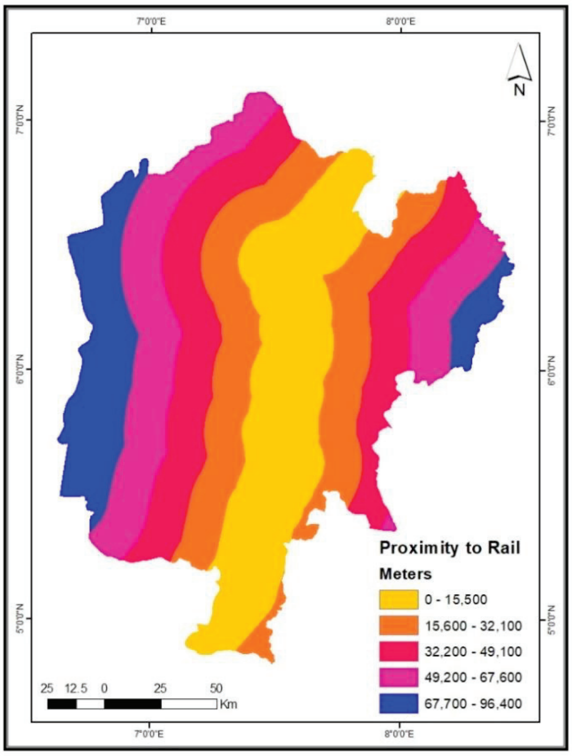
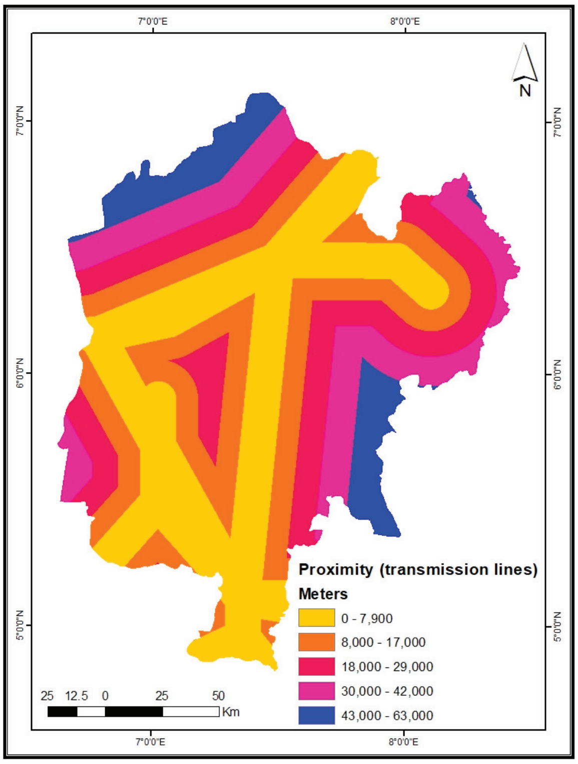
Railway	
Power/Transmission lines	

Figure 3.11: Distance Maps for Road, River, Rail and Power line (Source Author's Analysis, 2022)

3.2.6 Determining weights by Analytical Hierarchical Process (AHP)

Analytical hierarchical process (AHP) was developed by Saaty (1977) as a multi-criteria decision-making methodology that incorporates comparative techniques. The Scale of Relative Importance, a numerical measure that determines how much one criterion is more important than the other, is used to produce the Pairwise Comparison Matrix. The matrix is used to compute the weight influences (table 3.5). Solar hydrogen demand and potential were considered the topmost priority of the criteria because they are the topmost factor that help to determine the degree of suitability of the infrastructure i.e., how much can be produced and how high is the demand. In general, the AHP method is summarized as follows –

- Pairwise comparison matrix: For assessing complicated decisional situations, the AHP is regarded as an adequate mathematical method. It calculates the weights by using a pair-wise comparison matrix to compare the relative relevance of the criterion in pairs (Saaty, 1977). The criteria are first weighed according to their level of importance (table 3.4)

Table 3.4: Intensity of Importance of criteria (Source: Saaty, 1977)

Level of importance	Description
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

- Computation of criterion weights: this is done by finding the sum of the values in each column of the pairwise comparison matrix, dividing each element in the matrix by its column total (normalized matrix) and computing the averages by dividing the sum of normalized values of each row by the number of criteria (Saaty, 1977).
- Estimating Consistency Ratio: This measure the degree of deviation from inconsistency and is derived by dividing the consistency index (CI) by random index (RI) which is also derived from the matrix. It will help to show a reasonable level of consistency of the matrix i.e., if the weights are agreeable to be used. The ratio in this study is estimated to be 0.04 which is less than 0.1, which is the agreeable value (Saaty, 1977).

Table 3. 5: Pairwise Matrix and AHP weights generated for factors (Source: Author's Analysis, 2022)

Criteria	Power line	River	Road	Rail	Land use	Demand	Potential	LST	Slope	Elevation	Weight %
Power line	1	1	1	1	1/3	1/4	1/4	1	1/3	1/3	4.104
River	1	1	1	1	1/3	1/4	1/4	2	1/3	1/3	4.514
Road	1	1	1	1	1/3	1/3	1/3	2	1/3	1/3	4.859
Rail	1	1	1	1	1/3	1/4	1/4	2	1/3	1/3	4.514
Land use (*factor)	4	3	3	3	1	1/3	1/3	3	1/3	1/3	9.607
Demand	4	4	3	4	3	1	1	4	3	3	21.788
Potential	4	4	3	4	3	1	1	4	3	3	21.788
LST	1	1/2	1/2	1/2	1/3	1/4	1/4	1	1/3	1/3	3.521
Slope	3	3	3	3	3	1/3	1/3	3	1	1	12.652
Elevation	3	3	3	3	3	1/3	1/3	3	1	1	12.651

* Land use is used as a constraint where built ups and developed areas are excluded as well as factor where suitable areas such as bareland and grassland are potential sites for consideration.

3.2.7 Reclassification

The factors or criteria are quantitatively processed and produced in this study, and then converted to individual suitability levels through the reclassification method. This involves looking at the criteria and representing those suitable areas with a high value of 5 while unsuitable areas are reclassified as 1 (Table 3.6). This creates a set of suitability rasters for each criterion. This is done using the Reclassify tool.

Table 3.6: Reclassification values used in the study (Source: Author's analysis, 2022)

Values	**Suitability**
0	Unsuitable/Excluded/Restricted
1	Very Low
2	Low
3	Moderate
4	High
5	Very High

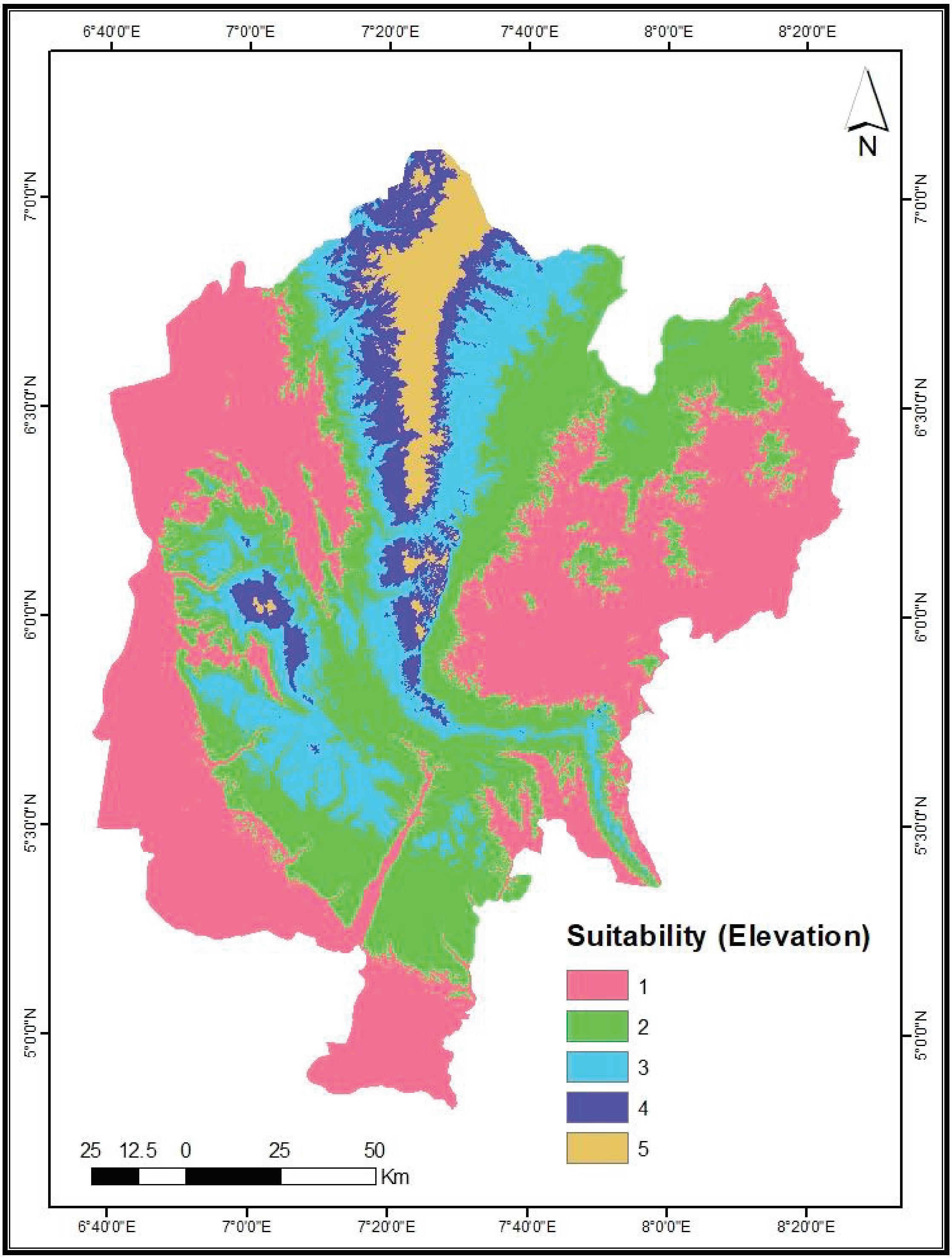


Figure 3.12: Reclassified DEM

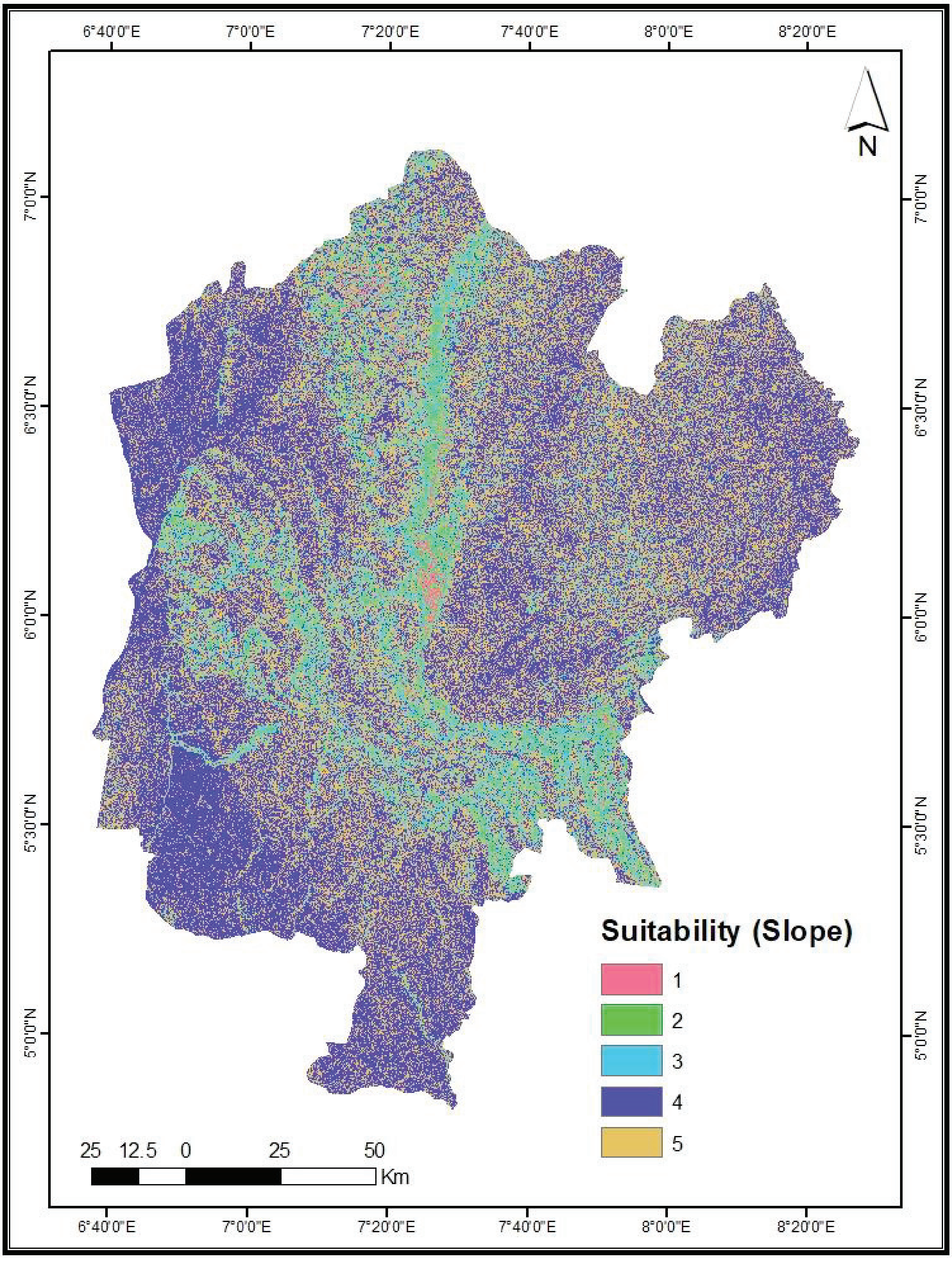


Figure 3.13: Reclassified slope

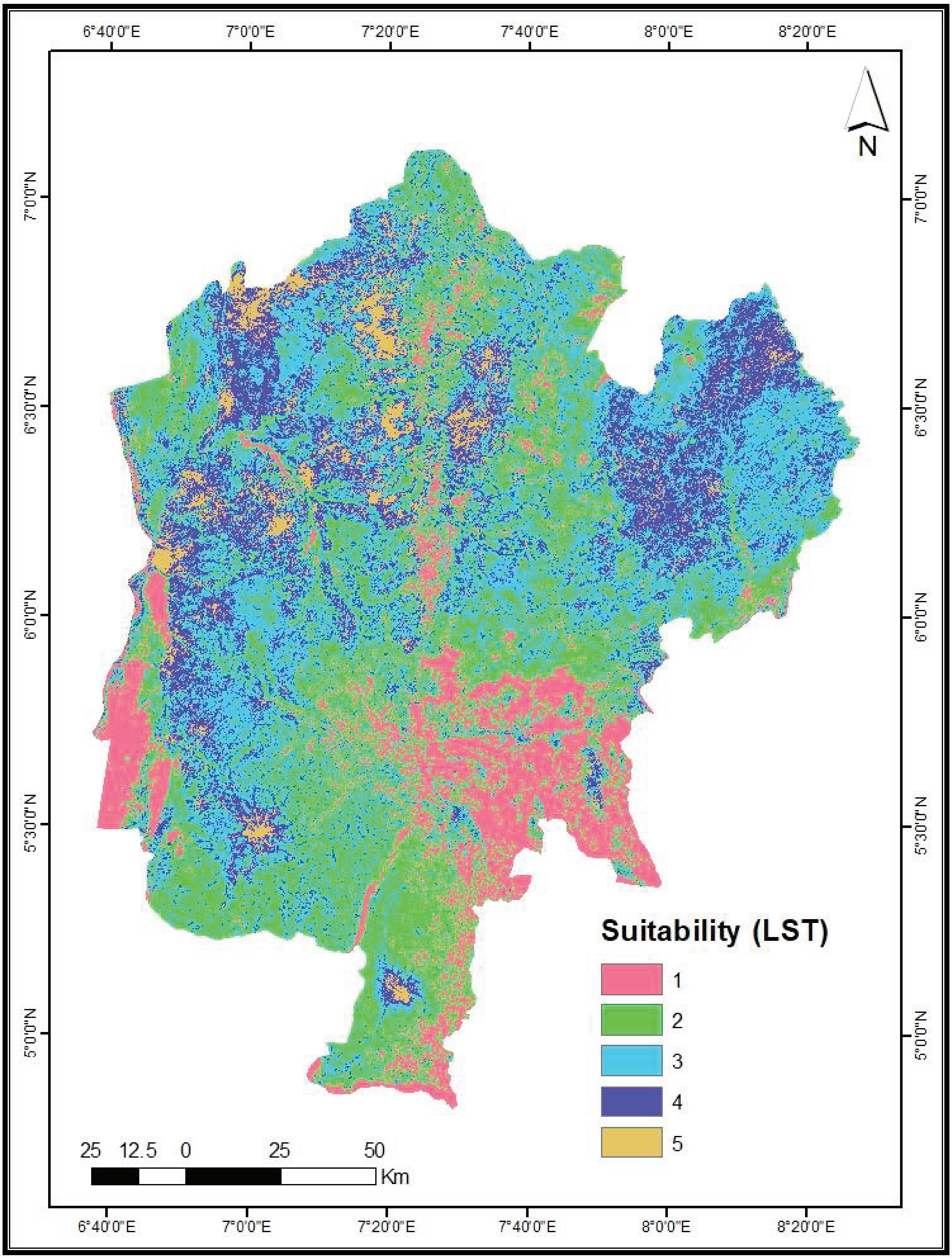


Figure 3.14: Map showing suitable areas in LST criterion

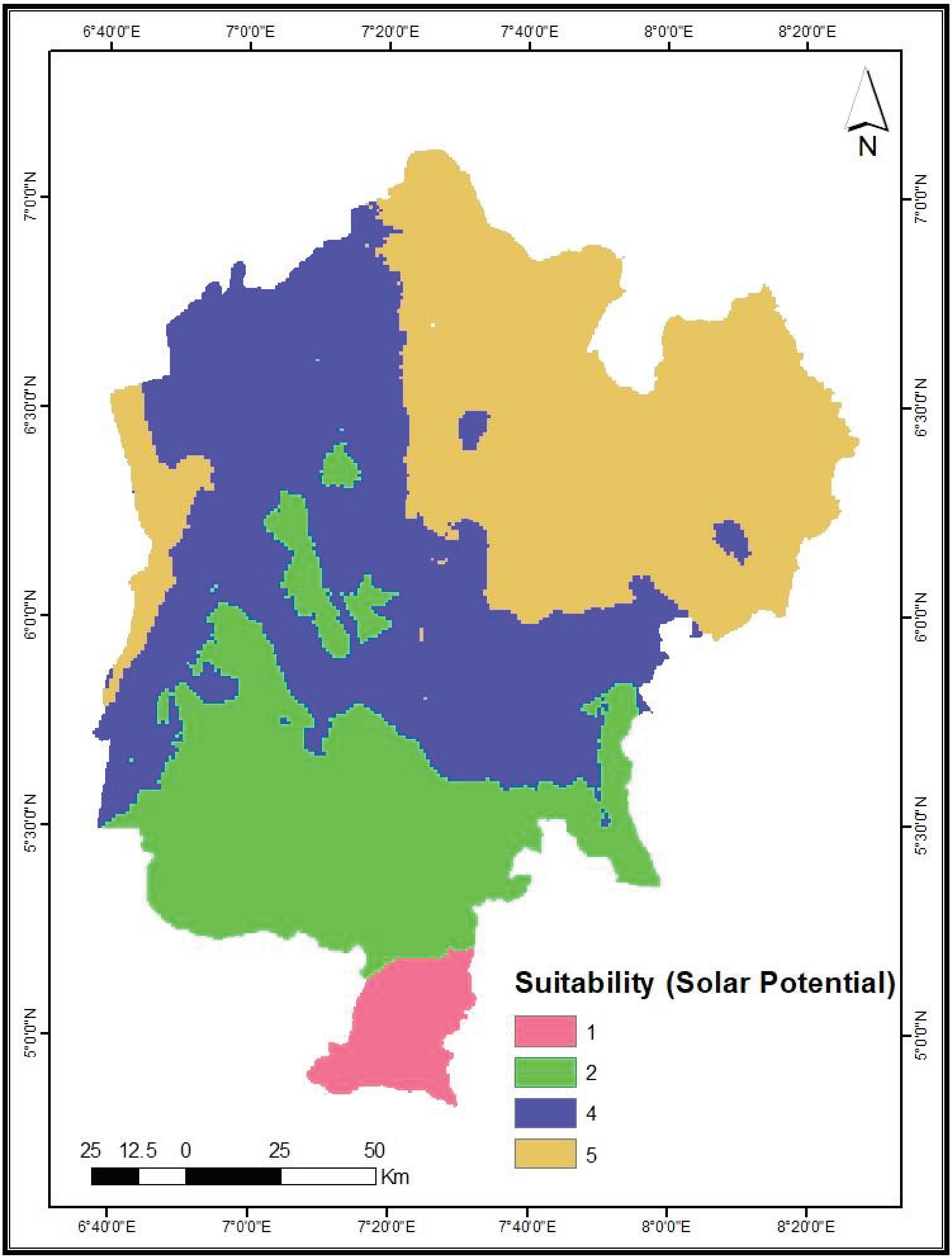


Figure 3.15: Reclassified Solar Hydrogen Production Potential Map

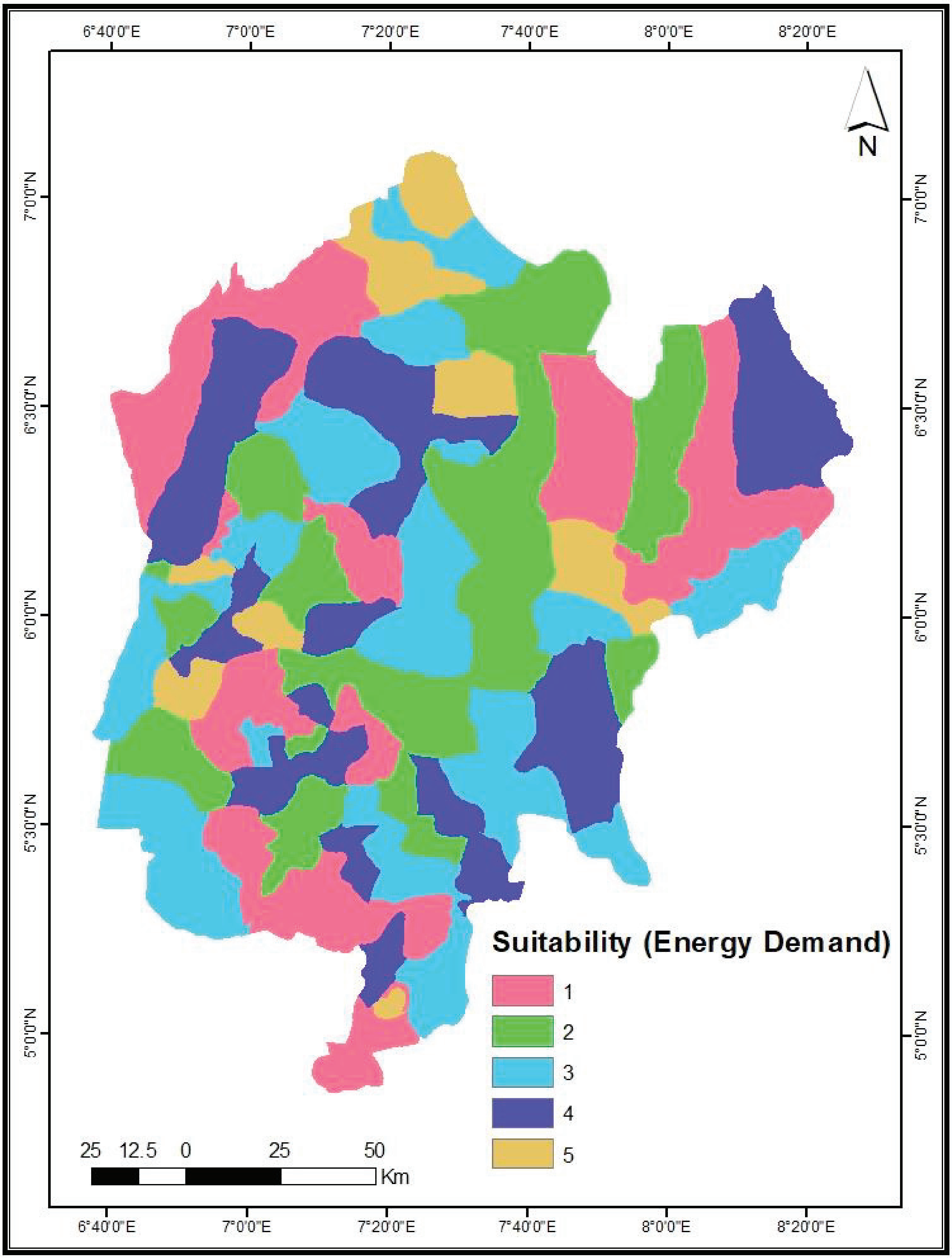


Figure 3.16: Reclassified Energy Demand Map

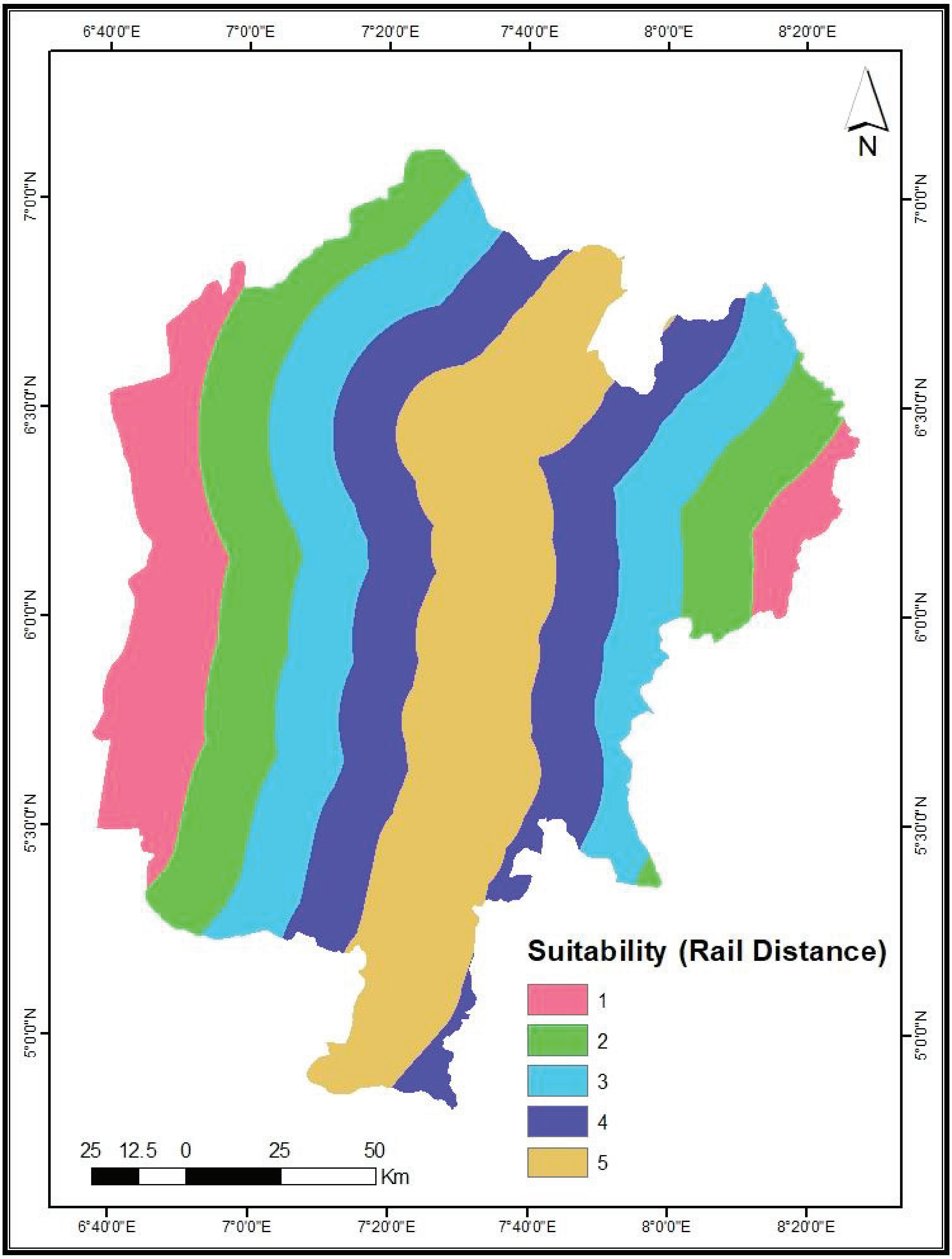


Figure 3.17: Reclassified Rail Proximity Map

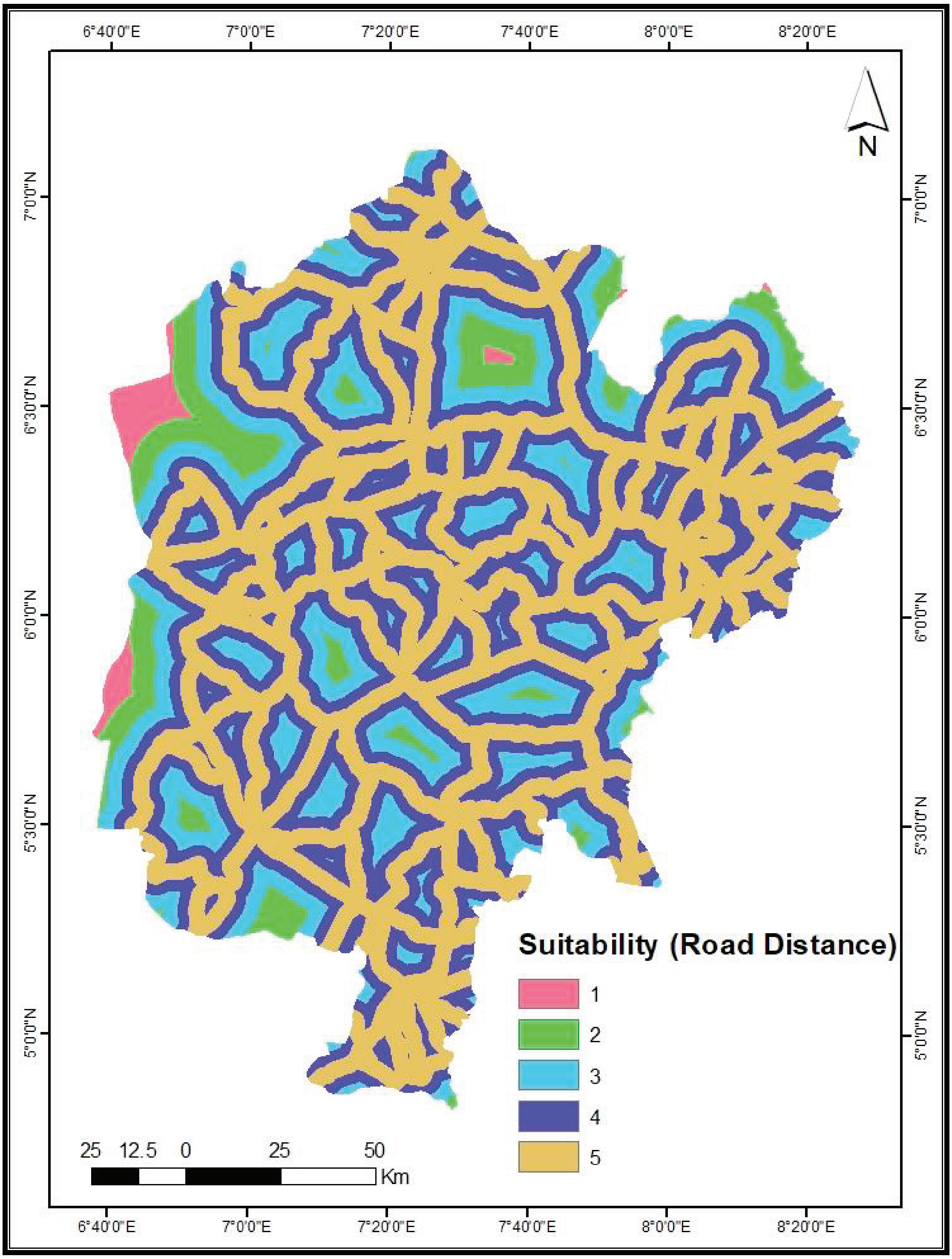


Figure 3.18: Reclassified Road Proximity Map

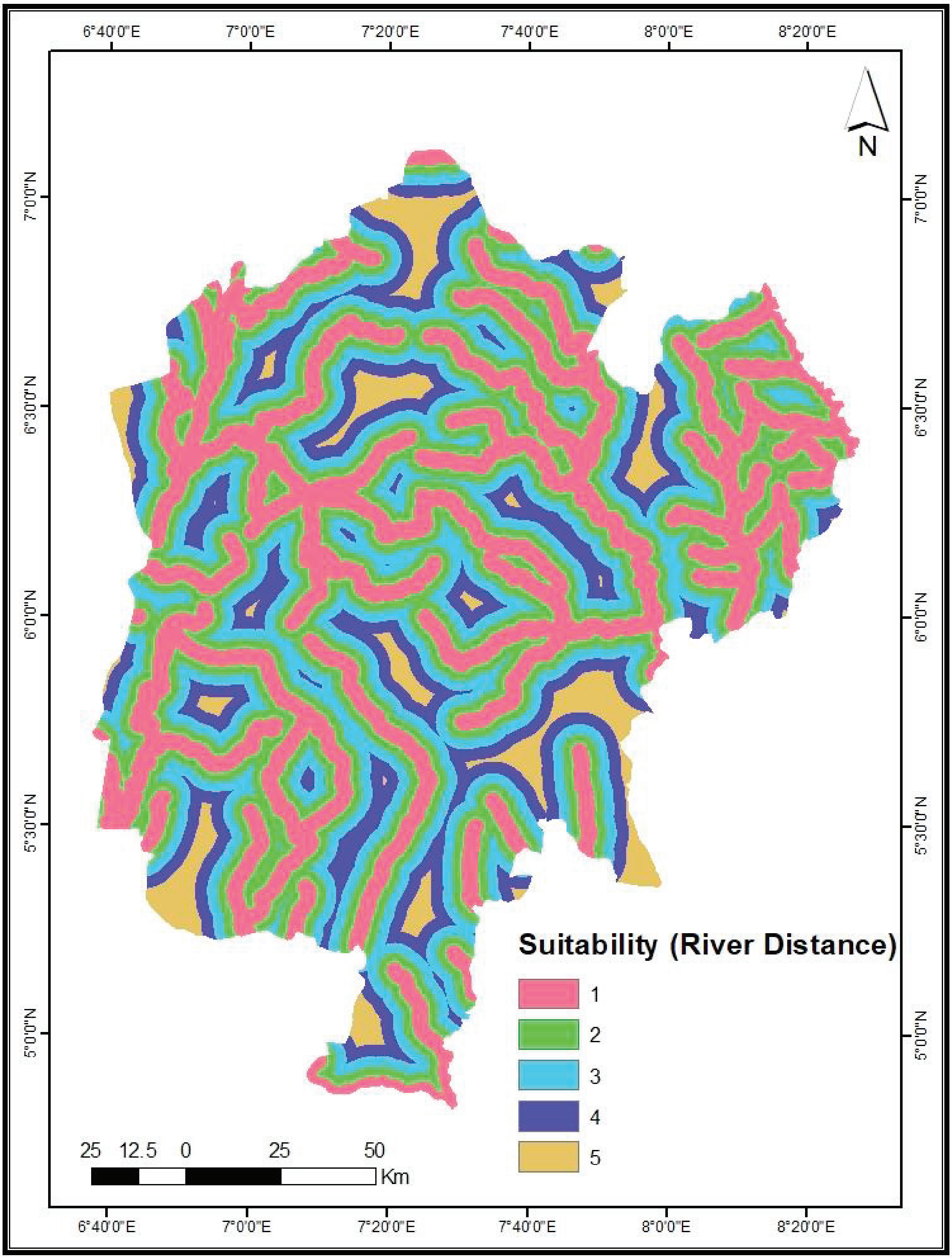


Figure 3.19: Reclassified River Proximity Map

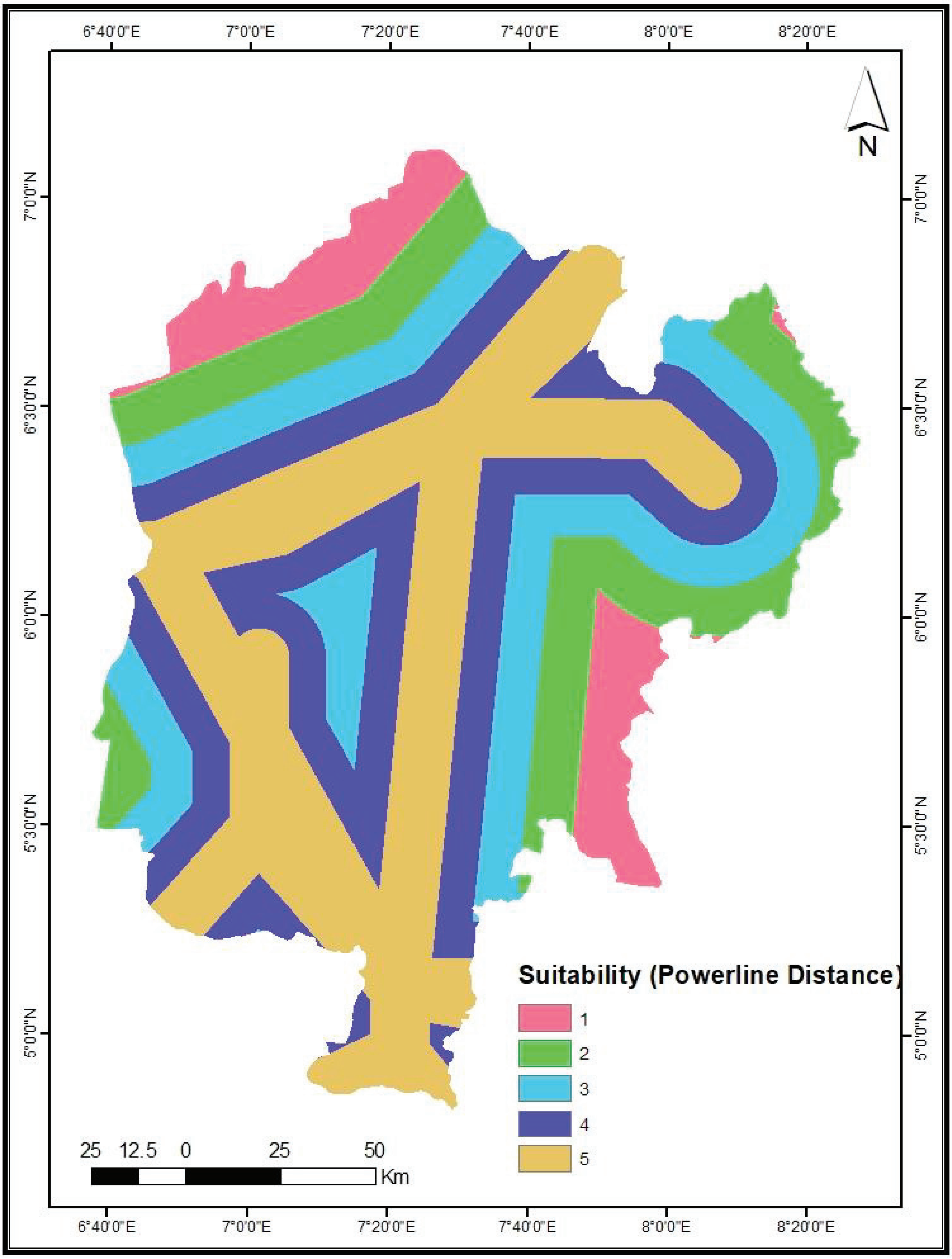


Figure 3.20: Reclassified Powerline Proximity Map

3.2.8 Weighted Overlay

The tool helped to combine the suitability rasters. Areas that were constraints were restricted from the combination. The weight influences (table 3.5) were combined with the suitability rasters to derive a suitability map that showed restricted areas, unsuitable areas, low, moderate and highly suitable areas for the development of solar hydrogen infrastructure.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Suitable Sites for Solar Hydrogen Infrastructure

Map in figure 4.1 depict the output of suitable sites for the proposed solar hydrogen infrastructure. Areas that were excluded include built up sites as well as regions of heavy forest or vegetation which served as conserved areas. Table 4.1 below depicts the area and percentage of each suitability level.

Table 4. 1: Area and percentage coverage for each suitability rank (Source: Author's analysis, 2022)

Suitability	**Area (km^2)**	**Percentage (%)**
0 - Unsuitable	12415.5	45.0532
2 – Low	1445.92	5.24694
3 – Moderate	11311.4	41.0467
4 – High	2364.61	8.58069
5 – Very High	19.9512	0.072399

From the above table, about 45% of the region are deemed unsuitable because they are restricted and excluded. In general, the whole region can be depicted as moderately suitable because over 40% of the area falls within this category (figure 4.1). Also, suitability across each state is examine to understand how the suitability varies at different locations. Only 8.5% of the area has high suitability and most of which is located in Enugu state. figure 4.2 – 4.6 showed individual states and suitability level.

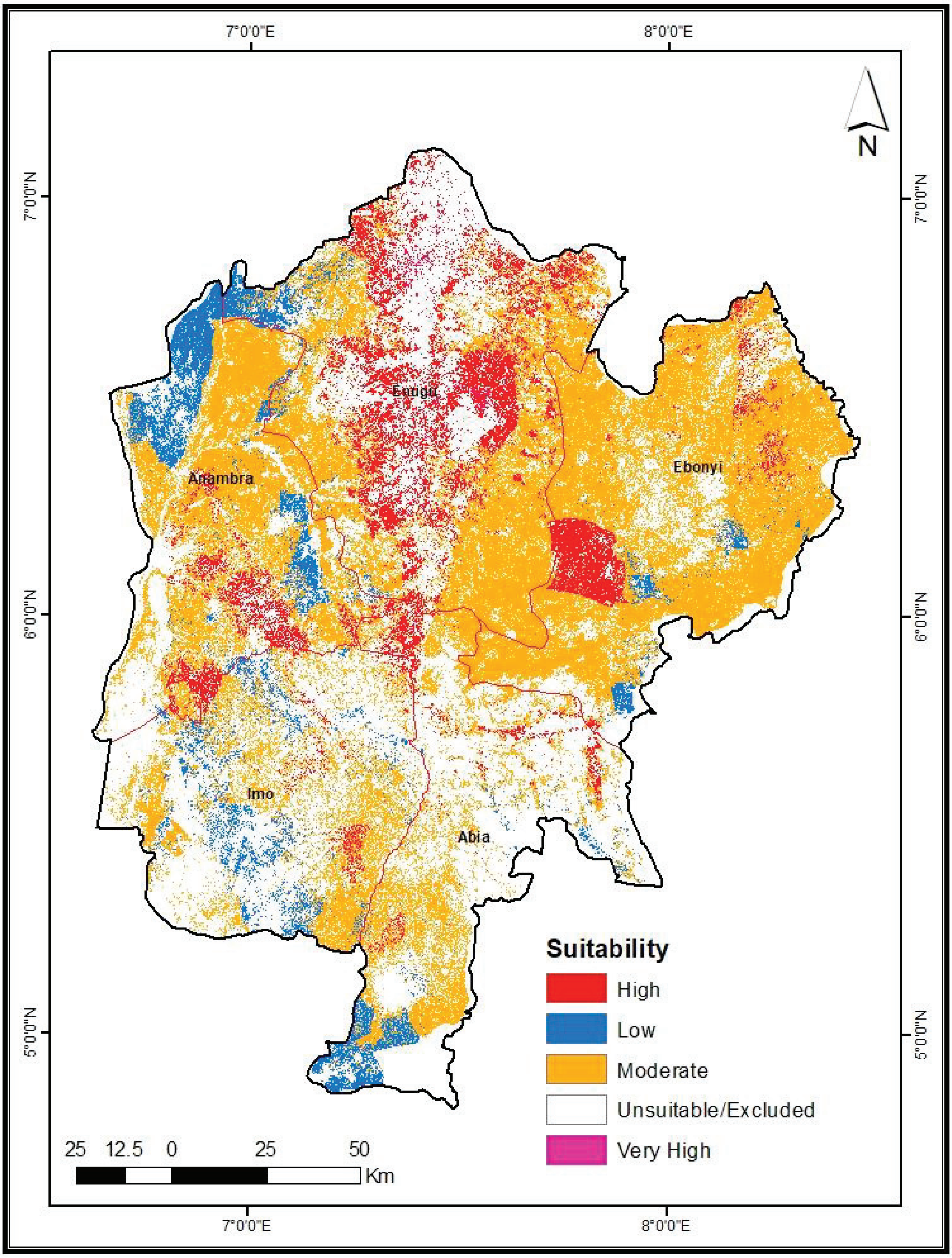


Figure 4.1: Suitability Map showing sites for solar hydrogen infrastructure

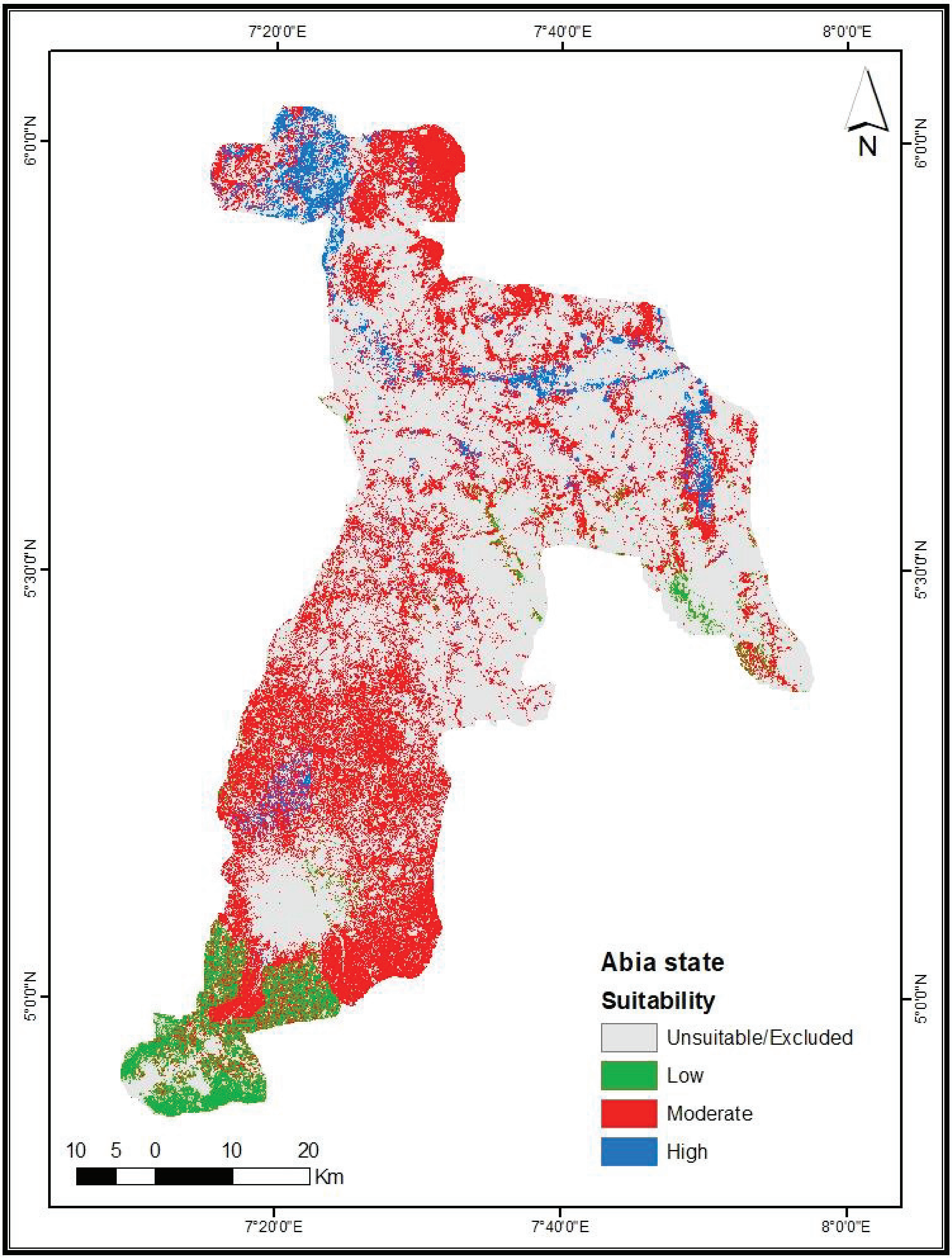


Figure 4.2: Suitability Map for Abia State

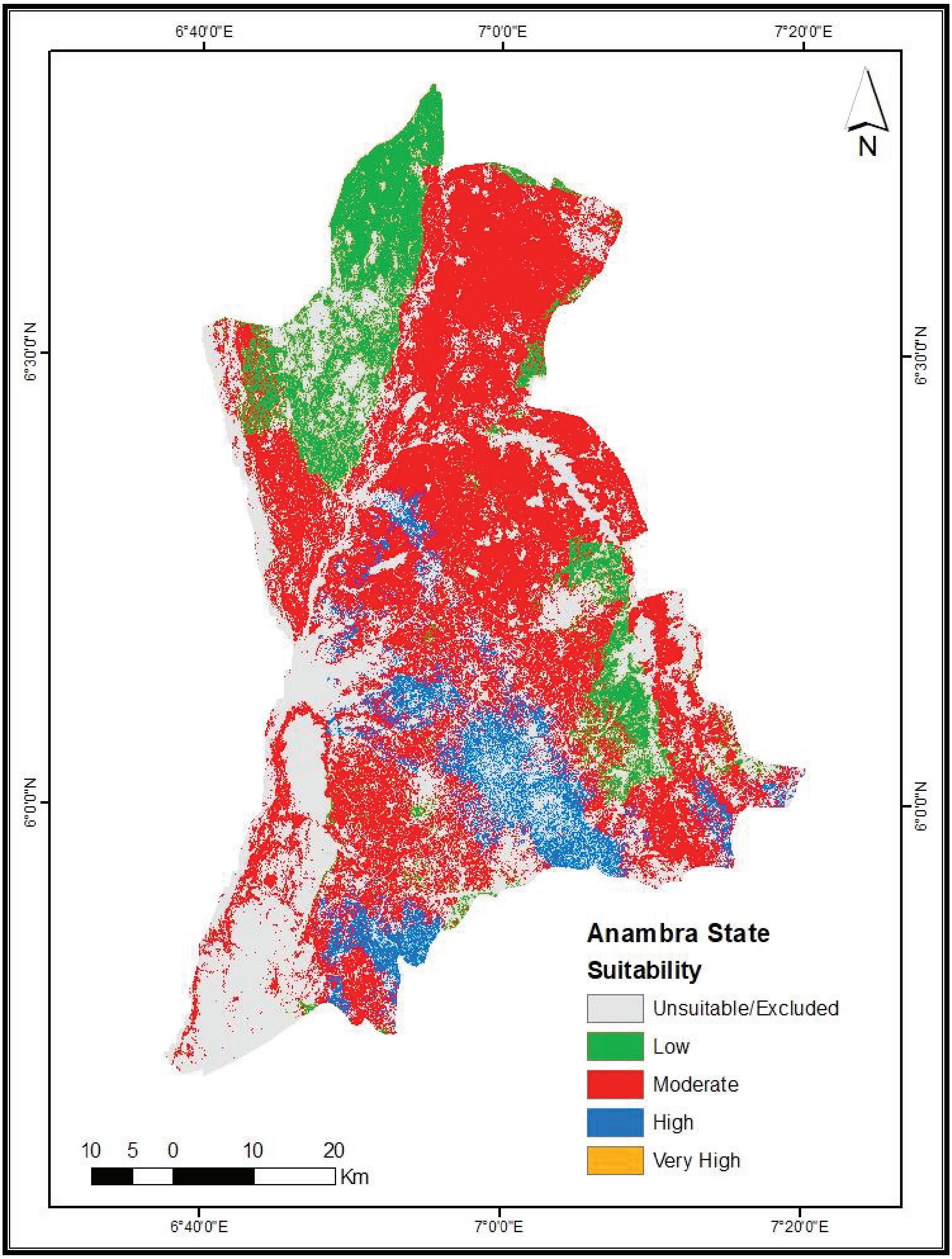


Figure 4.3: Site Suitability for Anambra State

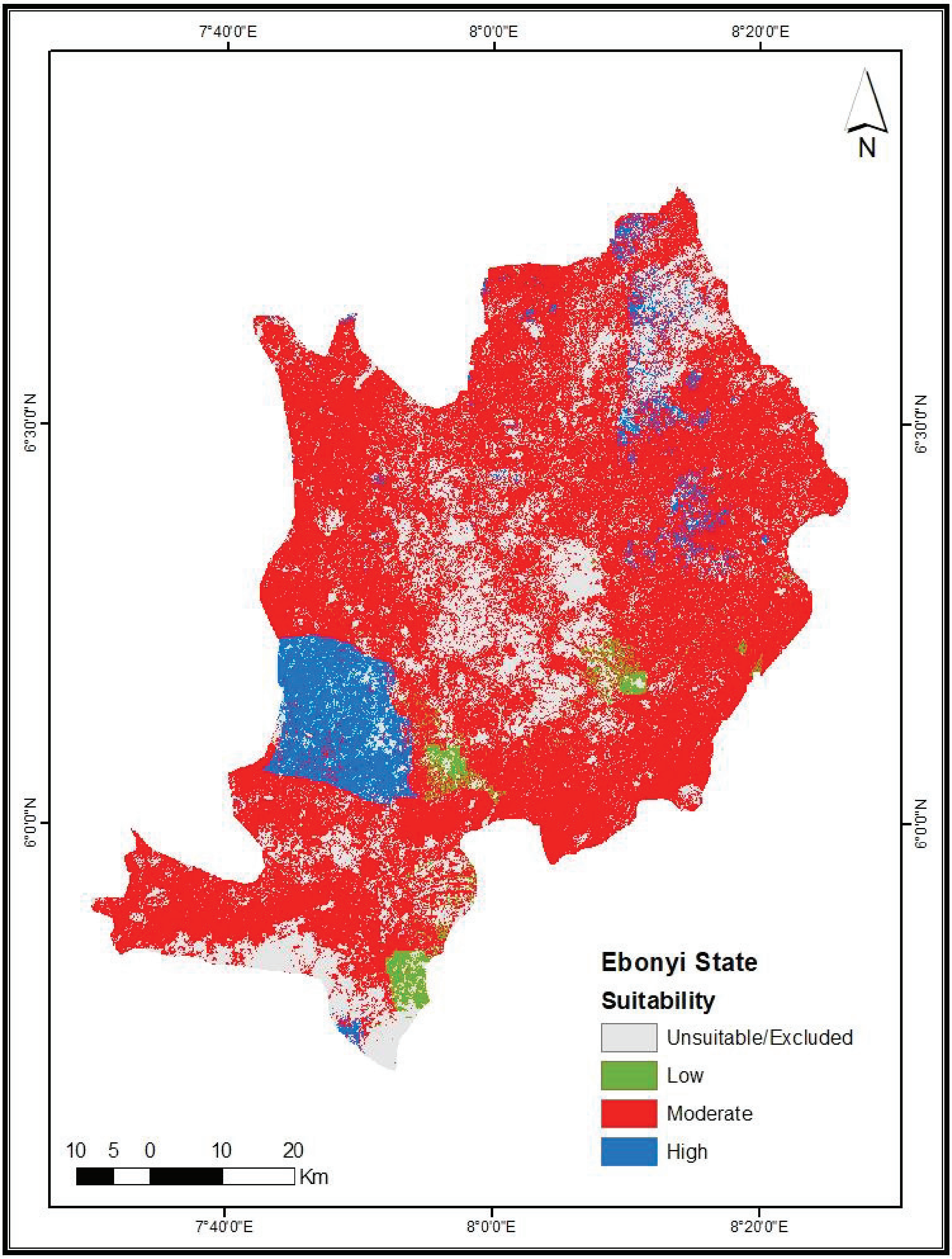


Figure 4.4:Site Suitability for Ebonyi State

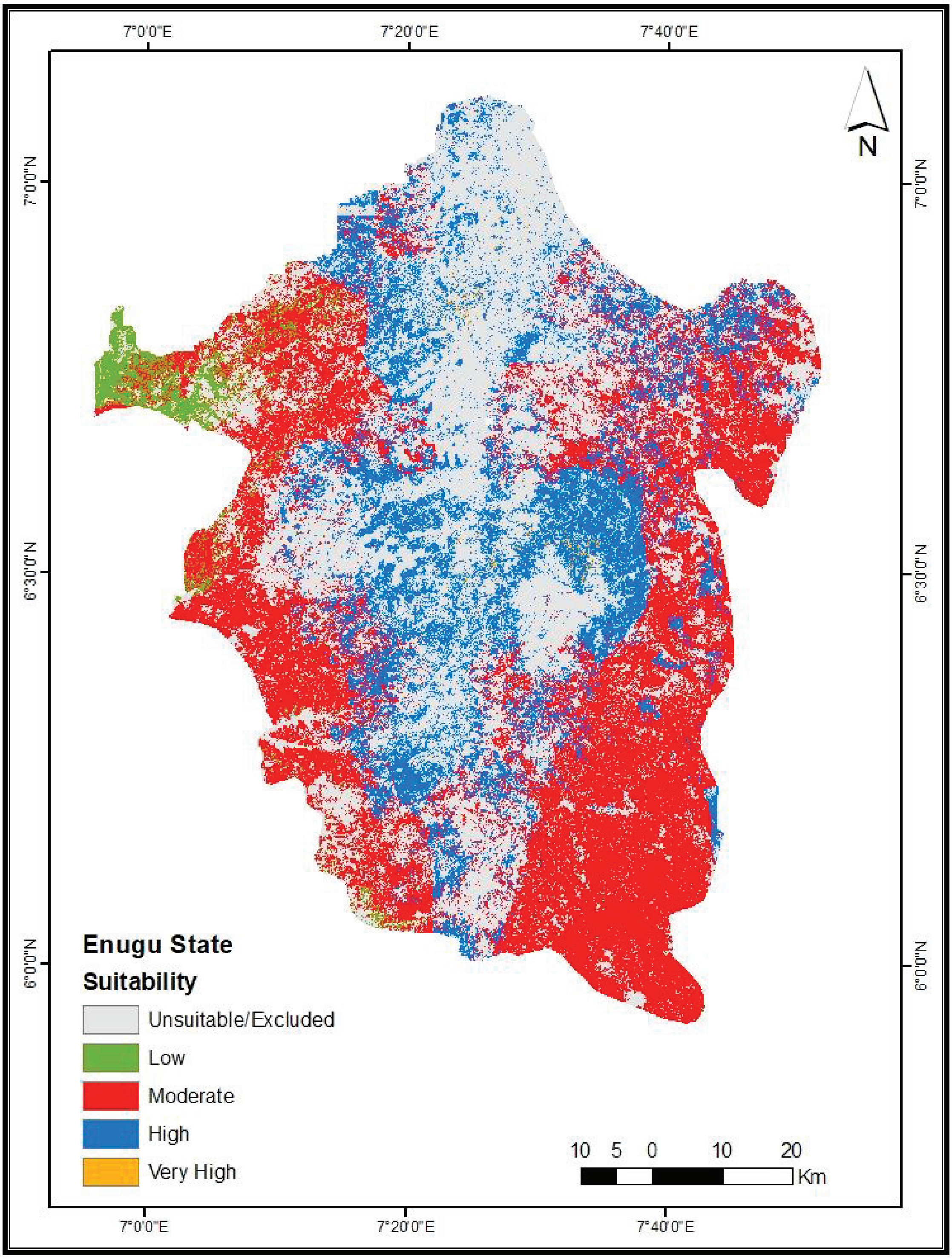


Figure 4.5: Suitability Map for Enugu State

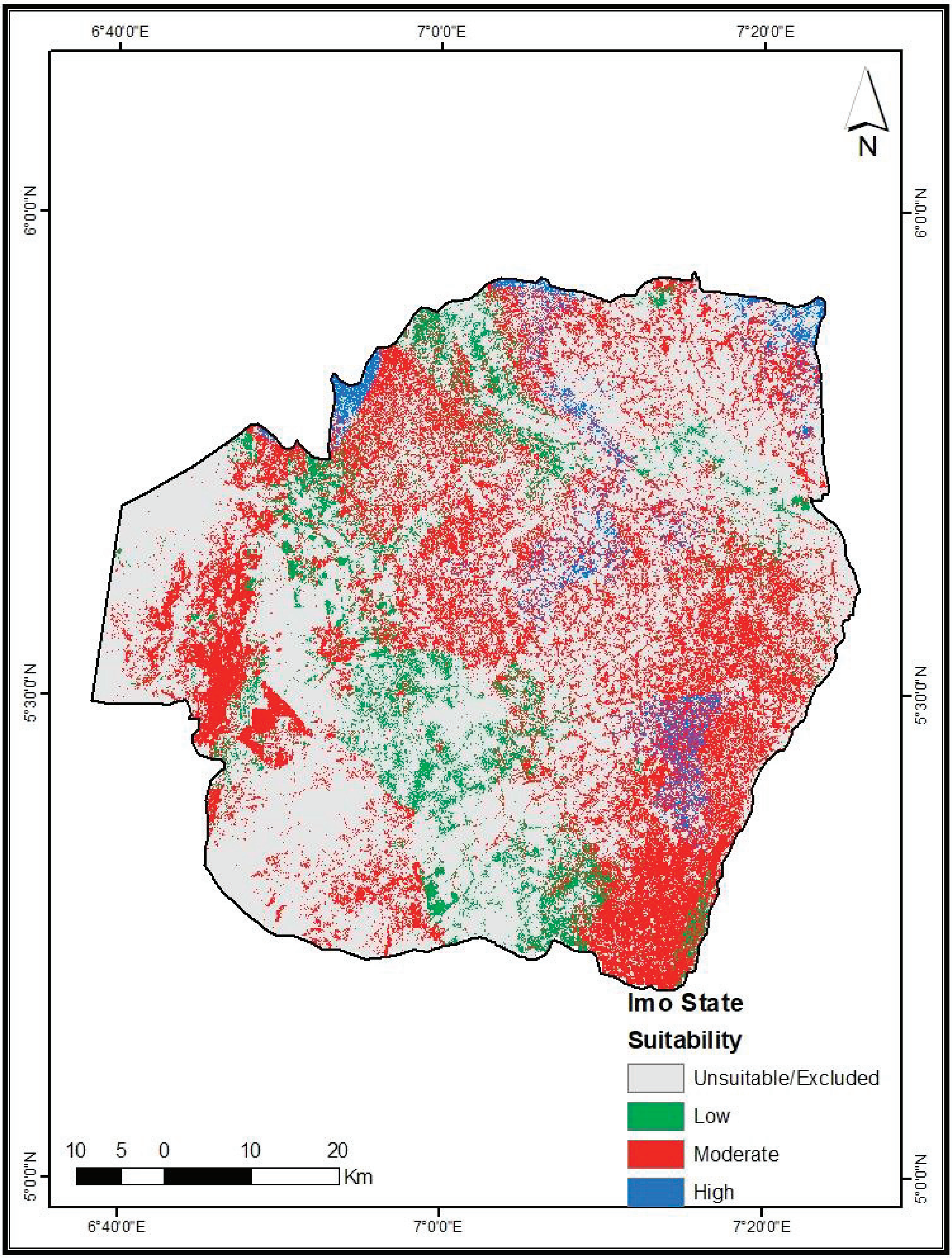


Figure 4.6: Suitability Map for Imo State

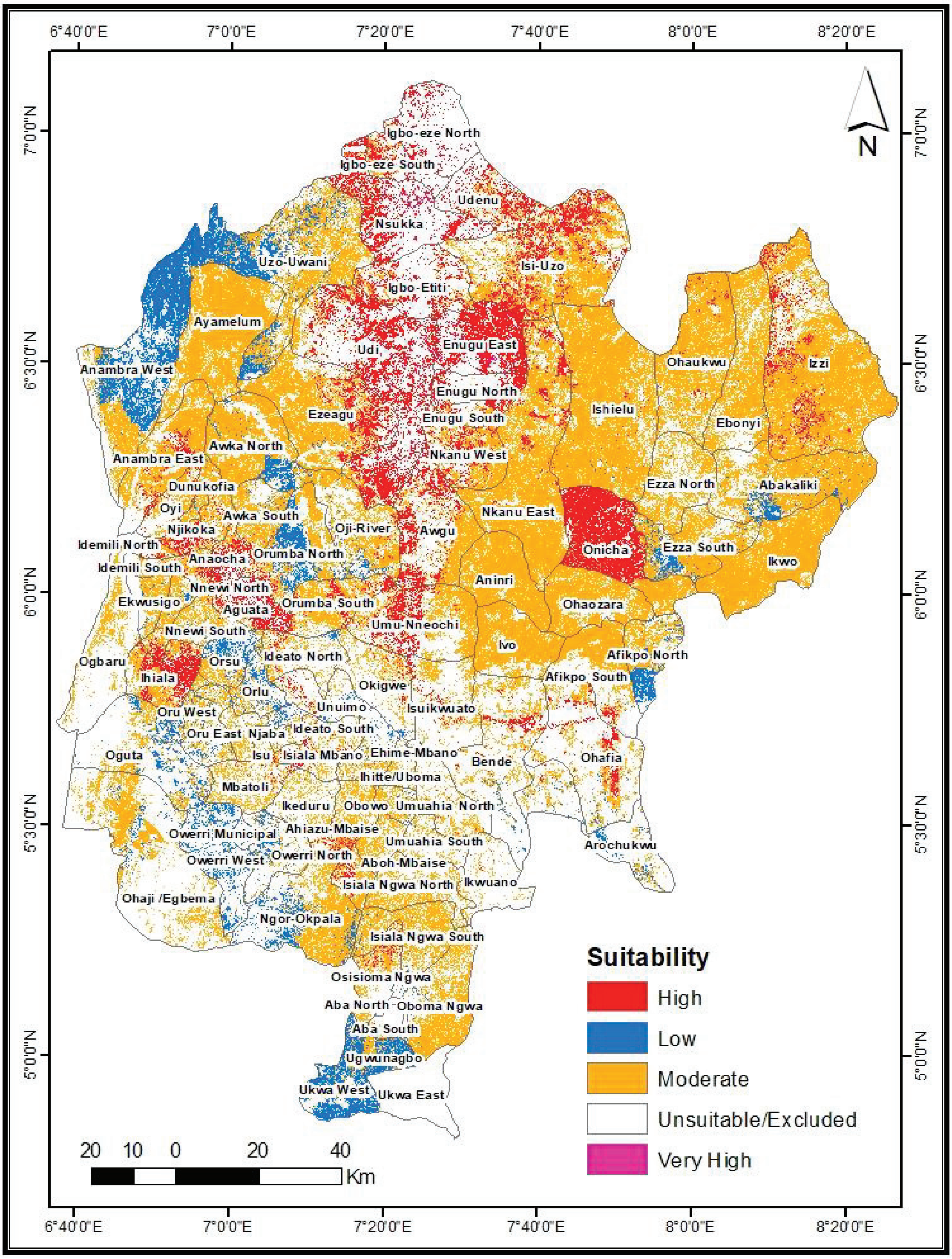


Figure 4.7: Site suitability by community (Source: Author's analysis, 2022)

In Abia state, 61.5% of the area is unsuitable while about 5.5.% falls within the low suitability category (mostly in Ugwunabo & Ukwa west areas in the lower south). Approximately 29% of the area has moderate capacity for the infrastructure (mostly regions in the mid-south) and 3.9% have high suitability which are located within Osisioma-Ngwa, northern Umu-Nneochi, Isiukwuato, Bende & Ohafia regions (figure 4.7). In the same vein, approximately 44% of Anambra state has moderate suitability for the site while 38% of the area is unsuitable and 6.5% of the state is highly suitable. Some areas within Ihiala, Aguata, Anaocha and Idemili (located within central Anambra) (figure 4.7) have highly suitable areas but areas in the east and north of the state have low suitability.

Furthermore, Ebonyi State is made up of mostly areas with moderate suitability (approximately 67% of the area) while 24% of the area is unsuitable – only 2% of the area has low suitability. Highly suitable sites (about 8%) are located in the south west area (Onicha region) and slightly in the north east (in Izzi area) (figure 4.7). in general, even though Ebonyi state is mostly within the moderately suitable zone, prospective sites for the infrastructure can still be pinpointed, making the state to be one of the suitable areas. In characteristics, the state has a high potential for production than Abia state and in terms of suitability, more areas have more moderate and higher suitabilities than Abia and Anambra States. This indicates that the state would be a better site to uphold such infrastructure.

However, Enugu state can be considered as the best suited and effective site for the location of the infrastructure. In general, unsuitable areas make up about 44% of the state but has 34.7% of moderately suitable areas and 18.5% of areas that are highly suitable – which is greater than other states. Most areas within the central area of the state (Udi, Enugu East, Enugu North, Nsukka) depicts both suitable and unsuitable areas. it is believed that the factor criteria are mostly favored more in the state than others – high solar hydrogen production potential, high elevation for more efficiency in production, favorable land temperature to name a few. Areas of low suitability only comprises of 2% (primarily located in the North west of the state). Another factor is that the state has the highest landmass than others, giving chances for more infrastructure placement.

Imo state has 64% of areas that are unsuitable but 26% of the area has moderate suitability – only 2% has high suitability. in general, table 4.2 below depict the suitability for each state and their percentage coverage. It can be inferred that the best sites would be Enugu and Ebonyi states because they have more highly suitable area than others.

Table 4.2: Percentage cover of suitabilities in each state

Suitability	**Abia (%)**	**Anambra (%)**	**Ebonyi (%)**	**Enugu (%)**	**Imo (%)**
Unsuitable	61.565	38.0868	23.9727	43.858	64.1042
Low	5.52773	11.6076	2.01087	2.57429	6.8821
Moderate	28.9426	43.8277	67.4436	34.716	26.8365
High	3.96468	6.4753	6.57283	18.5853	2.17723
Very High	-	0.002571	-	0.266489	-

4.2 Solar Hydrogen Infrastructure Potentials in the South East

The need for a solar hydrogen infrastructure in the country, particularly in the south east comes from the need to increase consumption without affecting climate change. As indicated in the result, it is understood that there are some places where the infrastructure would be more suitable in terms of availability and accessibility. According to Fan et al., (2021), low-carbon hydrogen has garnered increased interest as a viable low-carbon fuel and source under these emissions reductions concepts, particularly for difficult sectors such as heavy-duty transportation (trucks, shipping) and industries (e.g., steel, chemicals). Green hydrogen, defined as hydrogen produced from water electrolysis using zero-carbon power, has a lot of potential in terms of assisting countries and regions to achieve their climate goals. Green energy production now confronts numerous hurdles, including high costs and logistics, capacity issues, and significant CO2 emissions growth – when produced using fossil energy, it would not be called green hydrogen(Fan et al., 2021).

For south eastern Nigeria, urbanization and industrialization have contributed to its economy, making them to earn the title as the 'heart of Nigeria's business sector'. Commercial centers such as Aba, Onitsha, Awka, Nsukka to name a few, are known as places for commercialization, which have contributed to the high rate of urbanization – it is a zone known to attract businessmen, industries and investors. Therefore, solar hydrogen can be a way to ensure that costs of production is effectively managed while ensuring a reduction in green house gas emissions.

According to Nweke-Eze & Quitzow (2022), Africa has untapped hydropower potential and Nigeria with some African countries like Algeria have the largest gas reserves in the world. This makes green hydrogen production to be viable, especially in areas with high solar output. The production is a way to diversify the fossil-fuel dependent economy because the goal is to ensure that carbon use is reduced and an opportunity for bringing in renewable resources(Gershon & Emekalam, 2021). In the map below (figure 4.9), out of 95 communes or local governments, only 58 stands as a potential region that can house the infrastructure, meeting all the needed criteria. For instance, Enugu state which has about 17 communes, has most of them in the highly suitable category (about 14 communes). On the other hand, Onicha in Ebonyi state is also a potential area as well as Nnewi and Aguata areas. With this study, it would be easy to develop road map for productions and even extend into areas with greater potential like the neighboring south western states.

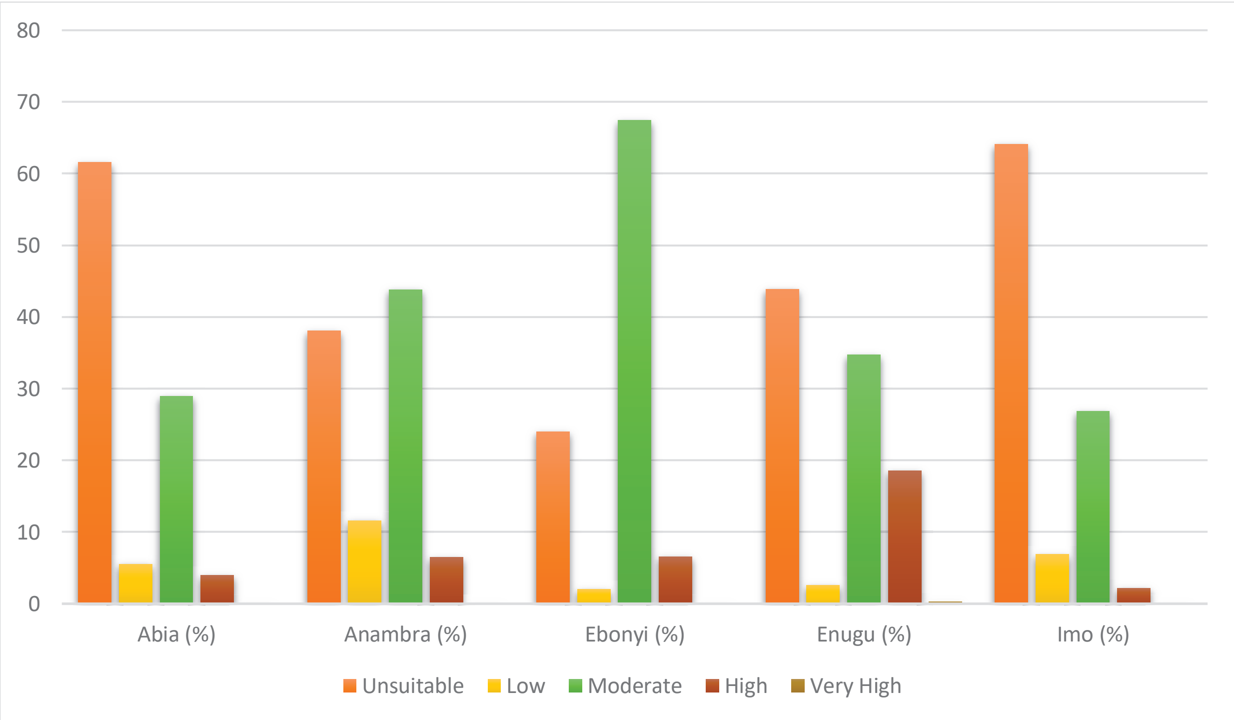


Figure 4.8: Suitability Percentages for each State

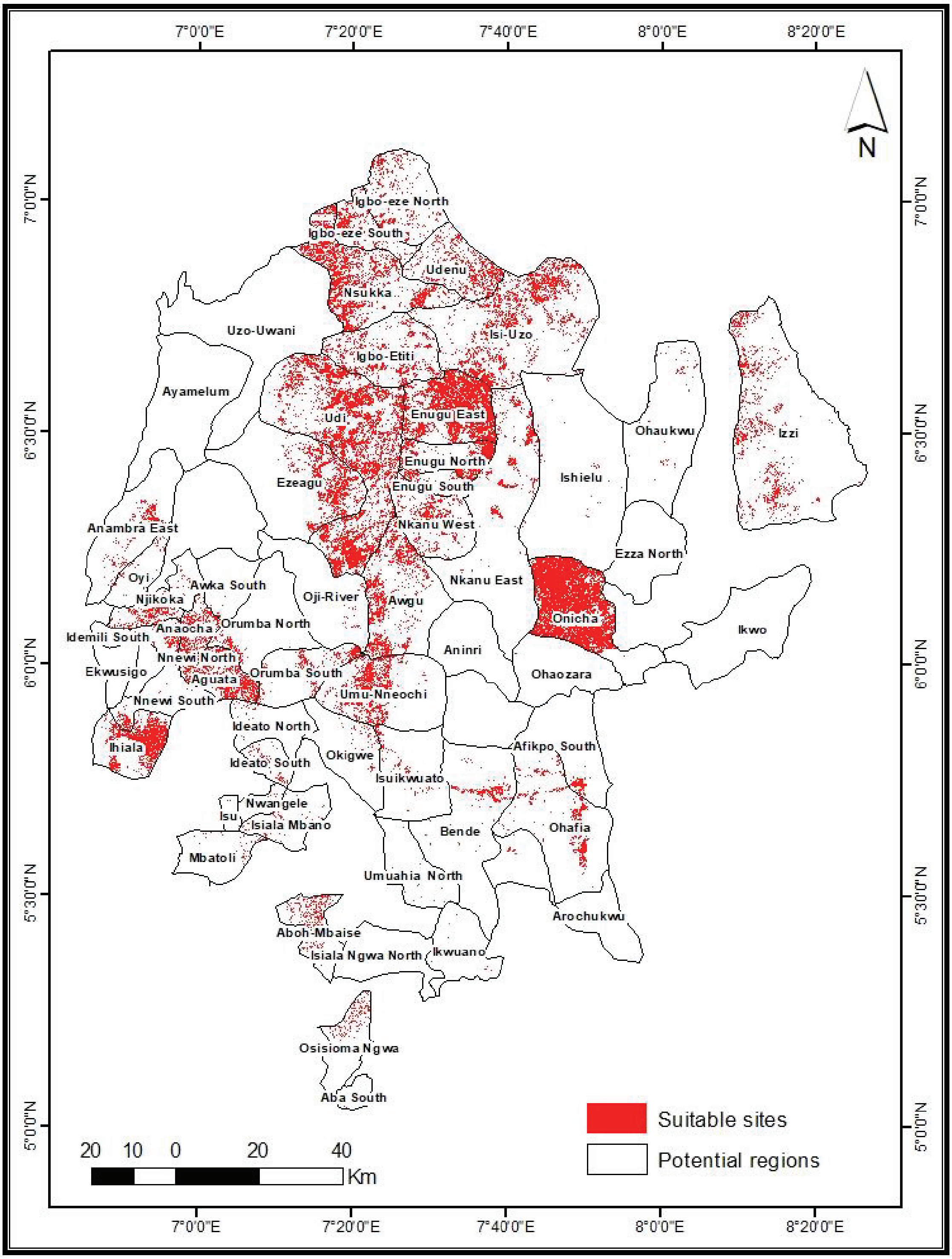


Figure 4.9: Suitable local government areas with high potential for solar hydrogen infrastructure

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

This study has looked at the potential for south eastern Nigeria to be home to green hydrogen infrastructure with a view to ensure and maximize consumption while reducing greenhouse gas emission tendency from fossil fuel. It would be recalled that green hydrogen is an effective renewable resource that can provide zero emissions and with its source from renewable energy such as solar, the potential for efficiency and effectiveness would always be known as a platform for energy growth for the country. The study area is home to 95 communes or local government area and has a population of over twenty million people living in over ten commercial cities and significant towns. This indicates that the area is highly developed and is home to different businesses and industries. The need for a green hydrogen infrastructure in such area cannot be over-emphasized.

In general, unsuitability depicts the absence of the capacity to have a green hydrogen infrastructure in such area. it is seen that about 45% of the region cannot have the resource because they have no potential. However, moderate capacity indicates a more than average capacity to have such resource - 41% of the region is slightly suitable. With 45% of the region regarded as unsuitable, it shows that there is still a chance for the infrastructure to take root in the country (as 55% of the region in general is suitable). 8.5% of the region have high suitability, indicating that they have high production potential, available land, high demand, favorable temperature, elevation and slope as well as better proximities to rail, road, railway and river.

Abia state can be considered as an area with less potential for green hydrogen infrastructure, as more than half of the land mass is unsuitable (61%). Also, Imo state has over 64% of its area in the unsuitable category as well, indicating that there is a reduced potential for production, even though over 20% of the area has more than average capacity. However, Anambra, Ebonyi and Enugu can be regarded as potential sites, with Enugu state having the highest potential for green hydrogen infrastructure. Due to its location as well, there is a high chance that the resources can even extend to areas of low or less potential. In general, about 61% of the communes or local government areas can be regarded as potential areas for such infrastructure as shown in figure 4.9. This means that there is a high chance green hydrogen infrastructure can take root in the south east with proper planning and maintenance.

5.2 Recommendations

As a form of renewable resources that can contribute to zero emission while meeting the demand of energy in the south, there is need to create some planning and creative steps to give room for such type of technology-efficient renewable resource that will reduce greenhouse gas emissions while ensuring safe use. there is need for a ground investigation in order to map out areas that will be useful for such projects. There is also a need to look at other factors not considered in this study such as point location of cities and their proximity to potential suitable sites and logistics concerning budgets for implements that will be needed to start off such production.

Also, it would be recommended to consider prioritized and detailed analysis such as resource availability, financial markets and competition in order to know the viability of such infrastructure in the region. There should also be priority to construct such infrastructure as a means to improve electricity transmission in the region and would be a kick-off point for such infrastructure in other regions of the country. There is also, a need for more innovation to improve energy and renewable resources that will increase growth and development.

5.3 Study Limitations

According to research, topics on land suitability potential for green hydrogen infrastructure have not been widely carried out in many instances. This study heavily relied on some literatures that discussed extensively on solar hydrogen infrastructure as well as some that discussed solar farm site suitability. This is why most of their criteria is adopted and applied for the regional study. Also, the research has not been carried out in the country, even at a small scale. The challenge of data acquisitions also played a role. For instance, some of the datasets were not up to date i.e., population which is important in deriving the demand criteria – the data is solely based on projections. Information on market penetration and per capita vehicle ownership for the region were not readily available. They were derived from the general information as stated in the website. There is also a need for ground survey for proper validation and would aid in ensuring accuracy of the results produced in the analysis. in essence, the suitability map can be an efficient tool for narrowing down actual areas that is greatly suitable

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