Geospatial Technology for Hydropower Site Selection and Rural Electrification Supply-Demand Analysis - A Case Study in the Yabem/Mape Rural of Finschhafen District, Papua New Guinea

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ABSTRACT

The pathways to increase rural electrification supply through renewable energy, off-grid, grid, and hybrid systems still need assessment and evaluation since most rural places, especially in developing countries, are isolated and located in rugged terrain zones with less availability of essential services. Some rural areas or communities in Papua New Guinea (PNG) are challenging to reach and interact with regarding infrastructure development. These are due to a lack of road infrastructure, unsolved customary land issues, the community's minimal willingness to support and participate in infrastructure development, low income, etc. Such challenging factors need comparative evaluation and monitoring for rural electrification development following the stated PNG national pillars to increase electrification in rural places. Data acquisition and planning is one approach if it means expanding rural electrification. The current study approach aims to identify and develop pathways that can bridge and enhance rural electrification development. The holistic approach to assessment was carried out. The researchers use geospatial technology coupled with electric power technology to evaluate future hydropower potential, assess power supply demand, and assess the economic situation of each household in the Mape catchment region of the Finschhafen district. The researchers used Soil, Water Assessment Tool (SWAT) coupling with QGIS involved in flow discharge estimation, and Shuttle RADAR Topographic Mission (SRTM) Digital Elevation Model (DEM) for potential head and site identification within the study region. Researchers conducted a field survey on the sites, verifying all possible river networks. Environmental factors and community responses were further investigated and analyzed to select the most potential sites for hydropower development. The researchers conducted household socio-economic surveys to asses power supply and demand, including sustainability factors. The household economic situation is evaluated, and the results are presented for decision-making. Twenty-nine (29) most feasible potential hydropower sites were selected. The amount of hydropower at a few places was found to be reasonable for supply to nearby communities in line with their respective energy demand and level of economic viability.

Keywords: Rural Electrification, Hydro Power, Geospatial, SWAT Model, Energy Demand, Discharge.

1. INTRODUCTION

Electricity is much needed by industries, business houses, farmers, and the general population worldwide for better living and incredibly sustainable development. Population, business houses, and industries connected to electricity around the world are within urban towns and primarily utilize fuel-powered electricity grid as the primary source of electricity with other more contributing advanced hybrid systems. Currently, more new and advanced technology is evolving as an alternative to produce electricity apart from fuel-powered grid-connected electricity.

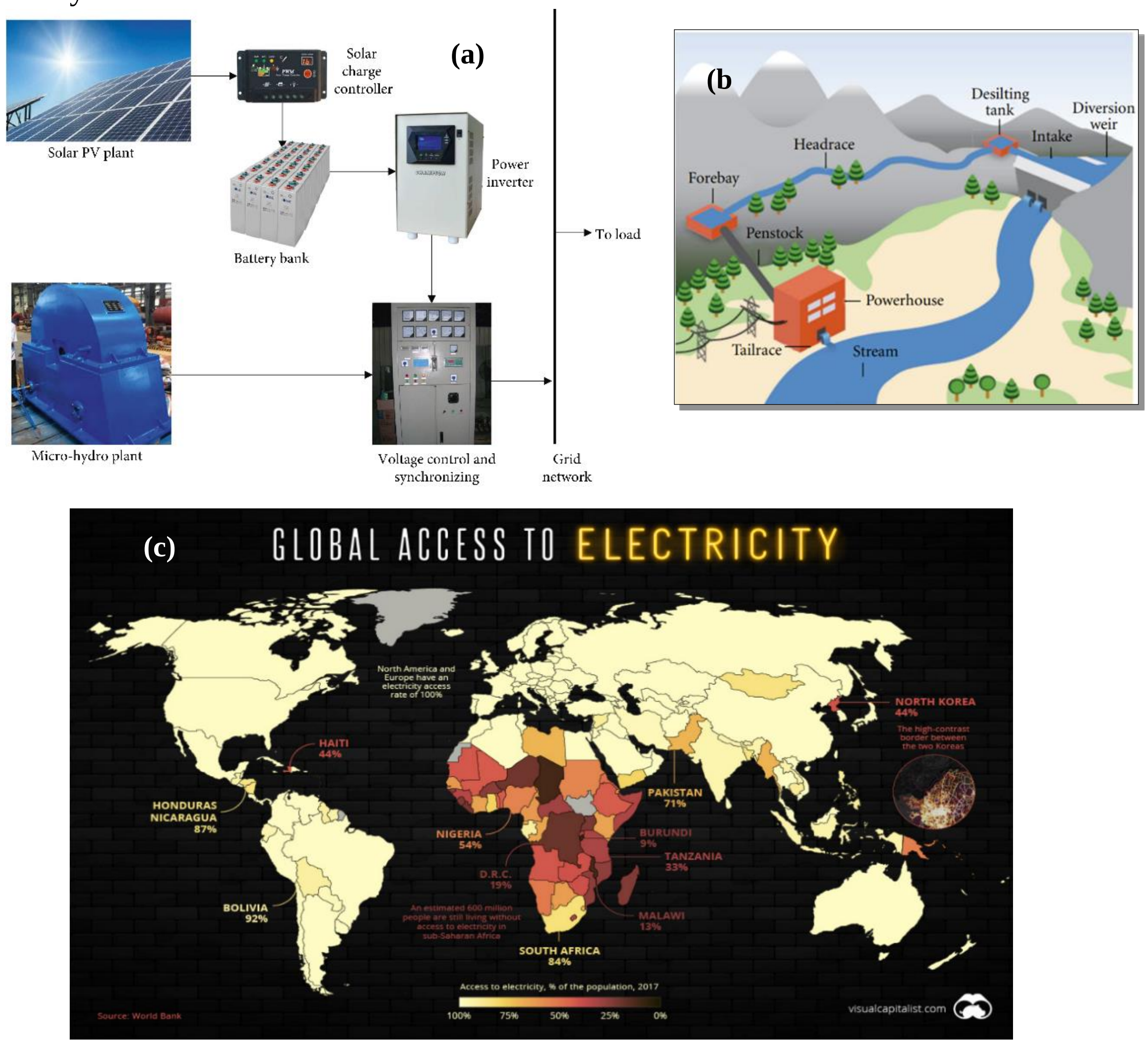

Figure 1. a. Hybrid micro-hydro and solar photovoltaic system for rural areas of Central Java, Indonesia (Source: Syahputra. R and Soesanti. I 2020), b. Run-of-river hydropower schematic diagram (Source: IPCC, 2012, c. The population level of access to Electricity (Source: World Bank, 2017).

The recommended technology now is to use renewable energy, such as; solar, hydro, wind, etc., to assist in producing electricity. Renewable energy has vast advantages in reducing fossil fuel burning and is readily available. Plans are put forward to connect and increase electricity to most remote areas by utilizing such technology with a hybrid connection system. The grid is also included (Refer to Figure 1 a).
By referring to Figure 1 (c), it can be observed that PNG is one of the countries among others that lacks a sufficient supply of electricity. The Energy shortages and supply disruptions, and high costs remain serious obstacles to economic activity and growth in PNG (National Energy Policy (NEP) 2017 – 2027).

Kaur and Segal (2016) highlighted that electrification production and supply to remote places within PNG is highly controlled and constrained by long-distance electricity transmission lines and poles distribution, very complex topography to run such transmission lines and poles, involve high cost, land issues, low population density, education level is deficient, low load density and low revenues. In addition, more market infrastructure must be needed to attract private investors to come in for power production and supply. Therefore, the rate and percentage of electricity supply in PNG are shallow. One of PNG's national pillars is increasing electricity in rural areas. It is stated that by 2030 PNG should reach up to 70% of electricity connected throughout the country, including rural areas (NEP 2017 – 2027). As such, the Government goal and target have been set; there has been nothing too little done or achieved so far up to the present.

The current research focused on identifying potential sites for mini (run-of-river) to extensive hydropower dam systems, including assessment of nearby villages' household demand in the Mape catchment of Yabem/Mape Local Level Government (LLG), Finschhafen district, Papua New Guinea. Run-of-river hydropower potentials were evaluated in this current research to provide an alternative to rural electrification schemes with other sources of electricity. Figure 1 (b) illustrates the run-of-river hydro infrastructure planning.

The current research is a one-off step among others to seek pathways for rural electrification. More geographical parameters, including socio-economic parameters, have been evaluated for hydro potential, including load demand assessment. The hydrological analysis of a particular catchment is very much needed to assess hydropower potential (Sammartano et al., 2019). In the present study, the catchment flow discharge and or hydrological processes of a catchment zone were estimated using SWAT Model (Zhou et al., 2014; Strauch et al., 2012; Cüceloğlu et al., 2021). Within different river reaches in the catchment zone, the SWAT model was employed to specify, delineate and extract every individual sub-catchment and simulate the flow discharge using specific required input data. The current study approach was adapted from many researchers worldwide to establish solutions for rural electrification. Thin et al. (2020) carried out a project on estimating run-of-river hydropower potential in the Myitnge River basin by integrating GIS and SWAT model. Dilnesa (2022) involved GIS and SWAT model hydrological analysis in identifying potential hydropower sites of the Temcha watershed. Sammartano et al. (2019) evaluated and identified in their study the potential locations for the run-of-river hydropower plants utilizing GIS tools with the application of the SWAT model in the Taw at Umberleigh River basin in South West England. Every geographical data integration and analysis was carried out within the SWAT Model platform, the ArcGIS, and QGIS plugin. The focus of the current research is to seek pathways to rural electrification. The Objectives of the research are to; "1. Evaluate flow discharge within the catchment region by utilizing SWAT model and SWAT Calibration and Uncertainty Programs (SWAT-CUP) algorithm, 2. Evaluate potential head in meters (m), 3. Calculate hydropower potential in Mega Watt Hour (MWh), 4. Evaluate communities' socio-economic strength, 5. Calculate energy load demand".

2. STUDY SITES AND RESEARCH METHODOLOGY

The study area is the Mape River catchment in the Yabem/Mape LLG of Finschhafen district, Papua New Guinea. According to PNG Bulletin (2022), the Yabem/Mape LLG will shortly be split into two (2) to be named Mape LLG and Yabem LLG. The catchment occupies 432.10 square kilometers of land area, and according to the 2011 census and current field survey data, the total population within the catchment region is approximately 7621.

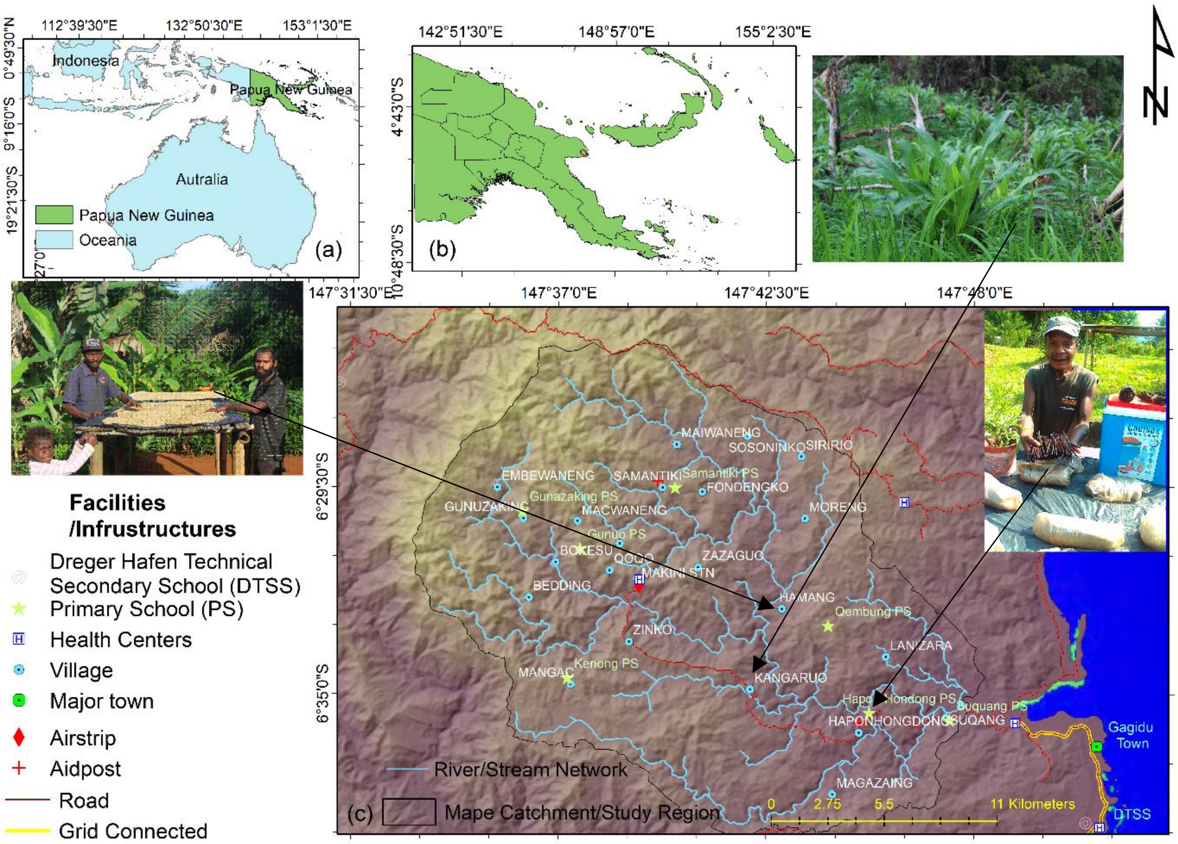

Figure 2: Study Area Locality; a. parts of Oceania, b. country PNG, c. Study area

The catchment region comprises seven primary schools, 27 villages or rural places where a cluster of human habitation and community exist, one airstrip, two aid posts, and one sub-Health Center. Few places or villages and facilities are connected by road. The catchment region does not have any continuous and genuine electricity supply from sources like the PNG power grid, hydropower, or other forms of energy. Refer to Figure two (2) for the study area locality map. The outlet of the Mape River is towards the mini town known as Gagidu station. The significant tribute for the Mape River at the down catchment region is Ziqong, Gao, Uwac, and Gonowo Rivers. The typical cash crop grown within the catchment region is vanilla, coffee, peanut, rice, cocoa, and Tabaco. The region's topography is mostly mountainous and very complex and made up of many small creeks. The most common land cover within the study region is forested land. The location of the study region is within 147^0 33’ 00’’E, 147^0 50’00” E, and 6^0 24’ 00” S, 6^0 38’ 00” S.

2.1 Data Preparation and Inputs

Four (4) most common data types or inputs were involved in running SWAT hydrological modeling using QSWAT, the QGIS. 3.16 plugin. "1. Topographical data (DEM), 2. Land Use data, 3. Soil type Data, and 3. Historical time series weather data". Refer to Figure 3 a, b, c, and d for spatial data used in the QSWAT. The DEM data was prepared from SRTM that was freely downloaded from the United State Geological Survey (USGS) website at 30-meter spatial resolution. The DEM data creates different layers in QSWAT to assist stream flow simulation and stream network delineation. The soil map shape file format was acquired from the Food and Agricultural Organization/ United Nations Educational, Scientific and Cultural Organization (FAO/UNESCO) soil map of the world (FAO, 1999, 1974, 1971-1981, 1995, 2003). The ArcGIS analysis tools were utilized to prepare and extract the FOA soil map for the Mape catchment region. PNG Geobook's (2008) soil map was integrated with the FAO soil map by regrouping and reclassifying to meet the soil code in the SWAT model database system. The land use land cover map of the study region was prepared from a 30-meter spatial resolution Landsat 8 Operational Land Imager (OLI) that was freely downloaded from USGS earth explorer. A minimum of four (4) land cover types were identified and classified using ERDAS Imagine 8.5 and prepared to suit the SWAT model input code. As discussed above, the weather data are the critical input with other data to estimate catchment flow at each reaches. The data was obtained from three (3) different sources and were reviewed and refined to select for years ranging from 2000 to 2022. The sources are; National Centers for Environmental Prediction (NCEP), NOAAs National Center for Environment and Near Earth Object (NEO), and the National Aeronautics and Space Administration (NASA) Earth Observation. The historical weather data in the present study contains daily and monthly precipitation data, temperature, solar, wind, and relative humidity. The historical weather data as described has been obtained for the whole of country PNG, and then later, several stations for the study region alone have been extracted and prepared for SWAT input. DEM was used to identify each location of the potential effective head along the river network, including river/stream network delineation. The QSWAT GIS analysis tool was employed to estimate the flow discharge within the catchment region. Refer flow chart in Figure 5 for a clear understanding of the data used.

2.2. Hydro Power Potential Estimation

In the present study, the river flow (Q) in m^3/s for each reaches or river network was estimated from SWAT hydrological modeling. The head (*H*) was extracted for each location along the river network using DEM as input, and stream network point features were overlaid to extract head values. From there, the drop head (*He*) was calculated for each specific location. The turbine efficiency was also considered in the present study. The river flow (Q), the effective head (*He*), and the efficiency of the turbine (η) are the main parameters in determining hydropower potential (Sammartano et al., 2019 and Sekac et al., 2017). In the present study, the hydropower potential at each selected location was calculated using the following equation:

$$P = \rho.g.Q.H_e.\eta$$

where, 'P' is power potential in Watts, 'ρ' is the density of water which is 1000 kg/m^3, 'g' is the acceleration due to gravitational potential, the constant of 9.81 m/s^2 was used, 'Q' is the daily river discharge in m^3/s, 'H_e' is the effective head in meters between inlet and outlet and finally ‘η’ is the turbine efficiency of the hydropower plant. In the present study, the generated electric power has been estimated by setting the turbine efficiency ‘η’ equal to 1 (Sammartano et al., (2019) and Sekac et al., (2017). Refer to Figure 5 for a better understanding of the method.

2.3 Effective Head Points Specification and Selection

The DEM of 30-meter spatial resolution was used to prepare and prioritize the river/stream network within the catchment region following the flow direction and accumulation computation in ArcGIS.

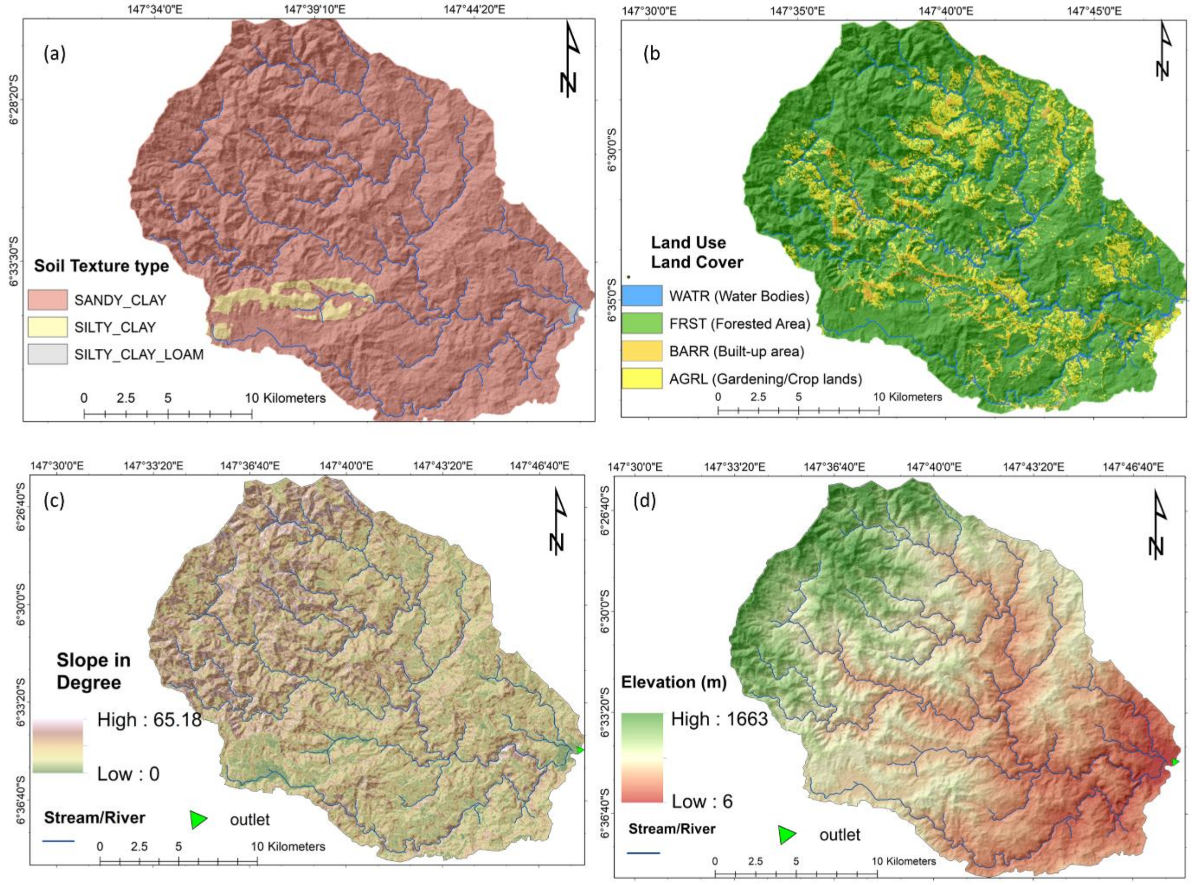

Figure 3: SWAT input Spatial data; a. Soil Texture, b. Land Use Land Cover, c. Slope, d. Elevation.

The threshold assigned to specify the stream/river network was 3000. Field observations were conducted to validate all river networks (Figures 4 and 7b). The slope was prepared using DEM for close visualization and point head specifications within the catchment zone. Refer to Figures 3 c and d to understand the DEM and slope utilized in the study. Identifying potential sites for hydropower development within the catchment region requires calculating and estimating effective heads *(He).* Selecting the most feasible potential sites requires the criteria linked to hydrological restrictions, topographical differences, environmental aspects, and proximity were all considered (Kouadio et al., 2022). More importantly, the field observations

data. In the present study, the research team visited several places within the Mape catchment region (refer to Figures 4 and 7) to collect data and map out potential locations where small to large hydro dams can be constructed. The team uses a GPS tool, questionnaire form, digital flow meter, and DJI Phantom 4 drone as a means of data collection.
Figure 4 a to j and Figure 7b illustrates several locations where field observations and data collection were made. From the idea developed from field observation, including the set criteria listed below, the feasible potential sites were selected at each location. These data were used to calculate the effective head (*He*) in meters (m) between the intake (weir) and turbine (powerhouse/outlet). Refer to Figure 5 for the methods used.

The criteria used for potential site selections with the help of field observation conducted:

1. The allowable minimum horizontal distance or the separation between intake and turbine should be not less than 500 meters (Kumar et al., 2010), (Tarife et al., 2017). Alternatively, between 200 m to 300 meters should be considered at a closer distance upon one condition: if the site is possibly evaluated as for large hydro Dam (Possible presence of a very high steep slope with a high head). The vertical elevation difference (Effective head) should be 20 m and above (Jason et al., 2017). However, since flow also decides the amount of power at each effective head, the flow was considered along with it.
2. The flow accumulation of 3000 and above pixels is required if the potential sites are to be selected.
3. The stream bed slope between 0.2 – 3 degree are to be considered for potential site selection, and from the location selected, there must be a steep slope at the surrounding and downstream to the next outlet. (Kusre et al., 2010).
4. The nearby topography from the selected sites is to be considered feasible for runoff of the river hydropower infrastructures layout down to the next proposed outlet.
5. The selected site must be close to the vehicle access road.
6. The site selected must be in close proximity to the nearby community and existing facilities

2.4 Hydrological Modelling and Flow Estimation

The current study involves the application of SWAT within the QGIS plugin, generally term as QSWAT, to asses and investigates the availability of water resources within the catchment zone, including assessing river or stream potential possible for hydropower site selection. According to Arnold et al. (1993, 1998), the SWAT model is a conceptual, semi-distributed, physical-based hydrologic model and involves readily available input data that enables users to study long-term impacts. The model was developed by the United States Department of Agriculture (USDA) purposely for sediments and agricultural yield quantification within the catchment region and including water management practices through simulation processes over a long period (Sammartano et al., 2019). The SWAT model requires a topographical map, changing soil-land use maps, including historical series of weather data as an input for simulation (Neitsch et al., 2005, 2011). The model identifies and delineates the stream network and sub-basins, having the mentioned data as input. Within the study region, 11 sub-basins were created based on each stream order network (Refer to Figure 7b). The sub-basins were then further divided by model into Hydrological Response Units (HRUs). The HRUs are understood as a spatial combination of changing soil, land use, and topography that forms the smallest unit in the SWAT model that helps describes heterogeneity combination pattern within a watershed region (Bista et al., 2021; Kouadio et al., 2022), and Anoh et al., 2017). The spatial datasets utilized in the SWAT model for flow simulation are presented in Figure 3. a, b, c, and d. The weather datasets were inputted into the SWAT model as non-spatial data. Refer to Figure 5 for the flow chart diagram to aid understanding. After the creation of HRUs, the weather data sets were inputted into the model as CSV/txt files with a defined station in SWAT readable format. For each HRU, the flow and runoff are computed and generated at each sub-catchment zone.

2.5 Model Performance Evaluation

Model performance evaluation is the process in which the performance and feasibility of the SWAT model are tested to check predictive quality and capability (Vilaysane et al., 2015). Refer to Figure 5. In this process, the model parameters are adjusted until the simulated flow output matches the observed flow as closely as possible (Pandey et al., 2015). In the present study, the SWAT model has been calibrated and validated using the SWAT-CUP software package by employing its available algorithmic tool, ' Sequential Uncertainty Fitting' (SUFI-2) (Abbaspour et al., 2018). A maximum of 10 sensitivity parameters (CN2, ALPHA_BF, GW_DELAY, GWQMN, ESCO, OV_N, CH_N2, RCHRG_DP and GW_REVAP, SOIL_AWC) were identified and selected, and the calibration and validation process was conducted. The model calibration and validation process was conducted using three years of the data record (2020, 2021, and 2022) on a monthly basis. Calibration was carried out from the month of August 2020 to August 2021, and Validation was carried out from August 2021 to March 2022. The model performance was evaluated within three (3) suitable locations where field flow measurements data were collected (Refer to Figures 4 and 7b). The sites were named; Mape_2, Ziqong_7, and Gonovo_6. The model performance was evaluated by using two (2) most commonly used indices such as the coefficient of determination (Correlation coefficient - R^2) and the Nash-Sutcliffe efficiency (NSE) (Nash & Sutcliffe, 1970). According to Santhi et al. (2001) and Coffey et al. (2004), the R^2 and NSE are highly recommended to be used to check the predictive competency of the SWAT model. The two (2) statistical indices used in the present study to evaluate model performance are;

$$R^2 = \frac{[\sum_{i=0}^{n}(Q_m - \overline{Q}_m)(Q_s - \overline{Q}_s)]^2}{\sum_{i=0}^{n}(Q_m - \overline{Q}_m)^2 \sum_{i=0}^{n}(Q_s - \overline{Q}_s)^2}$$

$$NSE = \frac{\sum_{i=0}^{n}(Q_m - Q_s)^2}{\sum_{i=0}^{n}(Q_m - \overline{Q}_m)^2}$$

The catchment lacks a proper record of flow discharge measurement over time due to the non-availability of a flow gauging station. The researchers, since August 2020, started making several monthly field observations up to 2022. In the near future, it will be better to involve more than three years of observed data to calibrate and validate the SWAT model.

In the following equations, Q_m represents the observed discharge value and Q_s represents the simulated discharge value. $\overline{Q}_m$ is the mean observed discharge value and $\overline{Q}_s$ is the mean simulated discharge value. According to Heathman et al., (2007) the R^2 value is the measure of how strong the linear correlation coefficient can be between the predicted (simulated) and observed or measured values. The value of R^2 ranges between 0 and 1, meaning the perfect linear correlation between observed and simulated data will result when R^2 is calculated to be close to 1 or greater than 0.5.

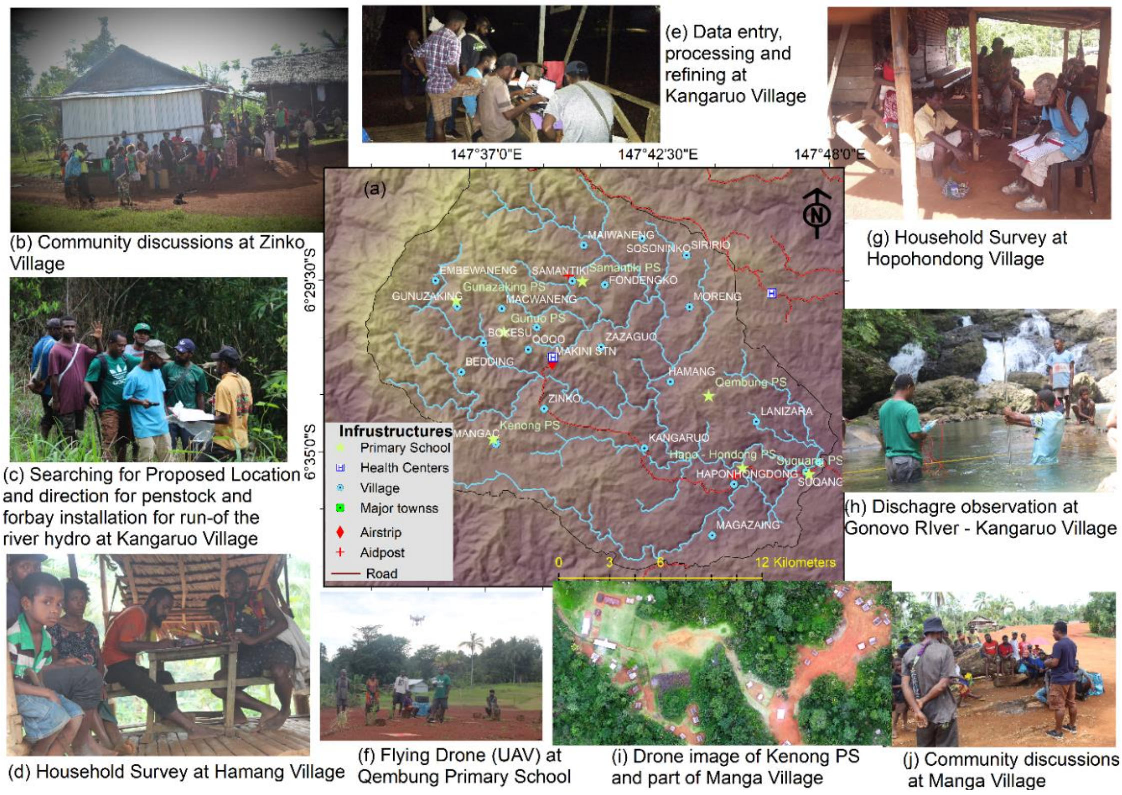

Figure 4: Fieldwork conducted within the Mape Catchment Region: a. Map of villages/places visited, b. Zinko Village, c. run-of-river hydro feasibility, d. Hamang Village, e. Data entry and data refining, f. Qembung PS, g. Hapohondong village, h. Flow observation, i. Aerial image of Kenong PS, and j. Manga Village.

If it is calculated to be close to 0 or below 0.5, then the perfect linear correlation will not result, therefore further adjustment of sensitive parameters is required (Pandey et al., 2015; Thin et al., 2020; Pathan and Sil, 2018). The *NSE* calculation indicates degree of fitness of measured and simulated data (Sammartano et al., 2019) which indicates measure of predictive power and efficiency of the model performance (Pathan and Sil, 2018). The calculated value of *NSE* is expected to range from one (1) to negative infinity (-∞ to 1). The value calculated to be close to 1 indicates a good match between observed and simulated data.

2.6 Village Electricity Load Demand Assessment

The household electricity demand assessment, including the socio-economic assessment within the Mape catchment region, was one of the objectives of the present study to seek pathways to rural electrification. According to Singh (2009), it is stated that, in order to carry out any household demand assessment for rural electrification, the most accurate method is to have community interaction. Singh (2009) further highlighted that the Participatory Rural Appraisal (PRA) method is to be utilized at the feasibility phases to enhance a quick understanding of energy usage patterns and energy demand growth in the near future. This is where the economics of the hydropower system is evaluated.

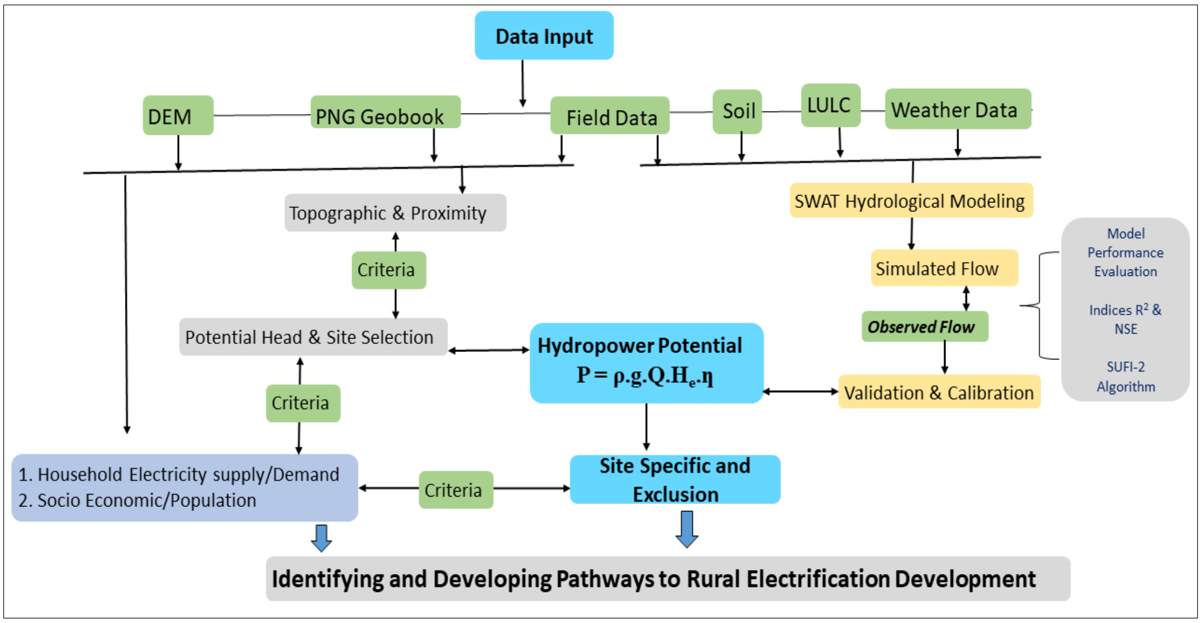

Figure 5: Methodological flow chart.

The present study conducted the demand assessment through community interaction during a field visit. A minimum of six (6) villages were visited, and various data types were collected. Refer to Figure 4. a to j to aid understanding of the field survey conducted with the type of data collected and method of data collection. The survey team used the questionnaire form and, applying interview techniques through the PRA method, collected various household data with GPS point tagging the locations of each household. Community gatherings and discussions were also conducted at each village, including conducting awareness of possibility, beneficiary, sustainability, and tariff plan for electricity supply demand.

In the present research, especially for the data analysis and results for rural electricity load demand and socio-economic status, the data collected for Kangaruo village were utilized. Kangaruo village was cited for the pilot study in the present study among other villages where data was collected. The idea is to bridge the gap and get the concept right first before further and detailed analysis to include every other village visited.

The household electricity demand assessment within Kangaruo village was estimated in line with the understanding of nearby hydropower potential calculated in MWh. The idea is to visualize and evaluate the possibility and potential of nearby hydropower to have enough capacity to supply electricity to households or villages with known estimated demand/load. Further to that, there could be in the near future availability of other energy resources like grid connection, mini-grids, solar, etc., possibly be made available; hence current electricity demand assessment, including socio-economic status assessment, will have a tremendous positive impact on the future development of energy resources within the catchment region.

3. RESULTS AND DISCUSSIONS

The researchers used the SWAT model within the QGIS analytical platform to calculate and delineate stream networks, including sub-catchment regions, and estimate the flow discharge of individual river networks within the catchment region. The model performance was calibrated and validated with a few on-ground discharge measurements. The researchers further calculated and specified potential heads within the catchment region to aid in power potential calculation in MWh. The researchers further went into calculating and estimating the electricity demand load of a sample village within the catchment region.

3.1 Stream Net Work Specification

The stream order prepared shows from order one, which indicates a tiny stream discharging into stream order 2, which is more significant than stream order one and more petite than stream order 3. Finally, stream order 3 contributes and discharges into creating stream order 4, the larger stream/river. From the field observation and GIS software calculation based on flow accumulation, it was observed that stream order one is classified as a small stream, and stream order 2, 3, and 4 are classified as small to a significant flowing river. The stream order and catchment regions analyzed and prepared are presented in Figure 7b. A field survey was conducted to verify each and every stream or river network that was generated.

3.2. Flow Discharge Evaluation

River discharge data is much more importantly needed for hydropower potential estimation. Most catchment regions within PNG are ungauged and lack continuous and proper measurement of river flow discharge. This may have limited the chances of quality and quantity of hydropower development within PNG. However, there is a possibility of estimating flows using the hydrological model as one utilized in the current study.

Table 1: Simulated and Observed flow statistical analysis

	August 2020 - May 2021			*May 2021 - March 2022*		
	Calibration			**Validation**		
Parameters	Mape_2	Ziqong_7	Gonovo_6	Mape_2	Ziqong_7	Gonovo_6
NSE	0.75	0.87	0.77	0.89	0.78	0.87
R2	0.94	0.79	0.85	0.88	0.83	0.89

After calibrating and validating, the researchers found the discharge data helpful in estimating hydropower potential. The present study estimated the monthly river discharge at each potential site after calibrating and validating the simulated SWAT model. The estimated river discharge was used for hydropower potential calculation. Table 1 highlights the statistical results of calibration and validation of simulated and observed flow at three (3) different locations. As can be seen from table 1, on average, the simulated discharge closely matches the observed discharge with $R2>0.8$ and $NSE>0.7$.

During calibration at site Mape_2, the perfect linear correlation was nearly met with the R^2 value of 0.94, and the predictive power and efficiency of model performance during calibration were observed to be satisfactory with NSE value of 0.75. Table 1 explains in such a manner for other sites about the calibration and validation carried out. Every year, the rainy season within the Mape catchment region starts from June to September, while the dryer or summer season starts in October and continues into the following year to May (Sekac et al., 2021).
The higher flow is expected during the rainy season, and the lower flow is expected during the dryer season. From the physical observation for the past 30 years, the streams or rivers, especially at the locations where the flow was measured, never at one time ran dry during dryer seasons; only the low flows were observed. Major floods are not always experienced. Only in 1980 and 2012 was the devastating flood observed that covered the maximum bank line height and overflowed. The destructions were minimal.

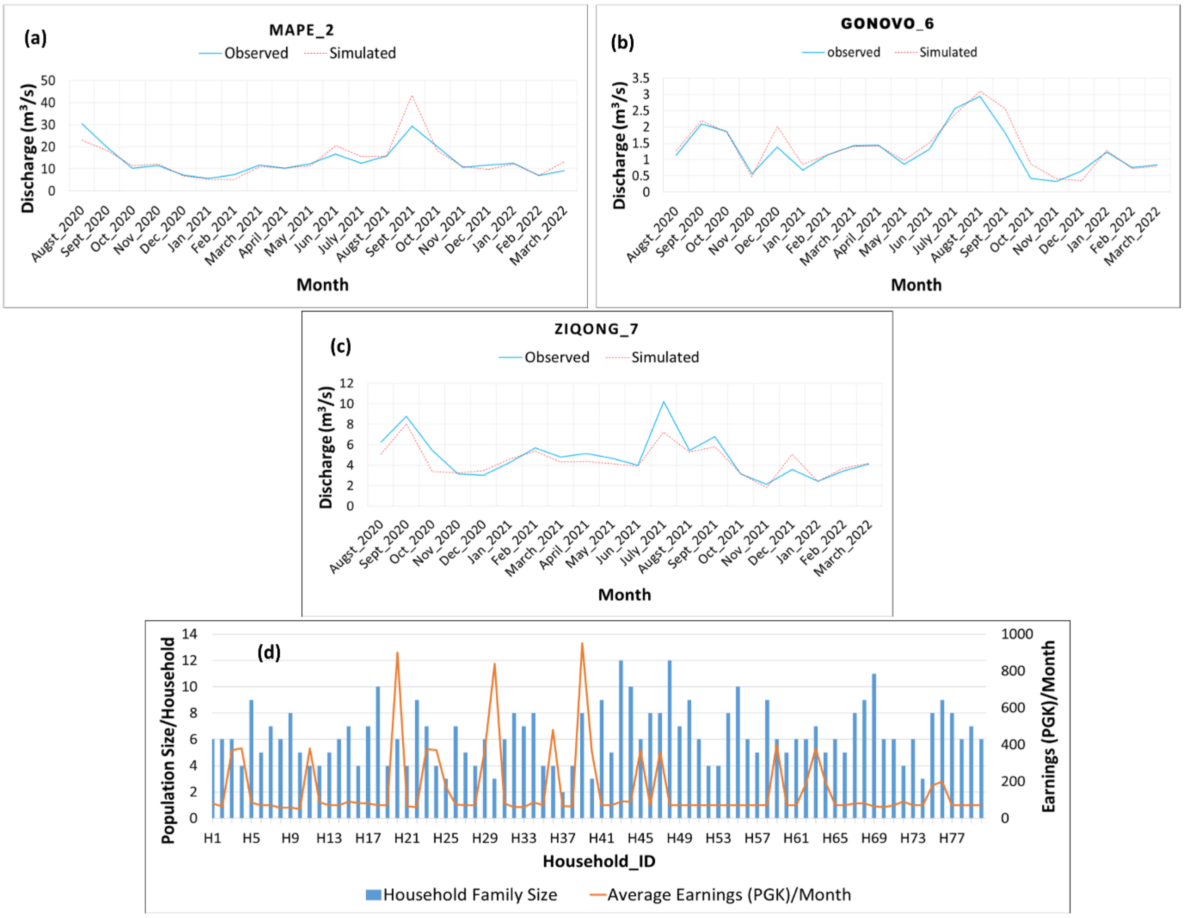

Figure 6: SWAT Model Calibration and Validation at; (a). Mape_2, (b). Gonovo_6, and (c). Ziqong_7. d. household population size vs. earnings per month.

The calibration and validation results of the SWAT model are illustrated in Figures 6 (a), (b), and (c). By referring to the graphs in Figure 6 (a), (b), and (c), the graphs for both the simulated and observed behave like going upwards, especially in the month of rainy seasons, while in the month of dryer season, the graphs behave downwards. There were over-estimation differences observed during rainy seasons. At the location Mape_2 during September and October, the observed flow deviates upwards or out from the simulated flow. The deviation was at least minimum. At the location Gonovo_6, a significant deviation occurred between August towards November, while at the location Ziqong_7, a minor deviation between observed and simulated flow was observed in the Months of August to November 2020 and the month of July 2021.

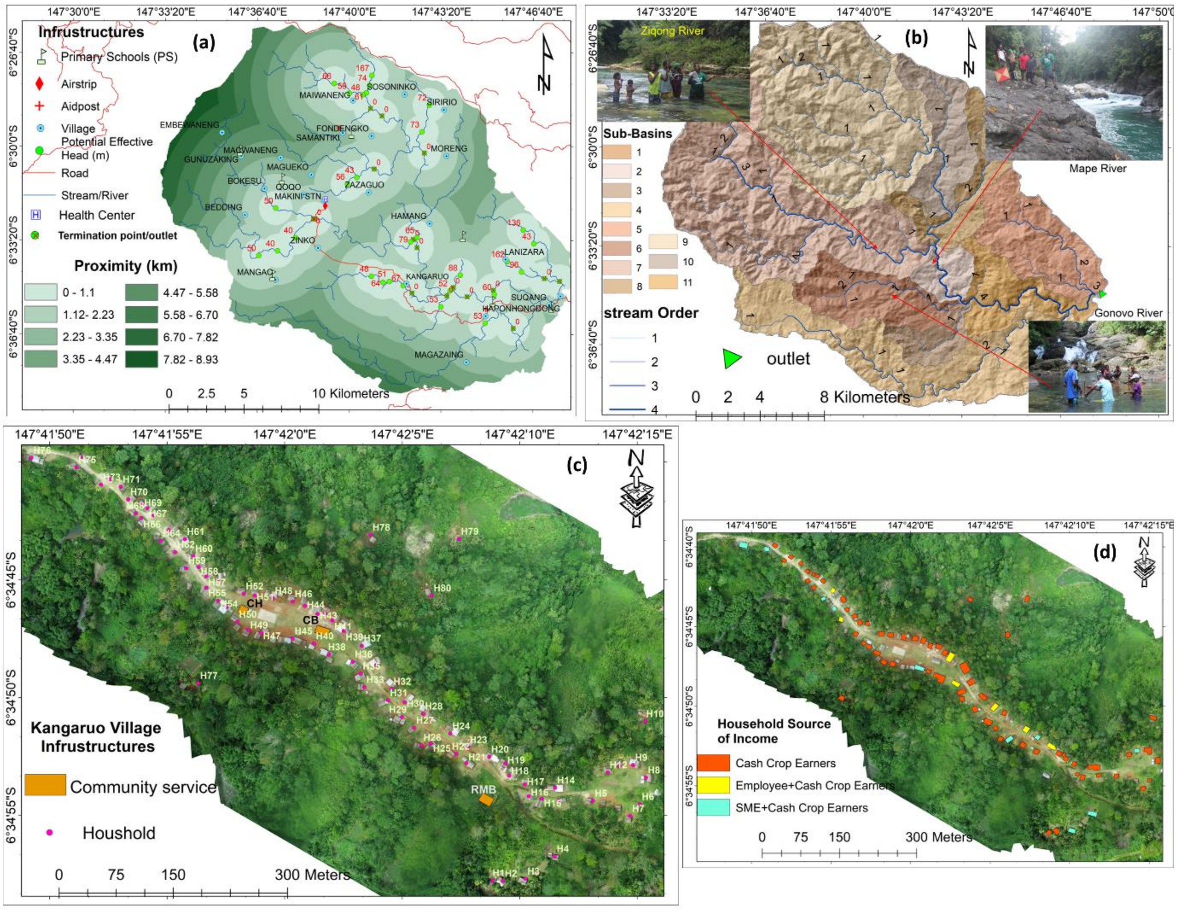

Figure 7: a. Criteria for potential head selection – Proximity, community, and Infrastructures, b. Stream order with field observation photos, c. Household and Public Institute ID (H=Household, CH = Community Hall, CB = Church Building, and RMB= Rice milling Building), d. Kangaruo Village household source of income.

The deviations observed at different locations resulted from limited observed data integrated with 22 years data range. Continuously recording observed data and then integrating it into the model to get a more accurate agreement between observed and simulated flow can improve the result.

3.3. Head Specification and Hydropower Potential

Considering six (6) criteria, the potential head was identified with a calculated effective head in meters (m). The first site selected upstream is considered a weir, and the successive site selected next downstream is considered an outlet or powerhouse. A site is considered a termination point going downstream since some criteria are not met and since the end stream is reached. The termination point is now considered an outlet or powerhouse of the pre-selected sites upstream. The topography plays a vital role in the selection of potential sites while visualizing downstream or upstream.

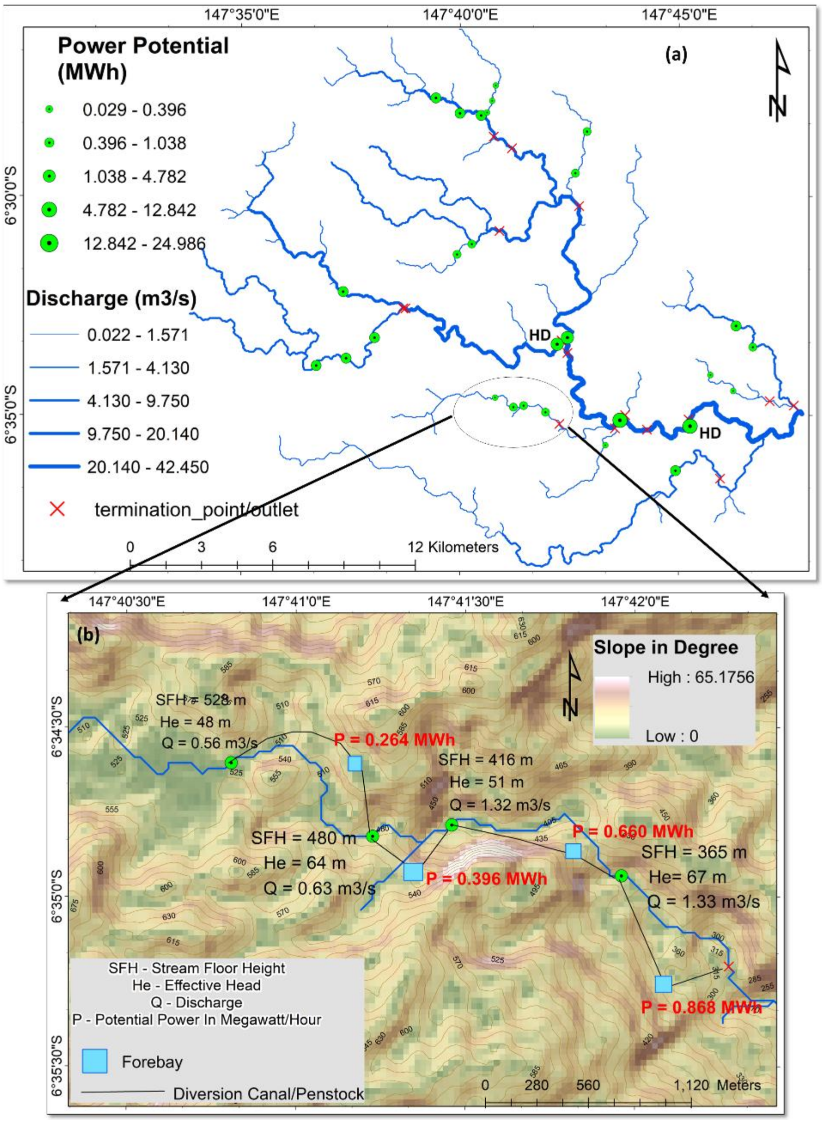

Figure 8: a. Hydropower Potential in MWh and flow discharge in m^3/s, b. the technical way forward for potential head selection and power potential calculations.

Figure 8 b illustrates the abstract of overall assessments to select the potential sites. The figure illustrates topographical parameters assessed for hydropower potential alone in the Gonovo River. Assuming it was run off the river hydropower scheme, the figure illustrates a penstock or diversion canal connection from the weir head to the forebay and then to the powerhouse or outlet governed by the topography.

This is one of the many ways topography was assessed for run-of-the-river hydropower infrastructures layout planning in the preliminary stage. If the planning layout fits and agrees with the site topography settings, then the sites are considered potential sites; therefore, the effective head is to be calculated, and discharge value is to be extracted at those sites.

During the assessments of the run-of-the-river hydropower scheme, two (2) possible locations/sites were spotted to be feasible for a large hydropower dam (HD), and the such selection and or assumption was based on considering the significantly steeper slope between two (2) sites that are at a very closer distance. The resultant power output for such a large hydro dam ranges from 8 – 23 MWh. Figure 8 a. illustrates the possible location of the large hydro dam (HD) that was identified in the preliminary stage. Most other sites are considered run-of-river hydropower schemes. The proximity to infrastructures and communities was calculated and is illustrated in Figure 7 a. The proximity calculation output presents the knowledge of how far each infrastructure is from the potential sites selected. If the potential sites were too far, then the sites are considered null and void to be considered for hydropower potential. From the assessment, 29 potential sites were identified. The estimated discharge was incorporated at those potential sites to calculate hydropower potential. Figure 8 illustrates the estimated flow discharge with the hydropower potential calculated at each selected site. On preliminary assessments, the calculation shows power ranges from 0.029 MWh to 24.987 MWh. The higher power output was observed in the major rivers due to the presence of high flow. The lower power output was observed at sites where flow is less, especially streams.

3.4 Electrification Load-Demand

The demand assessment study was conducted within Kangaruo village as a pilot study by considering the hydropower scheme as a source of electricity supply.

The present study evaluated main factors like population size, household earnings, source of income, electric load, and demand, including proposed electrical appliances and their rate.

The aim is to determine the feasibility of calculated hydropower to meet the electricity demand for the nearby villages. The aim was also to evaluate and determine each household and their interest in having electricity connected and whether each household has enough resources to pay for and support the electricity supply in the long run (economic viability). Eighty (80) households were surveyed, including other public services infrastructures like church buildings, community hall buildings, rice milling buildings, and Elementary schools within Kangaruo village, as illustrated in figures 7 c and d.

The elementary school location was not captured in the maps; however, the electric load and demand assessment was done for all. Each household was made up of bush and modern building materials with roofing iron. The public buildings were mostly made up of modern building materials. The household population size and earnings per month on average are illustrated in Figure 6 (d), and the source of earnings for each household is illustrated in Figure 7 d. The household population size ranges from 3 - 12. Sixty-three (63) household within the community generate their household income through selling cash crops like coffee, cocoa, vanilla, rice, tobacco, and other food gardens, and about seven (7) households are employed and also involved in cash crop activity to generate incomes and about ten (10) household they generate income through Small and Medium Enterprise (SME) and including cash crop. The electricity load and demand were estimated without considering seasonal changes. Currently, all households, including public facilities within a study region, are not connected to any form of genuine electricity; therefore, there is no such availability of any form of electrical

appliances. However, few households are expressly limited to lighting and charging, only using privately owned generators and solar panels.
The idea of common electrical appliances to be chosen and assessed in the present study was developed through communicating with local communities within six villages, including from many works of literature (Isihak et al., (2020); Pandyaswargo et al., (2020); Singh (2009); Rushman et al., (2019)) and past projects so far.

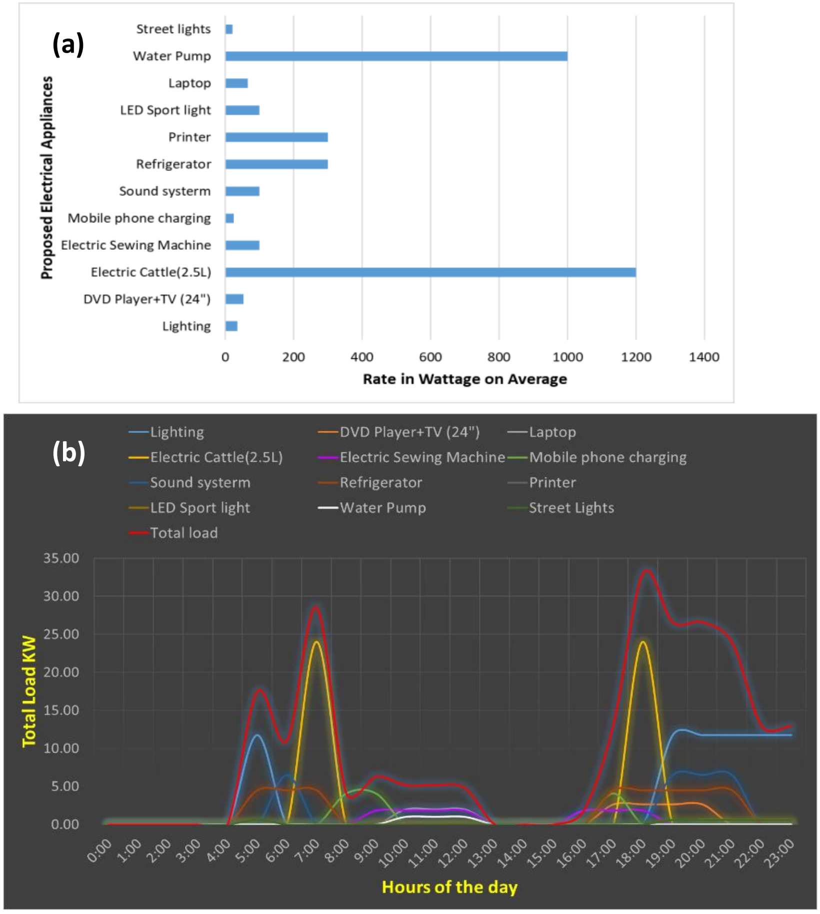

Figure 9: a. Appliances rate in wattage on average, b. load profile in *kw* for Kangaruo village

The electrical appliances that are important and common to every household, including some public institutes, are; a lighting system, Television (TV), sound system, and phone charging. These are the appliances where most of the responses were taken from the community.
Some individuals have household SME plans, and from their responses, electrical appliances such as refrigerators, electric sewing machines, laptops, and electric cattle were noted for inclusion in the calculation of load demand. Some more appliances needed for public buildings or institutions apart from household needs, like Light Emitting Diode (LED) spotlights, printers, and laptops, were considered. For general public benefits, the appliances like the electric water pump and street lights were considered.
The size and ratings in wattage for each appliance chosen were taken from several well-known shops and retail stores within the hometown (Gagidu) or city (Lae City). The average ratings

assumed and considered for demand load calculations are arranged and illustrated in Figure 9 a.

The energy demand evaluation and calculation were done together for both public institutes and general households in Kangaruo village. When assessing a particular village's energy demand, it was assumed that not every household or institute would have all electrical appliances at once. Based on such assumptions and the knowledge gleaned from the literature, Isihak et al. (2020); Pandyaswargo, et al. (2020); Singh (2009); Rushman, et al. (2019)), and with the help of field data collected, the number of households or public institution to have each electrical appliances were evaluated and determined.

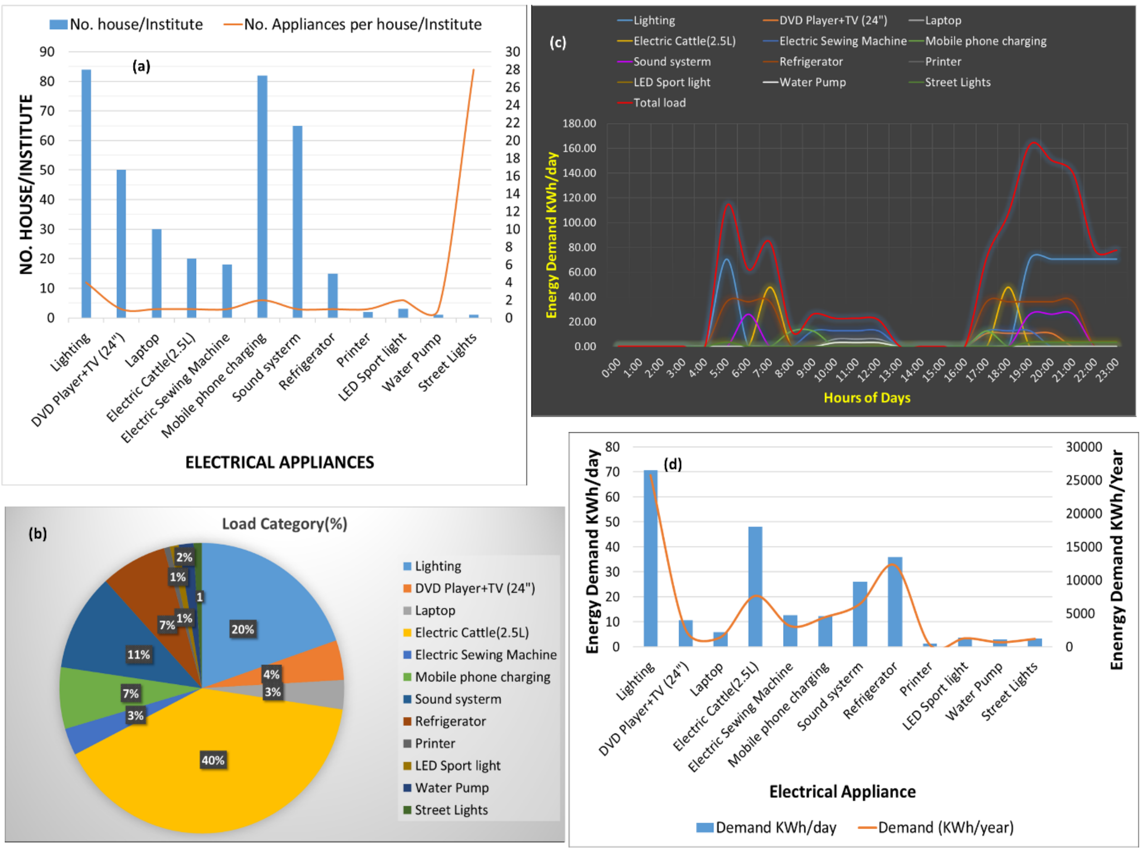

Figure 10: Kangaruo village household demand; a. Number of households having each electrical appliance, b. load category of Kangaruo Village household, c. total load for system sizing, d. Energy demand for Kangaruo village.

The output results are presented in Figure 10 (a). This data bridge the understanding of load calculation in kw and calculation of energy demand in kwh/day or kwh/year for Kangaruo village. The load category for Kangaruo village households plus public institutes is illustrated in Figure 10 (b). It was calculated by evaluating each electrical appliance's wattage (W) (figure 9 a), the number of households or public institutes to use each appliance, and finally, the number of appliances to be used at each household or public institute. Especially for the water pump and street lighting were considered general and not specific to any particular public institute or household. The load schedule or load profile was constructed by considering all electrical appliances to be used within 24 hours' time. This has provided fare idea for the system sizing for Kangaruo village. Refer to Figure 9 b for appliance usage within 24 hours and the load in kw for each electrical appliance that is to be used at each household and public institute. It was determined that the electricity supply is to be completely switched off for 5 hours between 12 am to 5 am and operational for 19 hours between time 5 am to 12 am. Hence, the appliance usage was scheduled in line with that. The lighting will be used for 6 hours, mainly in the evening session from 19:00 to 23:00 hour and 1 hour in the morning session around 5:00 am. The refrigerator will be used for 8 hours, 5 hours in the evening and 3 hours in the morning. The sound system will be used for 4 hours, 3 hours in the evening session and 1 hour in the morning, and so on. The LED spotlight will be used by public institutes like elementary schools, rice milling buildings, and church buildings, and it will be used for 6 hours, that is, 1 hour in the morning and 5 hours in the evening. After scheduling each appliance with its load, it is now verified that the system sizing for Kangaruo village can be 40 kW (+15%), and it is the peak load for a day that is to be taken into consideration. The total load for all electrical appliances for the village was estimated to be 60 kW. The calculated demand for each appliance for a day (24 hours) was scheduled, and it is shown in Figure 10 c. The peak demand for Kangaruo village in a day was estimated at 163 kWh. Figure 10 d illustrates the detailed demand rate for each electrical appliance both in kwh/day and in kwh/year for Kangaruo village. The total energy demand for the village was estimated to be 233 kWh/day and 67,486 kwh/year. In line with the demand and peak load assessment and result outputted, it is verified that any nearby estimated hydropower potential between 200 kWh to 800 kWh can be the source of electricity supply to the Kangaruo community. Refer to Figures 7 a and 8 for correlation and verifications. The same calculation approaches can be applied to five other villages visited, and data were collected within Mape Catchment. Furthermore, in the near future, other means of electricity, like Main Grid, Mini-grid, Solar, etc., will be required for rural electrification; therefore, the current demand and load calculation will play a vital role in system sizing with electrification distribution.

4. CONCLUSIONS AND RECOMMENDATIONS

The current study is one of which that focuses on creating pathways or alternatives to rural electrification with clean energy solutions. The study was carried out within the Mape catchment. Hence, such study approaches can be applied throughout other parts of country PNG, including other developing countries around the world, to promote and develop electrification with clean energy solutions. The current research was conducted in 2 phases within the Mape catchment in the Finschhafen district of Morobe Province, Papua New Guinea. First, calculate and identify potential hydropower sites, and second, assess household energy demand. The 29 most feasible potential sites were selected from the analysis, and the hydropower potential in MWh was calculated at each specified site. The calculated power within the catchment region ranges from 0.029 MWh to 24.986 MWh.

After identifying potential hydropower sites, the calculations were furthered into assessing the energy load demand of a particular village. The pilot study was conducted at Kangaruo village. The concept is to develop an idea where site-specific calculated hydropower can supply enough energy to meet each neighboring communities' demand load. From the load profile, it was found that the peak load for the village is 40kw, and the peak demand is 163 kWh per day. The total energy demand for Kangaruo village per day was calculated to be 233 kWh and 67,486 kWh per year. It was assumed that nearby hydropower potential has enough capacity to meet the energy demand for the nearby village by considering that power supply and usage will be under control. The implementation of tariff plans or rules will help control power usage. Some control measures to reduce stress paying are to switch off power from 12 am to 5 am completely, and the electrical appliances purchase are to be reported. In addition, in the case of load sharing, the household usage of electrical appliances is to be in control. The research was conducted so that every individual in the rural communities is made aware of the benefits of having electricity connected to their homes, the sustainability and affordability part of having electricity, the tariff plan (amount to pay), and the security of the property. From present research, it was verified that, once the rural communities are aware of such as listed, there will be a neutral understanding between communities and the investors/suppliers/electricity provider. Therefore, higher efficiency in electrification development right into rural communities can result, and the economic payback will be acceptable. Conducting field visits to where consumers or communities live, interacting, and communicating with them is the crucial role that needs to be considered for any rural electrification development. In the behavioral observation and analysis, and based on the lifestyle of living, thinking, and surviving, it is strongly recommended that a field visit with community interaction be conducted before any form of planning for electrification development in the rural places of PNG. Hence, this is the best solutions way forward. Carrying out desktop analysis for potential site selection and energy demand assessment should not be the only alternative way forward, it must be intercepted, complemented, and aided by field data collection and observation. The approach will create higher chances and possibilities for electrification development in PNG.

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