GIS and Remote Sensing Applications in Rural District Road Network Evaluation: The Case of Nebilyer in Western Highlands Province, Papua New Guinea

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Abstract

Infrastructure developments have not yet picked up pace in the Nebilyer Rural District, Western Highland Province, Papua New Guinea, since the end of the colonial era due to a number of reasons. As a result of inadequate road connectivity, particularly in the remote rural areas of the district, many areas with high development potential remain isolated and majority of the rural population is deprived of minimum basic necessities like health care, education, etc. Roads play an important role in all aspects of development such as agriculture, health, education and small-scale businesses, among others. The absence of standard roads in the district leads to the stagnation of socio-economic development of the villagers, despite ample resource potentials. The study aims at demonstrating the potentiality of Geographic Information System (GIS) and remote sensing (RS) technologies in the development of road information system, which in turn helps planners and administrators to identify the problems associated with rural road development, and with monitoring and maintenance of the road infrastructure created in the area. The Google Earth Pro 2010, multi Landsat Satellite image of 30 m resolution, topographical map of scale 1:100,000, PNGRIS, and Geobook Data sets together with the existing geospatial road database and GPS field survey data sets, are the sources of data used to do analysis within the GIS and RS environment. In this study, road network and connectivity, distance and density analyses have been performed in ArcGIS and thematic maps were produced. Relevant environmental factors such as drainage patterns, slope, landform, soil texture and lithology were analysed and assessed with respect to road networks in GIS environment resulting in findings that could prove useful for road management in the study area.

Keywords: *Infrastructure development, Remote Sensing, GIS, Road network, Evaluation*

1. Introduction

Bereft of any rail network, road transportation is one of the most common modes of surface transportation system in Papua New Guinea (PNG) designed to promote economic development. The roads augment mobility of people and goods from one province to another and help foster socio-economic growth and poverty eradication. The majority of the population of PNG is predominantly rural and having good road network is important for people to market their local agricultural produce and cash crops like coffee to earn money and support their livelihood. Therefore it is very important to maintain good road network in all the provinces. Although road transport plays a major role in economic development, the majority of the roads in rural areas have been ill-maintained for the past decades and conditions have deteriorated enough to render them almost impassable in most parts of PNG. This threatens economic development and limits access to markets and social services for much of the rural population. The government had often prioritised improving road systems in major cities across PNG whereas roads and associated infrastructures in the rural areas are neglected and require urgent upgrade and maintenance. It is important now to take a different approach to manage the road networks in PNG. Accurate information on transport infrastructure is the fundamental requirement for many decision-making processes and it is important to have reliable, real time, relevant, and easily accessible information (Fiatornu, 2006). Remote Sensing (RS) and Geographical Information System (GIS) can be considered as an effective tool for managing the road networks in PNG. This study was focused on mapping existing road networks in the Nebilyer Rural District using RS and GIS techniques. The main purpose of the study is to assess road conditions and types, and to identify missing road links with the objective of creating an up-to-date digital database for road networks within a GIS environment.

Western Highlands Province (WHP) is located in the central highlands of Papua New Guinea at 5° 12' 45.6"and 6° 14' 42.3" south latitude and 144° 47' 8.9" and 144° 31'7.5" east longitude at an altitude between 600 - 4800 m above mean sea level, with a land mass of 4,265 sq. km. The National Highway (Okuk) runs from the north-east of Jiwaka Province through the Western Highlands, linking Southern Highlands and Enga Provinces to the south and west respectively and has a total length of 86.87 km. The provincial roads have a total length of 240.7 km whilst bush walking tracks have a total length of 127.8 km. The road density of the entire province in 2007 was low (0.077 per sq. km) (PNGRIS, 2007), as indicated in Table 1. Some roads are well maintained but majority of roads in the rural areas have not been maintained and conditions have worsened drastically. Most villages are not connected by roads and this affects majority of the rural population with poor accessibility to services.

Table 1: Road category and total length (km)

RD No.	Road Category	Total Length (Km)
1	National road	86.9
2	Provincial road	240.7
3	Walking track	127.8
4	Total	455.3

Source: PNGRIS metadata (2007)

Lack of accessibility to good road network by majority of the rural population in the Nebilyer Rural District has been an ongoing problem. Conditions of roads that were built during the colonial era had grown worse and many are treacherous due to the virtual absence of planned and corrective maintenance. Many villages in the study area are not connected with roads and people still use bush walking to walk to the nearest provincial or national road to catch the available bus service to town to sell produce and fetch goods for their basic needs. Due to lack of a good road network basic government services like health have not reached these areas thereby worsening the general well-being of the people. Curable diseases like malaria, tuberculosis and common skin diseases are prevalent in the area. Many children are denied quality education because of lack of proper learning facilities and non-availability of teachers. This is due to negligence by authorities to maintain a good road network in the area.

2. Study Area with related Environmental Attributes

The study area is the Nebilyer rural district fig1 in Western Highlands Province, which covers an area of 1,004 sq. km. with a population of 29,206 (PNG NSO, 2011). The study area is one of the two sub-districts of Tambul Nebilyer electorate bordering Southern Highlands Province to the southwest and Enga to the northwest. Road transport is the only mode of transportation in the district. Most of the district roads connect to the Highlands Highway that runs through the western corridor of the district. Walking tracks are commonly used by those rural people who do not have road link to their villages to access basic services in town. There is no district headquarters or police station servicing the area. The existing roads have not been maintained over the past decades and conditions have grown worse. The land is very fertile and subsistence agriculture is common and tends to be the only mode of survival. Small holder coffee plantations have been established in certain parts of the district during the colonial era where soils, slope, and rainfall are ideal for the production of such crops. The eastern flank of the study area has low potential because of steep slopes.

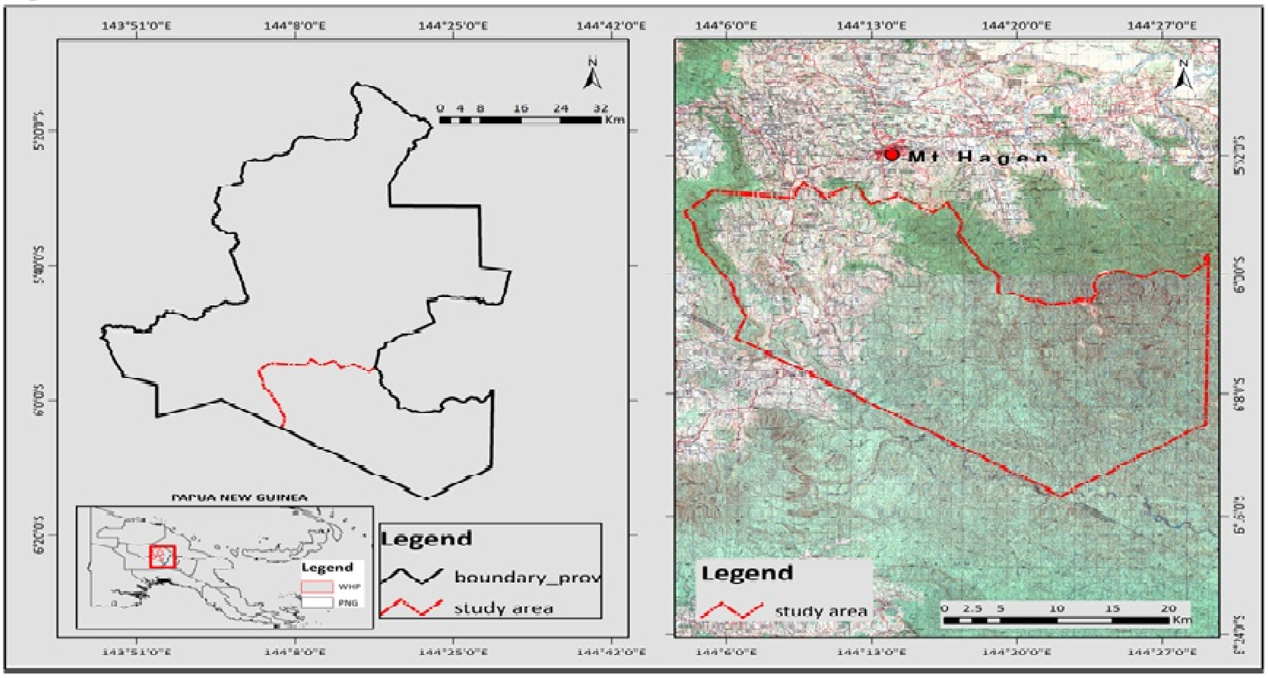


Figure 1: Locality Map of Study Area

Population

The population of the study area and its respective tribal regions is shown in Table 2 and Figure 2. The total population, according to the PNG Statistics Office (2011), was 29, 206 with a male and female population of 14, 800 and 14, 406 respectively. The Ulga tribal region was highly populated with a total population of 7, 382.

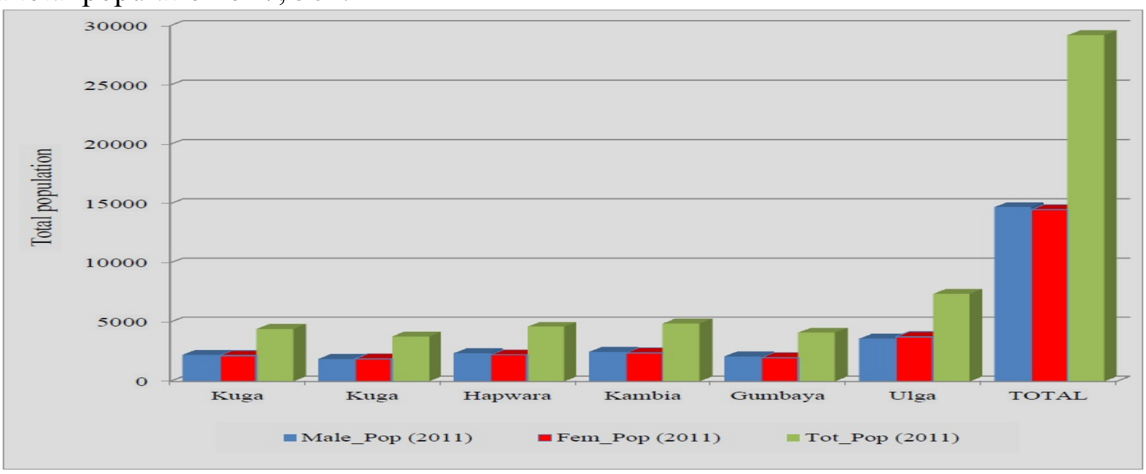


Figure 2: Total population of six tribal regions in 2011 (PNG Statistics Office, 2011)

Table 2: Population Data (PNG Statistics Office, 2011)

Tribal region	Male pop (2011)	Female pop (2011)	Total pop (2011)
Kuga	2241	2183	4424
Kuga	1888	1898	3786
Hapwara	2370	2237	4607
Kambia	2487	2407	4894
Gumbaya	2107	2006	4113
Ulga	3616	3766	7382
TOTAL	14, 709	14, 497	29, 206

Elevation

Elevation is one of the important factors that influence road projects and poses a lot of geotechnical challenges. The elevation factor is an important factor to be considered in any road construction and maintenance activity. Figure 3A illustrates the altitude levels and possible location of each road network passing through. The topography of the study area varies between 659m and 3,829 m. The highest elevation zones (2695 – 3829m) are located on the eastern fringes while the lowest elevation zones (659 - 1336 m) are observed where the road network, villages, coffee farms and government institutions are concentrated. Most villages in the study area are located within an altitudinal range of 1300 m-1800 m, while the upper altitudinal limit of agriculture is around **1,800** m.

Slope

Slope refers to change in height across a surface of an area and is an important factor since it affects land stability. Slope stability assessments should be considered prior to any road projects and appropriate measures should be taken to meet the site specific geotechnical challenges. Slopes range from <1° to >30°. Slope in the study area where villages and roads are concentrated range between 1° and 18°. The areas with >30° slope are located on the eastern flanks as illustrated in Figure 3D.

Landform

Land form refers to the recurring pattern of topography within a landscape (PNGRIS, 2007). Like elevation and slope as discussed previously site suitability assessments of landform should be done prior to any road projects. Land form in the study area (Figure 3B) is comprised of relict fans, fans and foot slopes, mountains and hills. The study area is comprised of fans and foot slopes while the eastern flank is mostly comprised of mountains and hills with weak or no structural control. The landform types within the study region plays different roles in governing and maintaining the stability of roads and conditions so as to avoid any destruction during bad weather. Visualizing the landform coupling with road system can assist in better road planning and management.

Drainage pattern (rivers and streams network)

Drainage patterns of an area should be studied prior to any road project because during high floods, roads and bridges could be affected. The rivers and creeks in the study area are permanent and discharge all year round. The flow direction of the drainage catchment from the map is from north to south. The Nebilyer River, which is the headwater of the Purari River drains from the Mul range and flows through the Nebilyer valley joining the Kaugel River from the west that drains from Mt. Giluwe. The major tributaries of Nebilyer River are Trulg, Tum, Pup and Ukulg Rivers. The river flows in the area are the highest from December to April. Figure 3C illustrates the drainage pattern of the study area.

Soils

Soil type provides very useful background information as required for site investigation, which can be used to validate and assess the suitability of road projects. The soil type influences appropriate engineering designs to construct safe and sustainable road systems. The different soil types in the study area are shown in Figure 3F. According to the analysis, sandy clay covers most of the study area where villages and roads are located followed by clay loam and silt soils. The clay loam is the dominant soil covering the eastern flank of the study area mainly occurring on the mountains and hill sides. The soils are formed from volcanic deposits and are highly suitable for subsistence farming and cash cropping agriculture (especially coffee) in the area as soils contain a lot of organic matter. The upper altitudinal limit of agriculture is around 2,400 meters.

Lithology

The lithology of the study area will help road engineers to apply correct designs and take appropriate measures to build good roads. The study area lies within the Kubor and Mul geological faults and mountains and hills are situated on the eastern and western flanks. The common rock occurrence in the study area as per the GIS analysis of the PNGRIS data (Figure 3E) are fine grained sedimentary, mixed or undifferentiated sedimentary, limestone, mixed or undifferentiated metamorphic, acid to intermediate igneous, pyroclastics and alluvial deposits. The pyroclasticsis rock is primarily composed of volcanic material and occurs in most parts of the study area where villages and roads are situated. The dominant rock types are acid igneous, mixed sedimentary and pyroclastics. Understanding of the rock structures relevant to road existence or construction is of vital importance as engineers can take precautionary measures during construction and maintenance activities so roads can last long.

Climate

The study area is characterized by all year round warm to very warm days. Average annual rainfall varies from 2,500 mm to over 4,000mm in the higher altitudes within the study area and such high rainfall often produces runoff that erodes road surfaces quickly thereby disrupting road stability and condition. Typically, the northwest and southeast trade winds dominate surface wind patterns. The northwest winds are predominant between November and March while April and May are transitional months where the wind starts to shift southerly. The south easterly winds are dominant from June to August with September and October being transitional months when wind is variable. The wettest months of the year are from November to December and January to March (Hanson, et al. 2001), which is common in most parts of the highlands region. The existence and changing pattern of weather types within the study area can be most influential towards road stability. Thus it is a natural process and in one way or another can affect the road systems. Understanding the weather patterns can assist in constructing weather resistant roads.

3. Data and Methodology

3.1 Data Sources

Different data sources (Table 3) and three GIS software (Table 4) were used for the study. Most of the data used were supplied from the archives of the Department of Surveying and Land Studies (DSLS) at the Papua New Guinea University of Technology (PNGUOT).

Table 3: Data layer for the study area

Data Layer for the Study Area	Source	Supplied by
Road, Soil, Lithology, Rainfall, Drainage, Slope, DEM	PNGRIS Meta Data	DSLS-PNGUOT
Population	National Statistics & Census Office	DSLS-PNGUOT
DEM	PNGRIS Meta Data	DSLS-PNGUOT

Landsat Satellite Image	LANDSAT 7	DSLS-PNGUOT
GPS Survey Data	Author	Author
Topographical map	Ryan Gogdon	PJV Geology Department

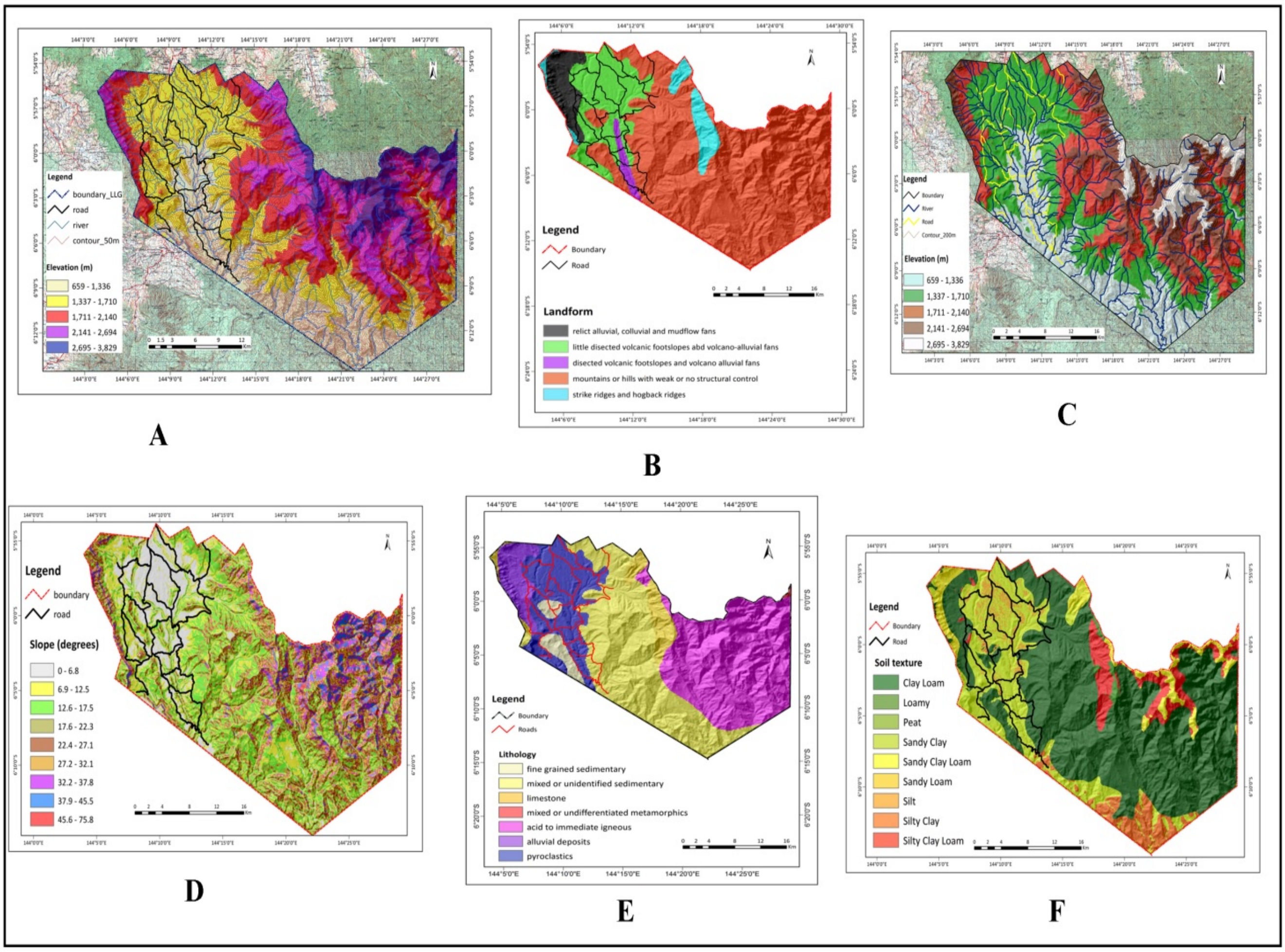


Figure 3: Study area environmental attributes

Table 4: Software used for data processing

Google Earth Pro	Google	Porgera Joint Venture
ArcGIS 10	ERIS	DSLS-PNGUOT
EDRAS Imagine	EDRAS	DSLS-PNGUOT

3.2 Methodology

Two topographical maps of scale 1:100,000 for the study area were obtained from Porgera Joint Venture (PJV) Geology Department. A LANDSAT satellite image of 30 m resolution, Google Earth Pro 2010 and ArcGIS 10 were used for digitising and extracting the road networks in the study area. A hand-held Garmin GPS instrument was used to collect the location of points of the features and map the walking tracks. All spatial data for roads and bridges were processed in ArcGIS. The topographical maps were geo-rectified in ArcGIS software using four control points obtained from the maps and were mosaicked in ERDAS Imagine 8.5 software. The GPS plots for the walking tracks were uploaded in Google Earth Pro for validity checks and later converted in ArcGIS (kml. to layer) using conversion tool in Arc Toolbox. The base map of the area was produced from existing vector data provided by the Department of Surveying and Land Studies at the PNG University of Technology. The road junctions were digitised as points. The community boundaries and roads were digitised as polygons and polylines respectively. The boundaries were calculated in square kilometres and road lengths in kilometres. The attributes of the road were given; road type, length, condition, bridge, etc. Other important topographical features like soil composition, season, slope, lithology, landform, elevation, rainfall, drainage patterns, etc., were investigated based on the understanding of road features. The road density analysis was determined for the study area and the six tribal regions by dividing the road length per unit area using the Gamma Index for Connectivity as expressed in Equation (1). The road network density was determined to explain how dense the road network within each section of study area is.

$$\textbf{Network Density, (ND)} = \frac{L}{A}$$

where L = *total length of network density in km*

A = *total area of network in km*^{2}

Equation ....(1)

The road density results were compared with the road density standard specified by Odaga and Heneveld (1995), which states that road density is high if it is more than 120 m per sq. km, moderate if it is more than 30 m or less than 120 m per sq. km and low if it is less than 30 m per sq. km" (Obafemi et al. 2011). All calculations were performed in ArcGIS for area and road lengths. Moreover, the connectivity of the road network was also evaluated using Beta Index (β) which is a measure of road connectivity in the study area. Beta index of connectivity was developed by Kansky (1963) and adopted by Vinod et al. (2003) and expressed in Equation (2).

$$\textbf{Beta Index, } \beta = \frac{e}{v}$$

where; e = *number of edges (line/arc)*

v = *No of vertex (node)*

Equation ....(2)

The nodes are the number of road junctions and arcs are connections between the nodes as straight lines. Beta Index ranges from 0.0 for network which consists of nodes without any arc through 1.0 and greater where networks are well connected (Vinod et al., 2003). The beta index analysis helped to decide the connectivity level of the roads. The thematic maps of road conditions for the six tribal regions were produced in ArcGIS. The data collection, preparation, integration and analysis were performed in a GIS environment to achieve the study objectives as presented in Figure 4.

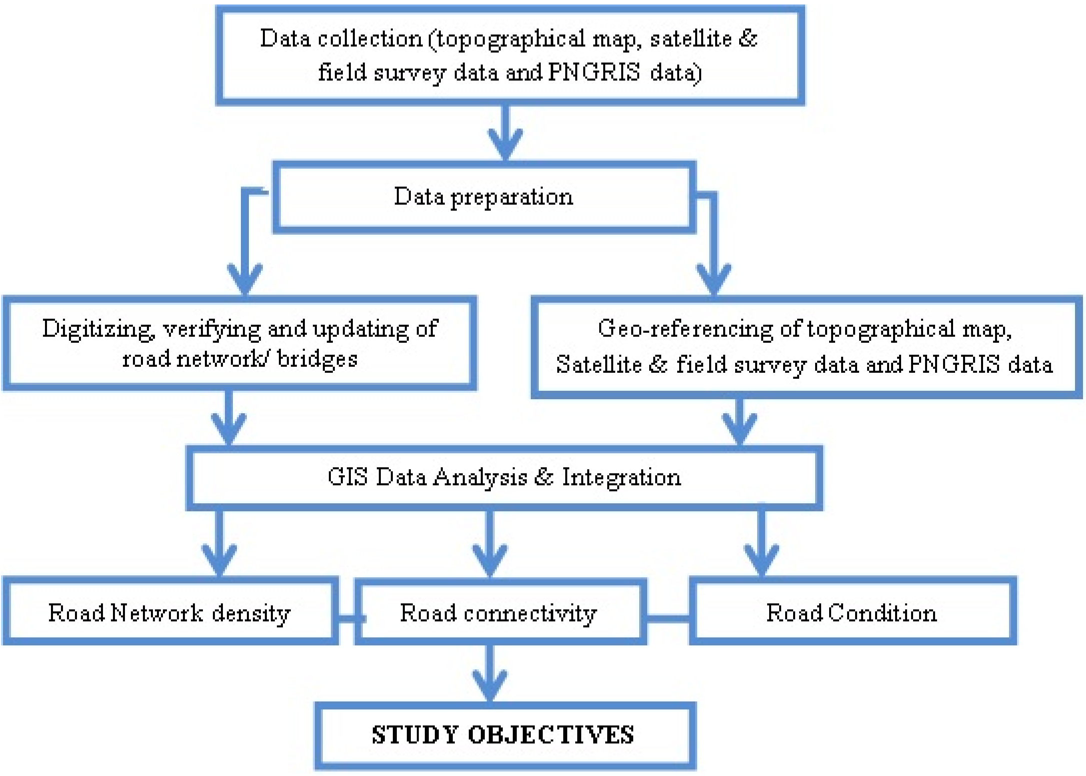


Figure 4: Methodological Flow Chart

4. Results and Discussion

Roads

The road conditions, types and lengths within the study area are presented in Table 5 and illustrated in Figures 5 and 7. It was prepared through extensive integration and analysis as discussed above. The overall summary of the road condition and length is presented in Table 7. The road networks were overlayed with a satellite image as shown in Figure 7. The roads were classified as national, provincial, district or walking track. The conditions of the roads were classified as good, bad and very bad. 'Good' was used for roads that were sealed or gravelled and well maintained which were currently in use, 'Bad' for those roads that were ill-maintained and not easily accessed by vehicles during bad weather and 'Very bad' for those roads that were not maintained, conditions have grown worse and were not accessed by vehicles. Bush walking tracks were identified using same classification. The information of the road types and condition were collected during a field survey conducted during the first half of 2016. The GPS track records for roads were uploaded in Google Pro, verified and then converted to shape file (polyline) in ArcGIS. Spatial analyses were done in ArcGIS using spatial query whereby the fields like road condition and road types were examined and converted to a thematic map (Figure 7). As can be seen from the analysis in Table 7, total length of the national road was 27.4 km and represents about 15.8% of 173 km total length of the road. The total length of the district roads was 76.2 km and represents about 44.1% while the total length of the bush walking tracks was 69.4 km which represent about 40.1%. There were no provincial roads in the study area. The longest bush walking track is from Paraka village to Gome village (WT11) with 12.1km while others ranged between length of 3.5 m and 9.1 km. The analysis showed that the villages located within Gome area are very remote with no access to roads, schools and health facilities. The road condition assessment results in Table 7 and Figure 7 showed that the total length of a good road was 31.5 km, which is 18.2% and was partly due to the well maintained

Highlands Highway that runs through the centre of the study area. The length of bad roads was 58.0 km, which was comprised of 33.5% while very bad roads comprised 83.4 km which represented 48.2%. The total length of the bush walking tracks was 69.4 km. The walking tracks are still being used by a larger portion of the rural population. Most of the district roads were not maintained. Only a small portion of the district road from Wapip to Dumukona and the section of the Highlands Highway between Togoba and Kaugel River were well maintained.

Table 5: Description of national and provincial roads

ROAD_ID	Road_Type	Road_Name	Condition	Rd_Leng (Km)
NH1	National Road	Togoba_Kaugel River	Good	27.3
DR1	Distrcit Road	Tabaga_Keranum	Bad	4.13
DR2	Distrcit Road	Tega_TimbkaKailga	Bad	8.85
DR3	Distrcit Road	Kuga_Nebilyer River	Bad/Vey bad	13.33
DR4	District Road	Dumakona_Paraka	Bad	26.17
DR5	District Road	Wapip_Dumakona	Good	4.19
DR6	Distrcit Road	Dumakona_Koibuga	Bad	10.51
DR7	Distrcit Road	Togoba_Walter	Bad	9.02

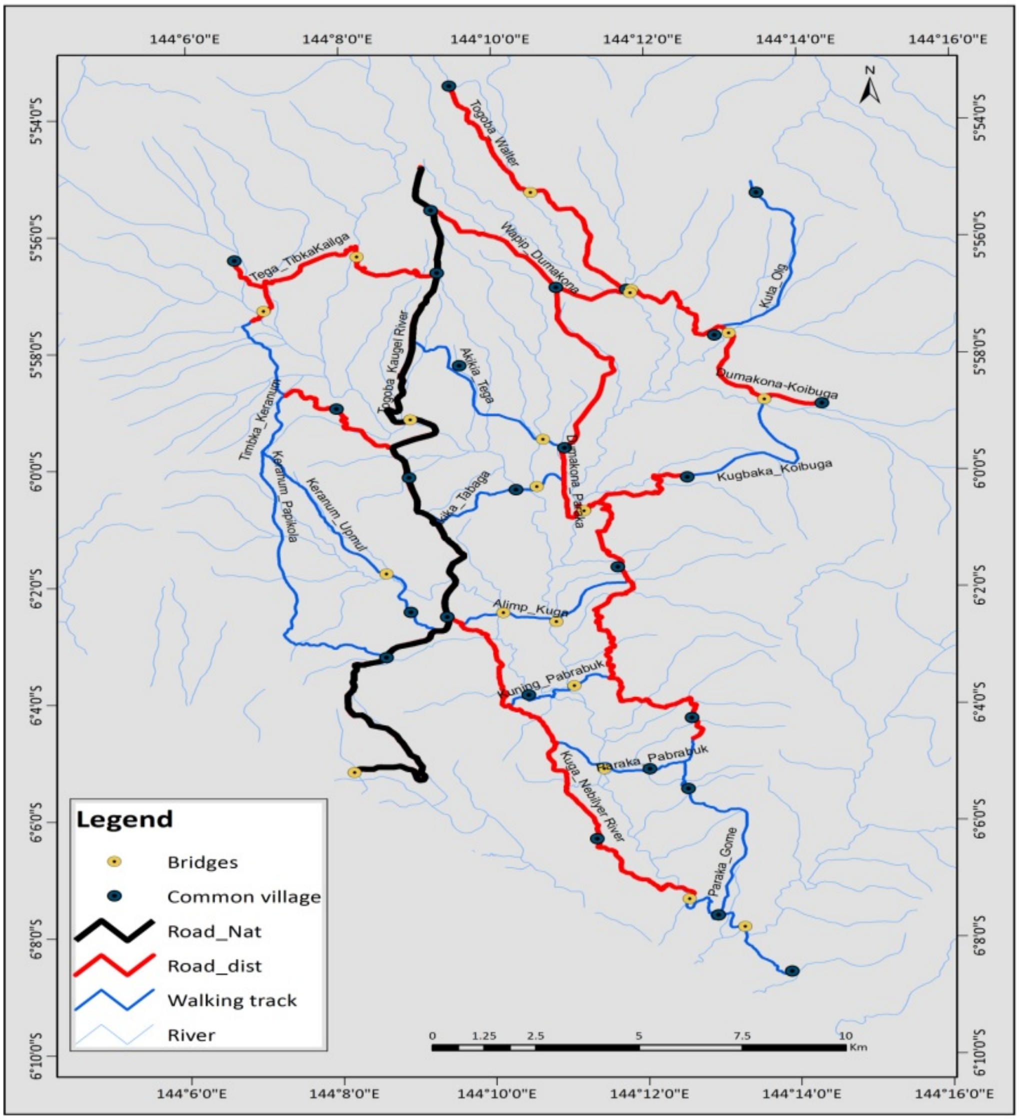


Figure 5: Road network in the study area

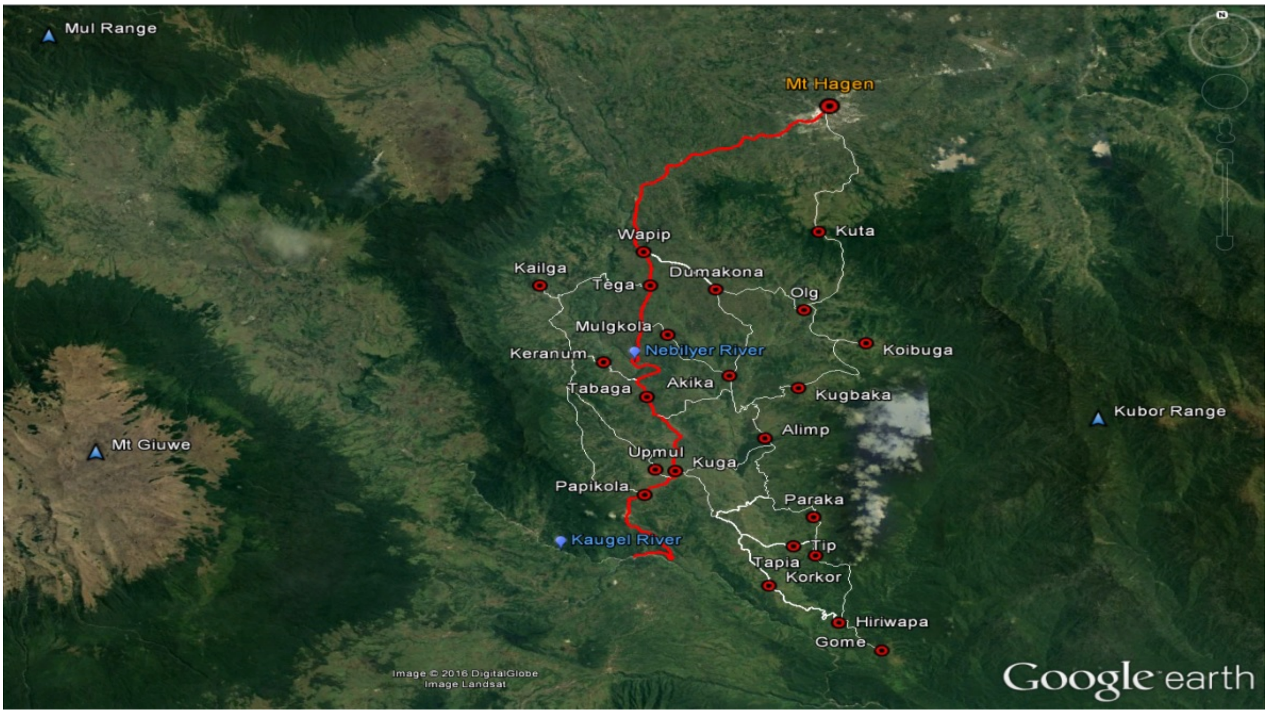


Figure 6: Satellite map with overlayed road network within the study area (**Source**: Google Earth)

Table 6:Walking tracks

ROAD_ID	Road_Type	Road_Name	Condition	Rd_Leng (Km)
WT1	Walking track	Paraka_Pabrabuk	Very bad	4.53
WT2	Walking track	Kuning_ Pabarabuk	Very bad	3.47
WT3	Walking track	Alimp_Kuga	Very bad	5.00
WT4	Walking track	Kugbaga_Koibuga	Very bad	5.56
WT5	Walking track	Akika _Tabaga	Very bad	4.46
WT6	Walking track	Akika_Tega	Very bad	5.94
WT7	Walking track	Keranum_Paipkola	Very bad	9.12
WT8	Walking track	Keranum_Upmul	Very bad	7.79
WT9	Walking track	Timbka_Keranum	Very bad	5.11
WT10	Walking track	Kuta_Olg	Very bad	6.24
WT11	Walking track	Paraka_Gome	Very bad	12.13

Table 7: Present road condition and length (km)

Condition	**Total length (Km)**	**Percentage (%)**
Good	31.5	18.2
Bad	58.1	33.6
Very bad	83.4	48.2
Total	173	100
Type	Total length (Km)	Percentage (%)
National	27.4	15.8
Provincial	0	0
District	76.2	44.1
Bush walking tracks	69.4	40.1
Total	173.0	100

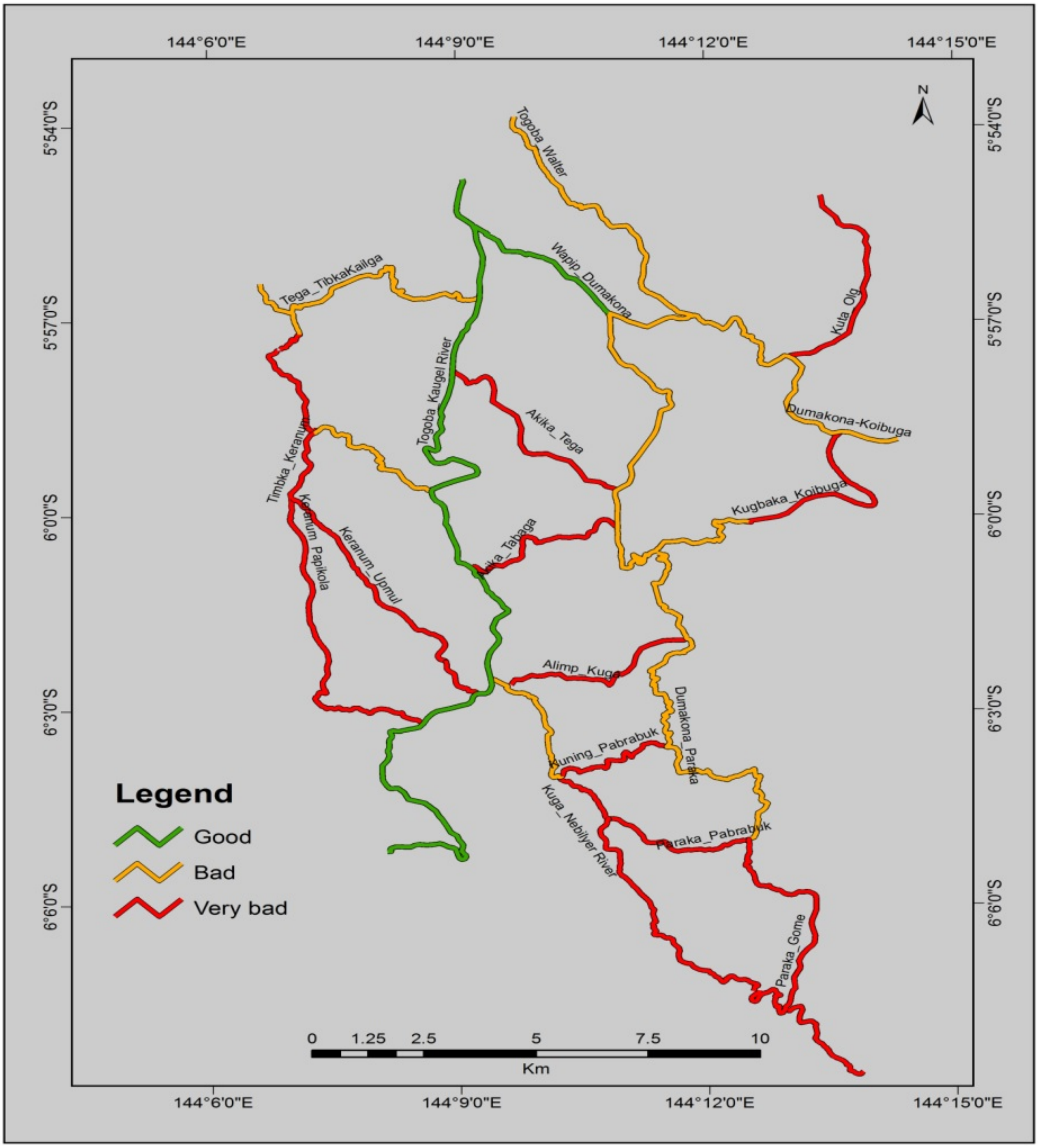


Figure 7: Thematic map showing road conditions

Bridges

Bridges located in the study area are permanent bailey bridges, swing footbridges and traditional footbridges made of wooden materials. The bridges were classified as 'Good' for bridges that are safe for use and 'Bad' for those bridges that are in dire need of maintenance, and 'Very bad' for those bridges that are unsafe for use. A total of 11 bailey bridges were established and lengths range between 8 m to 30 m. As shown in Table 8 and Figure 9, five of the bridges are in good condition, four are in 'Bad' condition and two are in 'Very bad' condition and unsafe for use. The two longest bailey bridges are located at Kunia and Kaugel Rivers with an estimated length of 25m-30m each. The longest footbridge is located at the Tum River on the eastern flank of the district.

Table 8: Bridge types and conditions

River_name	Bridge_ID	River_length (m)	Bridge_type	Condition
Turulg	BB1	10-15	Bailey	Good
Kunia	BB2	25-30	Bailey	Bad
Kend	BB3	8-10	Bailey	Very bad
Walter	BB4	8-10	Bailey	Bad
Turulg	BB5	8-10	Bailyey	Bad
Nebilyer	BB6	10-15	Bailey	Very bad
Nebilyer	BB7	10-15	Bailey	Good
Kaugel	BB8	25-30	Bailey	Good
Ukulg	BB9	10-15	Bailey	Bad
Pup	BB10	10-15	Bailey	Good
Nebilyer	BB11	10-15	Bailey	Good
Tum	FT1	25-30	Footbridge	Good
Nebilyer	FT2	10-15	Footbridge	Good
Nebilyer	FT3	10-15	Footbridge	Very bad
Nebilyer	FT4	10-15	Footbridge	Very bad
Kend	TB1	10-15	Traditional	Very bad
Nebilyer	TB2	10-15	Traditional	Bad
Pup	TB3	10-15	Traditional	Bad
Wemb	TB4	10-13	Traditional	Bad

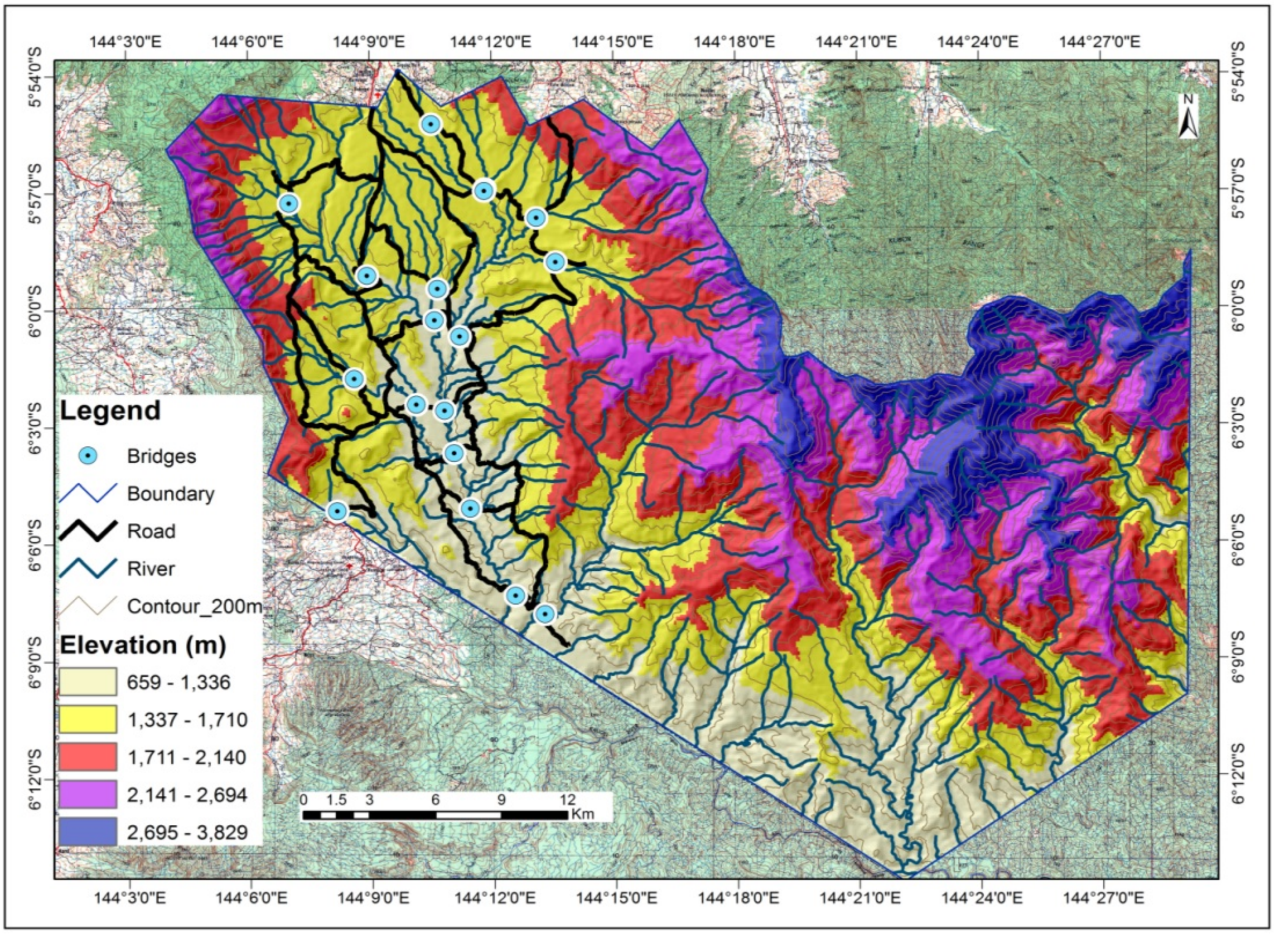
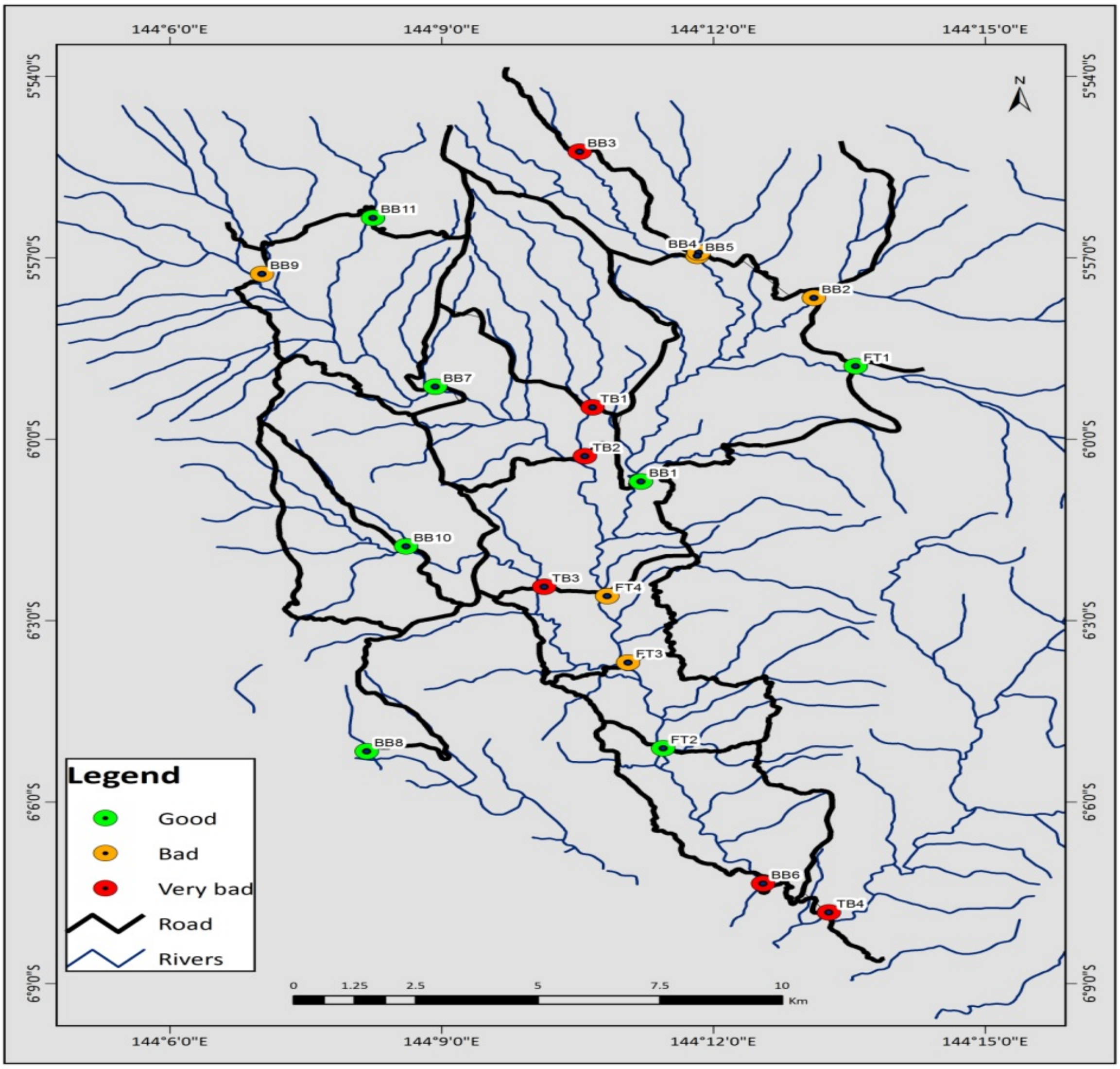


Figure 8: Map showing locality of bridges compared with drainage and terrain factor



***BB** = Bailey bridge **FF** = Footbridge **TB** = Traditional footbridge*

Figure 9: Map showing conditions of bridges

Determination of road density

The road density of the six tribal regions and the study area was determined by relating the total length of road per unit area. The total length in kilometres of the roads and the area in square kilometres of the tribal regions were calculated in ArcGIS 10. The formula used to calculate the road density is shown in Equation (1), a reminder of which is as follows:

$$\text{Network Density, (ND)} = \frac{L}{A}$$

where L = *total length of network density in km*

A = *total area of network in km*^{2}

Equation ....(1)

The road densities are presented in Table 9 and the thematic map is presented in Figure 10. Road density for each region and the overall study area was compared with the standard road density. The GIS analysis of the road densities of the six tribal regions indicates that the densities range from medium to high when compared with the standard (Odaga and Heneveld, 2009). Road densities are high for Kuga, Kulga, Ulga and Gumbaya regions and medium for Kambia and Hapwara regions. The overall road density for the study area is 103 m per sq. km. which is medium. This may be attributed to the roads evenly distributed running parallel to each other in the study area. The road density of W.H.P. was formerly 77 m per sq. km (PNGRIS, 2007). The Kubor Range which is located on the eastern flank of the district with high elevation, slopes and rugged mountainous terrains is also studied because of its important vast natural resources. The local residents use the area for hunting and collecting bush materials for building traditional houses and source traditional medicine.

Table 9: Road density for seven (7) tribal regions

Tribal region	Total road length (km)	Total area (km^2)	Road Density (km^{-1})	Road density (m^{-1})	Classification
Hapwara	4.9	62.2	0.08	79	Medium
Kulga	19.7	49.0	0.40	402	High
Ulga	30.2	53.2	0.57	568	High
Gumbaya	17.4	128.6	0.14	135	High
Kambia	12.1	158.6	0.08	76	Medium
Kuga	19.3	53.3	0.36	362	High
Kubor	0	497	0	0	Nil
Study area	103.6	1001.9	0.103	103	Medium
WHP	327.5	4265	0.077	77	Medium

Road Densities Standard (Odaga and Heneveld, 1995): High; >120m/km^{-1}, Medium; >30 m and < 120m/km^{-1}, Low; < 30 m/km^{-1}

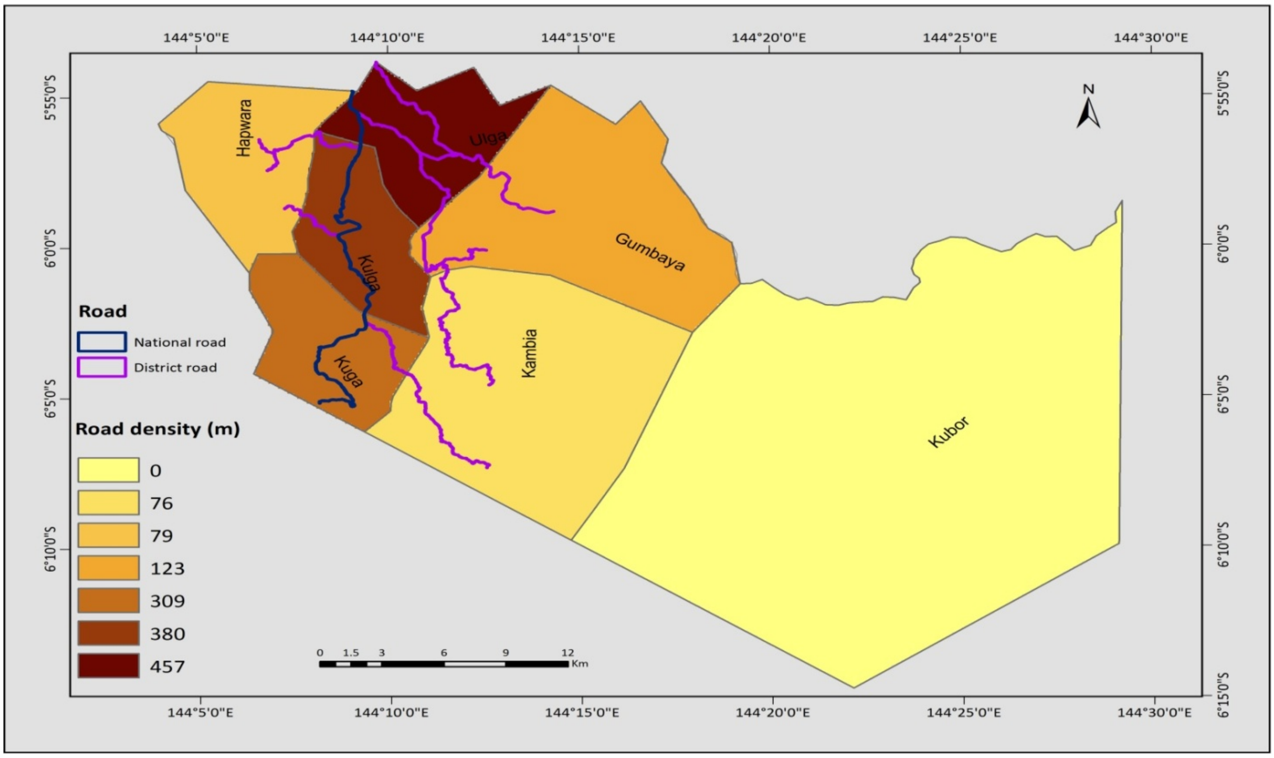


Figure 10: Thematic map showing road density for the six tribal regions

The road connectivity level

Road connectivity in the study area was assessed using a Beta (β) connectivity index whereby total number of road line or arcs is divided by the number of intersections or nodes and expressed in Equation (2), a reminder of which is as follows:

$$\textbf{Beta Index, } \beta = \frac{e}{v}$$

where; e = *number of edges (line/arc)*
v = *No of vertex (node)*

Equation ....(2)

In the case of this study, Arcs = 16, Nodes = 8, therefore the beta index was 2. The map of road intersection is shown in Figure 11. The result from the beta index shows that the connectivity of the road network is medium to high in the study area. This could be correlated with the road density, which was also medium to high. The high connectivity may be attributed to the bridges constructed for the main rivers connecting the tribal regions in the study area. District roads are connected to the tribal regions but a lot of people use walking tracks because they live few kilometres away from the main roads. Although the analysis results are positive there is a need for roads to be evenly distributed as the majority of the rural population who live in the outer parts of the district do not have road connection to their villages and they still use walking tracks to access services which is very unreliable. An evenly distributed road network is required in the area which will help deliver the needed services and improve the general living standards of the people.

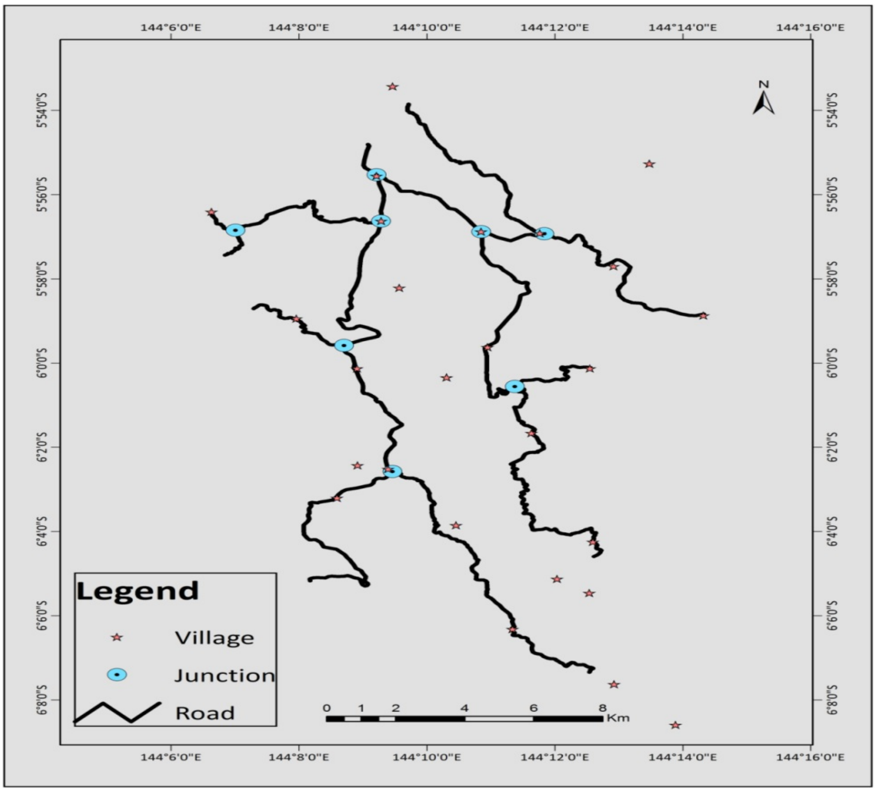


Figure 11: Road junctions in the study area

5. Conclusion

Road network is an important infrastructure in the rural areas of PNG. It allows connectivity and movement of people and goods from rural to urban areas and other places. Therefore, it is important to keep the roads in good condition all the time. The efficiency of using RS and GIS in extraction and analysis of road network is clearly evident in this study. The technique was used to assess the road network in Nebilyer Rural District in terms of the present condition of roads and bridges, types, road density and connectivity. Furthermore, the two techniques were employed to assess bridges in terms of conditions and existence. It may be concluded from this study that the road connectivity was moderate to high, while road density was also moderate to high. However, the conditions of the majority of the district roads are bad or very bad and need urgent attention. The National Highway (NH1) is in good condition and is well maintained including a small section of the district road. Two bailey bridges are in very bad condition. Only two footbridges are in good condition while the rest are either in bad or very bad condition. Additionally, the traditional bridges are unsafe and are categorised as in very bad condition. Those bridges in bad or very bad condition need urgent attention regardless of their types as safety of people and vehicles using the bridges is of paramount importance. Road infrastructure mapping developed under GIS environment has efficiency in monitoring, management, planning and subsequent development of the road network in the Nebilyer Rural District, and could be utilised in decision making processes. Therefore, the management authorities of the area are encouraged to use GIS and RS as integrated tools to manage the road network and other infrastructures in the area.

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