Preliminary Site Selection for Small-Scale Hydropower Potentials, in Bulolo, Morobe Province, Papua New Guinea: *GIS & RS Approach*.

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Abstract

The efficacy of hydropower in general is determined by river discharge and falling height (head). Hence this research uses advanced technologies of Geographic Information System (GIS) and Remote Sensing to identify most of the parameters required for hydropower calculations. The parameters such as runoff, head and watershed areas were thoroughly considered. The objectives of this research include; identification of sites having suitable 'heads' from SRTM DEM, integrating Soil Conservation Service (SCS) runoff equation and sub watershed areas in GIS environment to calculate annual river discharge, estimating annual hydropower energy using above variables (Head and Discharge) and finally to map out preliminary sites showing small-scale hydropower potentials based on annual hydro power estimation. The SRTM DEM data having 30 m spatial resolution, Landsat satellite data together with PNGRIS data sets are used for head determination, watershed delineation & area calculations, Land Use/Land Cover Mapping and finally SCS runoff modelling for annual river discharge estimations. The study utilizes the standard hydropower calculation, which is P = ρ m x h x g, where P is annual hydropower (in W), ρ is density of water (kg/m^3), m is Discharge (m^3/s), h is Head (m) and g is acceleration due to gravity (m/s^2). Head (h) is calculated using focal statistic analysis tool in ArcGIS software, where as annual discharge (m) is obtained from annual runoff, watershed area and total number of seconds in a year. The results indicate that there are 91 sites having good Head (h> 20 m), however lack of river discharge in most of the hilly region has resulted most of the sites unconsidered. The final results indicate that there are 44 potential sites for small-scale hydro power developments in study area. The estimated annual power ranges from 1 – 10 MW.

Keywords: *GIS, Remote Sensing, Small-Scale Hydropower, Head, Watershed Area, Discharge, Annual Runoff.*

1. Introduction

In developing countries like Papua New Guinea (PNG) where free falling water is abundant, the necessity of having clean, reliable and affordable energy service is crucial especially in the context of rural areas where majority of people live in highly scattered, tiny clusters. With increasing demand for use of electricity in PNG, the country is currently at the initial phase of extending existing grids through establishing Small-Scale hydropower Plant (SSHPP), which can appreciably increase the existing power generation capacity to cover many rural areas (Kuna & Zehner, 2015). Selecting suitable site for establishing SSHPP is therefore of paramount concern in order to mitigate plausible natural disasters in selected site. RS and GIS technology is the proven tool that can be used to identify most suitable sites for locating SSHP plant (Singh, 2009).

This research encompasses the relevant and analytical approaches of Remote Sensing (RS) and Geographic Information Science (GISci) that are used collaboratively to identify main variables that are significantly contributing to the production of Small-Scale Hydropower Plant. SSHP is one of the significant energy sources from renewable energy basket that can be used over and over again. Previous studies have shown that small-scale hydropower plant has fewer adverse effects on environment. As stated by Patil, Shirkol & Joshi (2013), "Energy produced by hydropower has several advantages over fossil fuels and nuclear power: it is renewable; it has low pollution impact on the environment; it is devoid of greenhouse gas emissions or nuclear wastes; it implies relatively low maintenance; it is reliable in terms of technology and it is proven over time". In terms of cost solar and wind energy seems to be the cheapest energy sources, however, there are certain limits involved like solar energy needs presence of sunlight and batteries which have a limited life-time where as wind energy needs the presence of wind. SSHP appears to be expensive in initial phase which involves construction of civil structure but once installed it appears to be the cheapest and reliable source of energy that can last long.

The ultimate aim of this research is to apply Remote Sensing and GIS techniques or space technology to identify potential sites that are suitable for locating small-scale hydropower plant as part of preliminary studies. A Small-Scale Hydropower is characterised by river discharge and head profile (Singh, 2009). Hence, Variables such as heads, flow rate, watershed area, and runoff were main approach of this research in order to estimate annual power output. Based on these calculations, the suitable sites for locating SSHPP are identified. All necessary procedures (methods) were thoroughly carried out in chronological order and satisfactory results were obtained which satisfied prime aim of this research.

2. Study Area

The upper Catchment area of Watut River basin, located in the heart of Bulolo-Wau District was selected to carry out this research work. Bulolo-Wau is one of the political districts in Mororbe Province of Papua New Guinea. It comprises of two distinct districts, namely Wau and Bulolo. The electorate is one of the most isolated electorates in Morobe Province. Bulolo-Wau District lies South–West from Lae City, the Provincial Headquarter of Morobe Province. The actual study area (Upper Watut Watershed) covers geographical area of 2678.69 square kilometers and is located 146° 20' 47.20" E to 146° 53' 40.19" E longitude and 6° 57'41.15" S to 7° 26' 37.12" S latitude.

The district of Bulolo-Wau comprises of Six (6) LLGs namely; Mumeng Rural, Waria Rural, Watut Rural, Wau-Bulolo Urban, Wau Rural and Buang Rural. According to the 2011 Census, Bulolo-Wau electorate has a total population of about 101,568, occupying a total of 20,865 households (NSO, 2014). The vast majority of these households and people have no access to electricity and other basic services.

The study area has a total annual precipitation of 2336 millimetres (mm) and falls within a regional annual temperature range of 22 to 34°C (Bryan &, Shearman, 2008). It also has major forest covers in the north-eastern and south-western parts where there is high elevation. Elevation peaks range from 150 to 1000m above sea level. Due to ongoing alluvial mining activities along river banks, the town of Bulolo is often referred to as a Mining town.

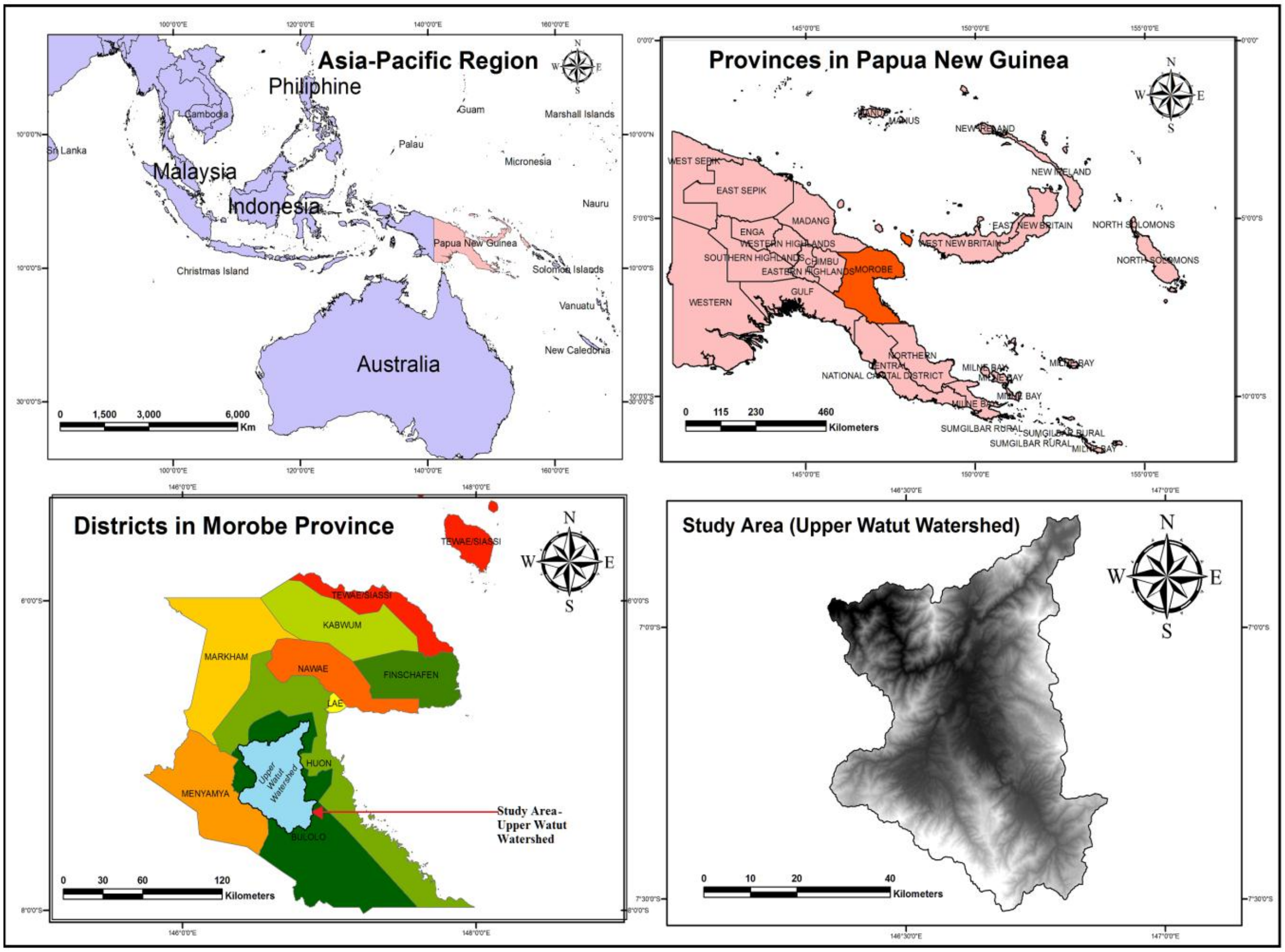


Fig. 1 Location map of the study area (Upper Watut Catchment area in Bulolo-Wau Districts).

3. Materials and methods

3.1 *Study Design*

The methodology of this research was developed to exploit the integrated use of remote sensing and GIS as well as small-scale hydropower generation knowledge and models to develop new spatial information collection techniques or procedures and specified spatial analysis tools for supporting the formulation and identification of suitable site for developing small-scale hydropower plant. There were several procedures involved in identifying most of the required parameters that were needed as inputs for annual power estimations. These assessments were undertaken by actual energy potential calculation using input variables that were generated from SRTM DEM and runoff. The summarized flowchart in Figure 2 illustrates the entire procedures carried out.

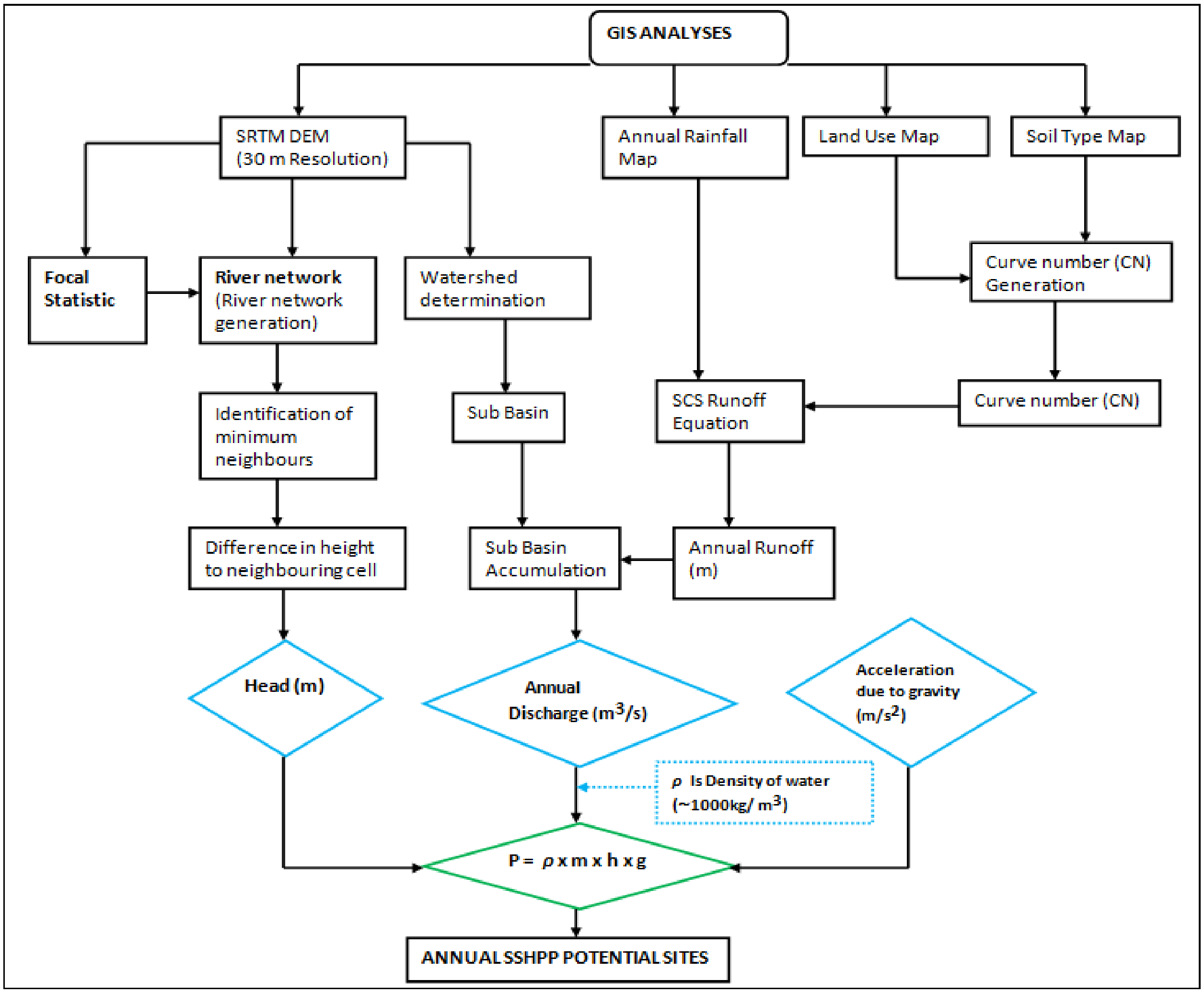


Fig. 2 Flow chart showing Research Methodology for Annual Hydropower Estimation.

3.2 ***Small Scale-Hydro Power Calculations***

The availability of small-scale hydropower is a function of two variables namely; head and river discharge or flow rate under the influence of gravity (Setiawan, 2015). Hence, in present study the output of hydropower energy was calculated using the following equation:

$$P = \rho \; x \; m \; x \; h \; x \; g$$

Where, P = Annual Energy Potential (Watts/year)

ρ = Density of Water (~1000kg/cubic meter)

m = Annual River discharge or flow rate (cubic meter/second)

h= falling height or head (meter)

g = Acceleration due to Gravity (9.81 meter/square second)

By taking above equation into consideration, the two variables (.i.e. Discharge and Head) as well as watershed area were needed at primary stage. Hence, these variables were initially produced and the outputs or the results were subsequently inputted into the above mentioned hydropower calculations and the final results were considered for determining the suitable sites for SSHPP. The procedures involved in determining these variable are further discussed in separate phases below.

3.2.1 *Watershed Delineation & Geometric Calculation.*

The primary task was to delineate the watershed area. O'Keefe *et al* (2000), defined watershed area as the area of land that basically drains water, sediments and other dissolved materials to a common receiving body, often referred to as outlet. Outlet is often referred to as pour point and is the point on the surface at which water flows out of an area (O'Keefe *et al.*, 2000). Watershed comprises of more than one small watersheds often referred to as sub-basins. Here, hydrology tool set in ArcGIS (Version 10.0) was used to delineate watershed or catchment areas as well as sub-basins. The SRTM DEM having spatial resolution of 30m was used as an input data to delineate the watershed area. The output of watershed delineation was the sub watershed and river network. The flow chart in Fig 3 summarized the watershed delineation process.

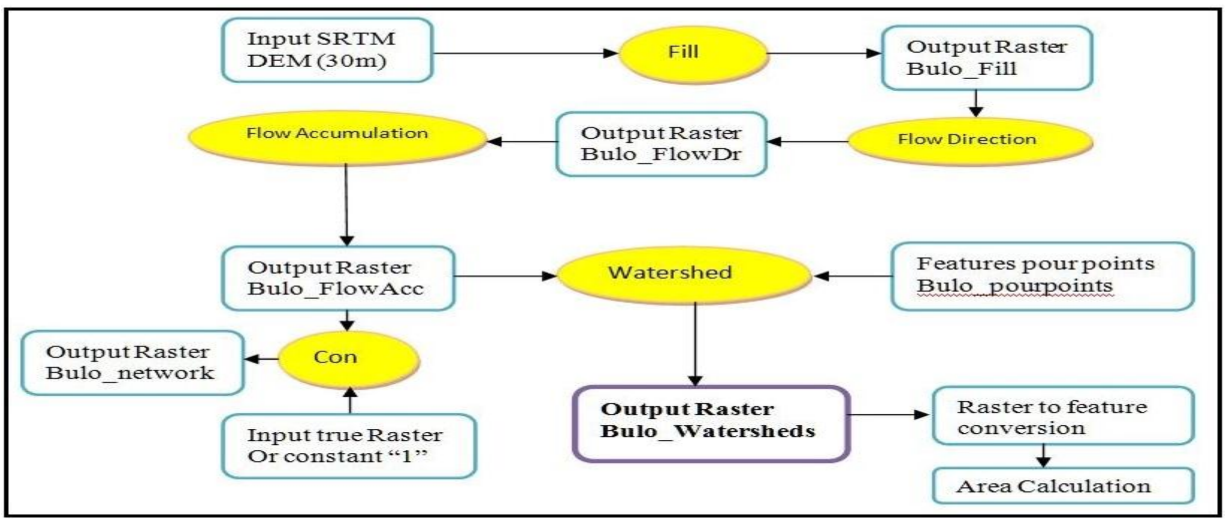


Fig.3 Watershed delineation Process

3.2.2 Head Calculation (h)

River head calculation was approached using GIS methods where, DEM data containing elevation information was initially clipped with river network to generate riverbed topographic profile. Neighborhood analysis tool in ArcGIS software was used to calculate river head. This analysis calculated the elevation range between neighbourhood pixels from the river bed topographic profile generated above. According to Feizizadeh & Haslauer (2012), focal statistic is one of the functions that calculate statistics for the neighbouring cells of each cell such as minimum, maximum, sum of all values etc. Hence this research utilized a minimum function in focal statistic analysis, where 3 x 3 cells rectangle around each cell was selected to calculate minimum cell values for neighbouring cell. By performing this, the lowest cell values for each neighbouring cell were calculated. The head values were finally calculated by subtracting minimum values from the original SRTM DEM using raster calculator option in ArcGIS software. Finally, all the stream segments with head higher than 20 meters were selected and converted into point layers and used as target points for flow rate estimation. The values in the output were then used for hydropower calculation.

3.2.3 Annul River Discharge or Flow Rate (m)

The annual river discharge or flow rate (m) for any given site is the product of Watershed Area (A) and Annual Runoff (Q). The accumulation of runoff in sub catchment area is assumed as Annual River discharge (Askar, 2014). The annual runoff calculation was approached using SCS Runoff Curve Number (CN) equation which was formulated by SCS with rainfall and CN as input (Pal *et al.*, 2012).This equation is shown below.

- $Q = (P – Ia)^2 / (P – Ia + S)$ .... *(equation 1)*

Where; Q = annual runoff in mm,

P = average annual rainfall in mm,

Ia = 0.4S Initial abstraction (mm). This is the losses of water before runoff begins by soil and vegetation in a form of infiltration or rainfall interception by vegetation. The constant value of 0.4 was used for Papua New Guinea (Pal et al., 2012).

S = Potential maximum retention in mm and the equation 2 below was used to calculated it values.

- $S = (25400 / CN) – 254$ .... *(equation 2)*

CN = curve number of hydrologic soil cover complexity and is the function of soil type, land cover and antecedent moisture condition (AMC) (Pal et al., 2012).

After generation of spatial annual runoff map, the accumulation of sub-watershed runoff was determined by multiplying runoff (mm) with catchment area or sub watershed (m^2) for each basin (Seitiawan, 2015). The final runoff was then calculated by dividing runoff (m^3) with the total number of seconds in a year (365 days X 24 hrs X 3600 seconds = 3153600 seconds). In this process the final annual runoff has a unit of m^3/s, therefore it was considered as Annual Discharge or flow rate (m).

3.2.4 SSHP Potential (P)

As mentioned in the earlier stage, the present study utilized the standard hydropower formula for preliminarily site selection process for small-scale hydropower potentials. The standard formula used to estimate hydro potentials in selected sites is again mentioned below:

- *Power = Head x Flow Rate x Density of Water x Acceleration due to gravity*

The values derived from variables above were put into standard hydropower formula and the best possible sites were selected based on the output. Hence, sites having energy output ranged between 1-10 MW were identified as potential sites for small scale-hydro power plant. These sites were represented in a form of thematic map.

The efficiency due to turbine and generator as well as transmission losses were disregarded in current study, due to the fact that this research was purposely carried out for preliminary site selection. However, further assessment is needed to derive the actual power output of small-scale hydro power plant by inclusion of the efficiency factors of turbine and generator.

4. Results and Discussions

4.1 Watershed Delineation

The watershed delineation was carried out based on SRTM DEM data having a spatial resolution of 30m using hydrology tool in ArcGIS 10.0. Four main maps were generated and these are Sink, Fill, Flow Direction and Flow Accumulation. Figure 4(a) shows the four types of maps generated to delineate watershed or catchment area. The pour points were placed in highest potential areas where more than two rivers or streams meet or where river accumulates. Using snapping tool option in hydrology tool, the maximum distances for each stream were taken and sub watershed areas were generated. A total of 45 sub watershed areas were derived in the study area and their geometric areas were determined using geometry option in ArcGIS attribute table. Figure 4 (b) shows the sub watershed areas. The total Upper Watut Catchment area is 2678.69 square kilometer.

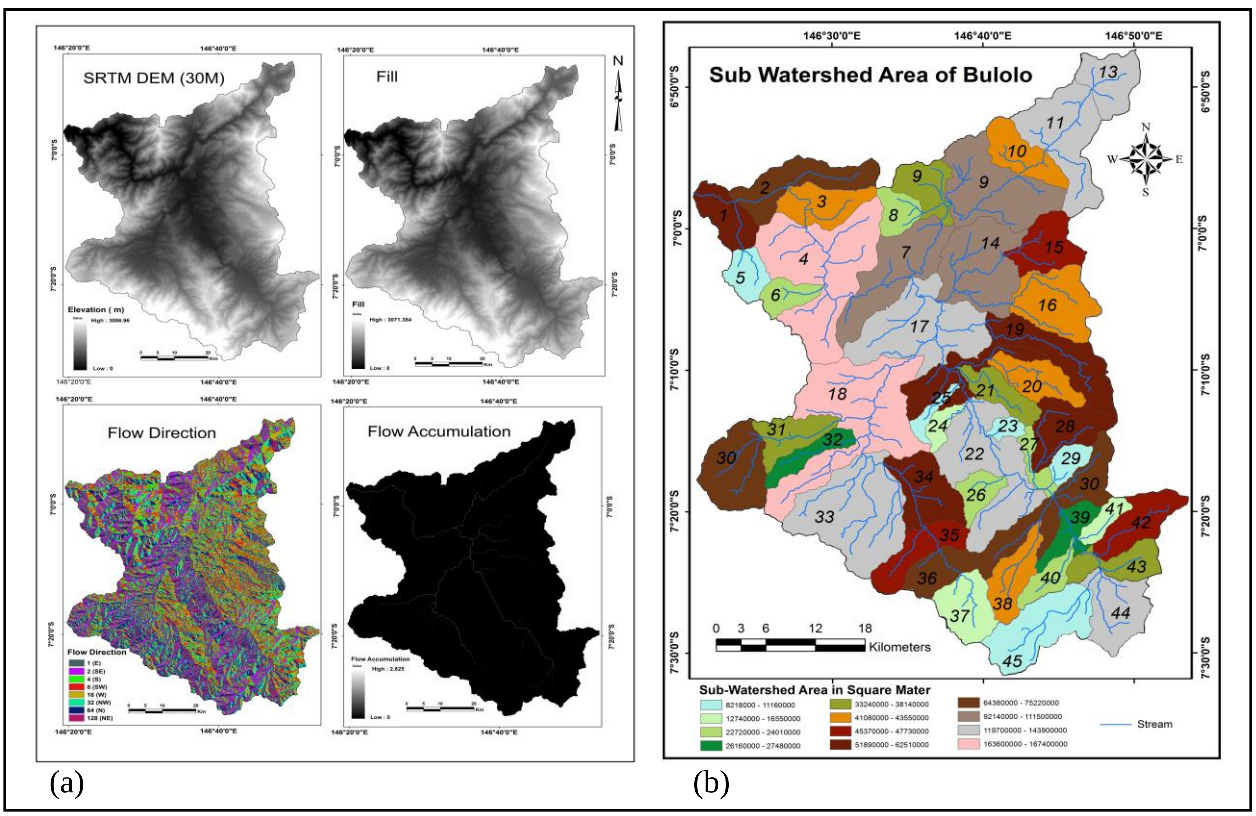
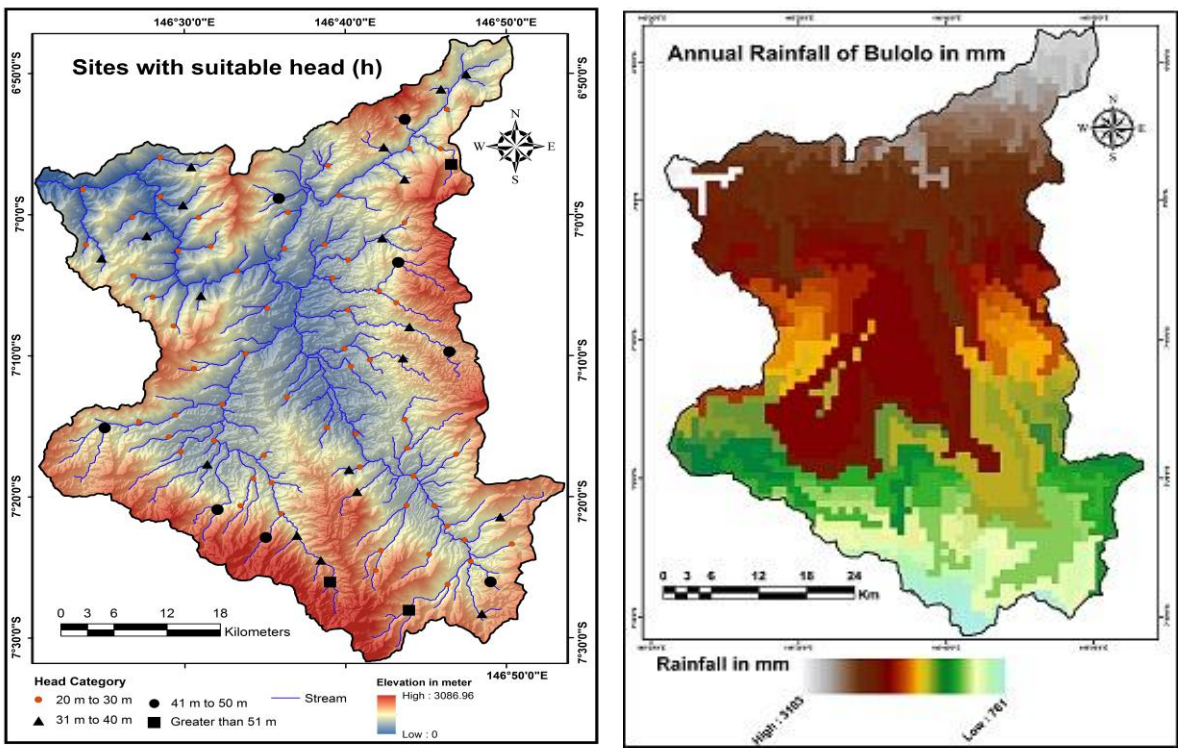


Fig. 4. Watershed Delineation:(a) Sub watershed delineation process (b) Sub watershed areas

4.2 Head Determination

The falling heights or heads used for hydropower calculation were derived from DEM data using Neighborhood analysis tool in ArcGIS software as mentioned in the methodology above. The final result indicates that there are total of 91 sites having good heads in the entire study area. The result also indicates that, the height having values greater than 50 meters are found in steepest region where as most of the height below 40 meters are found along central regions where there is gentle slope. Figure 5a shows the sites having suitable heads and Table 1 show the classes of heads in different ranges.



(a) (b)

Fig 5. a. Sites with suitable heads, b. Annual rain fall in mm

Table 1.Number of sites with good heads according to neighborhood analysis.

Heads in meter	Total Number of Sites	Grand Total
20 m to 30 m	61	**91**
31 m to 40 m	19	
41 m to 50 m	8	
Greater than 51m	3	

4.3 Annual River Discharge

The result for Annual River Discharge (Flow rate) in this research was derived from the product of annual runoff and watershed area. Here, the geometric area in square meters are derived from above watershed, whereas annual runoff is derived from SCS runoff modeling using Curve

Number (CN) methods where soil type and LU/LC are used as inputs. From the results obtain in Land Use/Land Cover classification, about 75% of entire study area is covered by forest and the overall accuracy achieved was 87% (Figure 6c). Looking at Soil characteristics, there are major presence of Hydro Soil Group D, mostly composed of clay loam, silty clay loam, sandy clay, silty clay or clay and fewer presence of Hydro Soil Group A (Figure 6a). The result obtained from rainfall indicated that there is more rainfall experienced in northern zones than in southern zones. The annual rainfall of study area ranges from ~700mm to 3000 mm (Fig 5b).

The annual river discharge of any particular site is derived from the product of geometric area of sub watershed and runoff of that area was divided by total number of seconds.

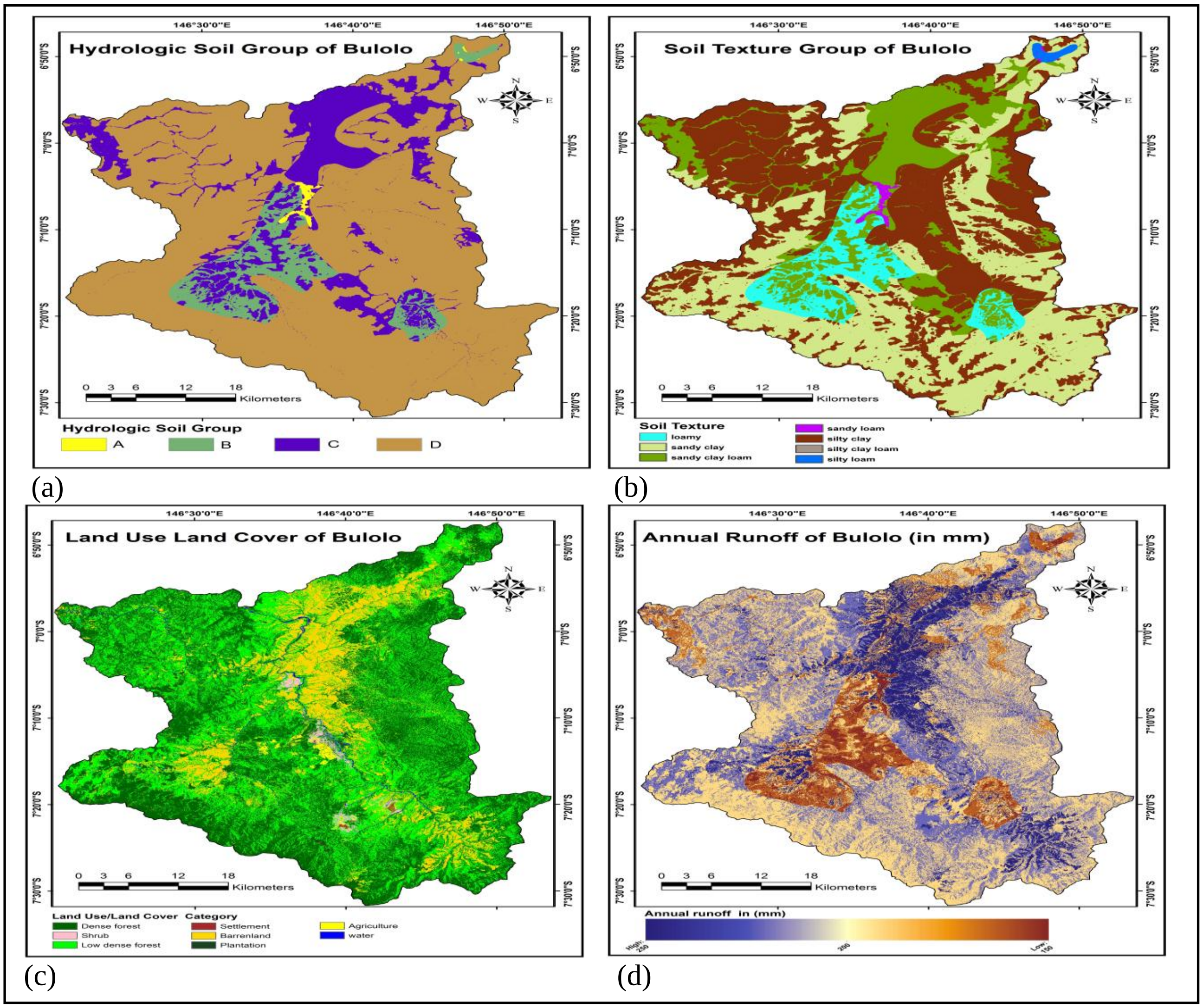
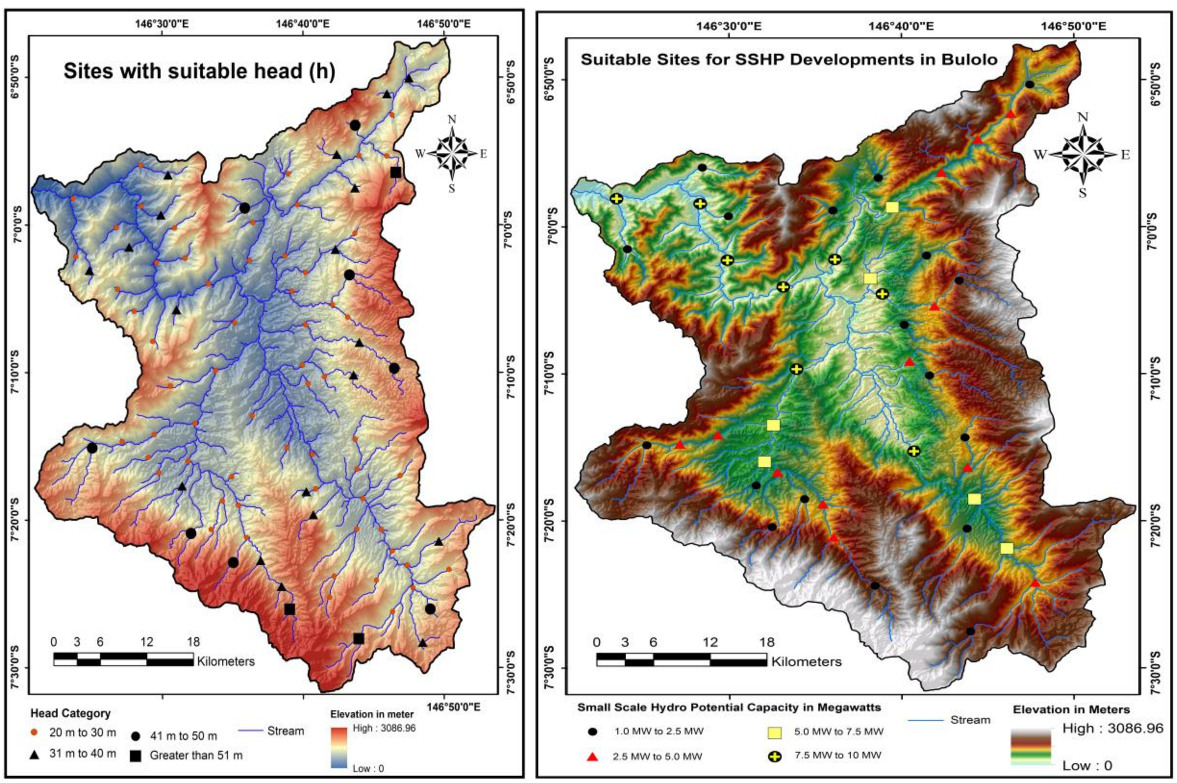


Fig.6 Input maps for discharge. (a) Hydrologic Soil Group (b) Soil Texture Group (c) Land Use/Land Cover (d) Annual Runoff in mm.

4.4 SSHPP Estimation

The results of hydropower potential sites in Upper Watut Catchment are displayed in Fig 7(a) below. The results were obtained by summarizing the total hydropower capacity for each site where suitable heads are located and the sites that fall between the ranges of 1MW to 10 MW are considered for small-scale hydropower developments. While carrying out this process, there are total of 44 sites that are selected for small-scale hydro power developments in current study area. These sites are categorized into four groups as shown in Table 2 below. The result indicates that the highest hydro potential sites that fall within the ranges of 7.5MW to 10MW are found in the central region and towards the outlet of the entire catchment area. However, the lowest hydro potential sites, having estimated output energy capacity of 5 MW and below are found to be sufficient and are equally distributed over the entire study region.



(a) Location of suitable heads (b) Location of suitable sites for SSHPP

Fig. 7 (a) Location of suitable heads. (b) Location of suitable sites for SSHPP

Table 2. Category of number of SSHPP sites in study region

Small Scale Hydro Power Potentials	1.0 MW to 2.5 MW	2.5 MW to 5.0 MW	5.0 MW to 7.5 MW	7.5MW to 10 MW	**TOTAL**
Total Number of Sites	18	12	6	8	**44**

5. Conclusion and recommendations

The success of any such research or project is entirely dependent on the availability of data sets, use of appropriate softwares and the methodology. This study apparently demonstrates that there is always a possible option available for the estimation of theoretical hydropower potential sites through the advance use of Geographic Information System (GIS) and Remote Sensing (RS) Techniques. The method adopted in current research has successfully generated suitable sites having good head (falling heights greater than 20m) and river discharge (superior flow rate) through the use of available remote sensing data sets and GIS software. The results produced from this research clearly demonstrates that sites having good heads are not always suitable for hydro power developments as such sites were saddled with low river discharge, which resulted in unviable hydro potentials.

The final result indicates that there are 44 potential sites available for small-scale hydropower development in entire study region. There are also good number of sites having hydropower capacity of 1 Mega Watts and below but, all were discarded as this research solely emphasized on small-scale hydropower which have output energy between 1MW to 10 MW. Having met the requirements of hydropower production through theoretical hydropower calculations, the results obtained are looking good, however there are few limitations in this research that need further considerations. The limitations such as calculation for runoff using SCS CN formula with annual rainfall input seems to produce higher values in some instances and it needs further field verifications in future study. This method is recommended for preliminary site selection process for screening small-scale hydropower potential sites only and detailed feasibility studies is also needed which involve direct measurements and analyses.

Finally, the results obtained through such research is very important for any decision making bodies such as government organizations in particular Ministry of Energy and Public Enterprise for the promotion of total energy production in the country. It is also important for any non government organization, companies, industries as well as all levels of government (Local, Level Government, Provincial and National) who really want to develop clean energy regime in tune with national goal.

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6. References

1. Askar, M. K. (2014). Rainfall runoff model using the SCS-CN method and geographic information systems: A case study of Gomal River watershed. *WIT Transactions on Ecology and The Environment. 178*, 159-170 [doi:10.2495/WS130141].

2.Bryan, J.E., & Shearman, P.L. (Comps) 2008. Papua New Guinea Resource Information System Handbook 3rd ed. University of Papua New Guinea. Port Moresby.
3.Feizizadeh, B., & Haslauer, M. (2012). GIS-based Procedures of Hydropower Potential for Tabriz Basin, Iran. *International Journal*, 495-502.
4.Kuna, I., & Zehner, R. (2015). Papua New Guinea Country Update. *Word Geothermal Congress 2015*. Paper presented at the World Geothermal Congress, Melbourne, 19-25 April, 2015. Retrieved from https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/01028.pdf.
5.NSO (National Satistic Office)., (2014), *Final Figures Papua New Guinea National Population and Housing Census 2011*. Waigani, NCD.
6.O'Keefe, T. C., Elliott, S. R. and Naiman, R. J., (2000), Introduction to Watershed Ecology. *US Environmental Protection Agency*. Retrieved from http://www.epa.gov/watertrain
7.Pal, B., Samanta, S,. and Pal, D.K. (2012). Morphometric and hydrological analysis and mapping for Watut watershed using Remote Sensing and GIS techniques. *International Journal of Advances in Engineering & Technology,2* (1), 357-368.
8.Patil, N.S., Shirkol, I.T,. and Joshi,S.G. (2013). Geospatial Technology for Mapping Suitable Sites for Hydropower Plant. *International Journal of Innovative Technology and Exploration Engineering, 3* (3), 2278-3075 [doi: 10.1.1.679.2045]
9.Setiawan, D., (2015). Potential Site Screening for Mini Hydro Power Plant Developments in Kapuas Hulu, West Kalimantan: A GIS Approach. *Procedia*, *65*, 76-82 [doi:10.1016/j.egypro.2015.01.034].
10.Singh, D. (2009). Micro Hydropower Resource handbook, Renewable Energy Corporation Network for Asia Pacific (APCTT). Retrieved from: http://apctt.org/recap/sites/all/themes/recap/pdf/MicroHydro.pdf.

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