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Applying GIS to Identify Potential Location of Small Hydropower in Catchment Region

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Abstract

The effects of global warming and climate change have increased the frequency of floods and droughts, while over-urbanization has exacerbated the problem of disasters. In 2015, the United Nations proposed Sustainable Development Goals (SDGs), which state that the proportion of renewable energy in the energy structure should be significantly increased, and that such a goal is a joint effort of governments, businesses and citizen groups. In addition, the Intergovernmental Panel on Climate Change (IPCC) report states that global warming should be limited to 1.5°C to avoid increasing impacts of climate change, and in order to achieve this goal, global carbon emissions must be reduced by 45% in 2030 compared to 2010 and must reach "net zero" by 2050. For this reason, the world is actively developing green energy. Comparing to other renewable energy, small hydropower might cause little impact on the ecological environment. The steep terrain and abundant rainfall in Taiwan should have abundant potential for small hydropower, so this study aims to develop a GIS tool to quickly locate potential small hydropower sites in each catchment area. The feasibility assessment of small hydropower takes into account hydraulic head, discharge, water quality, geology, economics, and transportation. Traditional surveys are labor-intensive, time-consuming, and costly, so this study will develop a visualization tool that uses topographic data (DEM) and average annual runoff to assess small hydropower potential sites. The study area was located in central Taiwan. The QGIS software package was used to process the data, and the topographic data was used to find the appropriate hydraulic head and calculate the average annual flowrate for small hydropower potential assessment.

Keywords: Small hydropower, Geographic information system, Renewable energy

1. INTRODUCTION

Small hydropower is a clean, renewable and reliable source of energy and is one of the most important sources of renewable energy. Small hydropower installations have relatively little ecosystem impact, and in addition to addressing the limitations of large hydropower, their flexibility can improve grid stability and support other intermittent renewable energy sources, hence the renewed global demand for small hydropower plants (G. Ardizzon et al., 2014). Most of the world's small hydropower potential remains untapped, with the 2019 World Small Hydro Power Development Report (WSHPDR) indicating that the global potential for small hydropower under 10 MW is about 229 GW, but the installed capacity is only 78 GW. This is not only time consuming and costly, but may also miss many potential small hydropower sites. In fact, GIS tools and hydrological modeling tools combined with DEM and rainfall data can be used to quickly assess the generation capacity of small hydropower sites and complete a preliminary feasibility assessment (B.C. Kusre et al., 2010). Small hydropower can be installed in natural rivers or existing water supply channels. R. N. Prajapati (2015) used HEC-HMS to delineate sub-catchments and calculate the generation potential of each section of junction, but the study did not analyze the variation of different river sections, different water intakes and total generation potential. In this study, QGIS and HEC-HMS are used to investigate the impact of selected river segments on the generation potential of natural rivers, which can be used to examine the generation capacity of each river segment in detail and help investors to decide whether each site is suitable for investment.

2. STUDY AREA AND DATASET

Beigang Basin lies in central Taiwan (Figure 1). The Beigang River is an important tributary for the Wu River, the drainage area is approximate 536.33 km^2, average annual rainfall ranges between 2000 and 2400 mm/year. It has been assumed that the annual rainfall was 2300 mm, the process of preparing rainfall data is described more detail in chapter 3. The 20 m resolution DEM has been used to calculate the drop in QGIS and delineate the stream network in HEC-HMS.

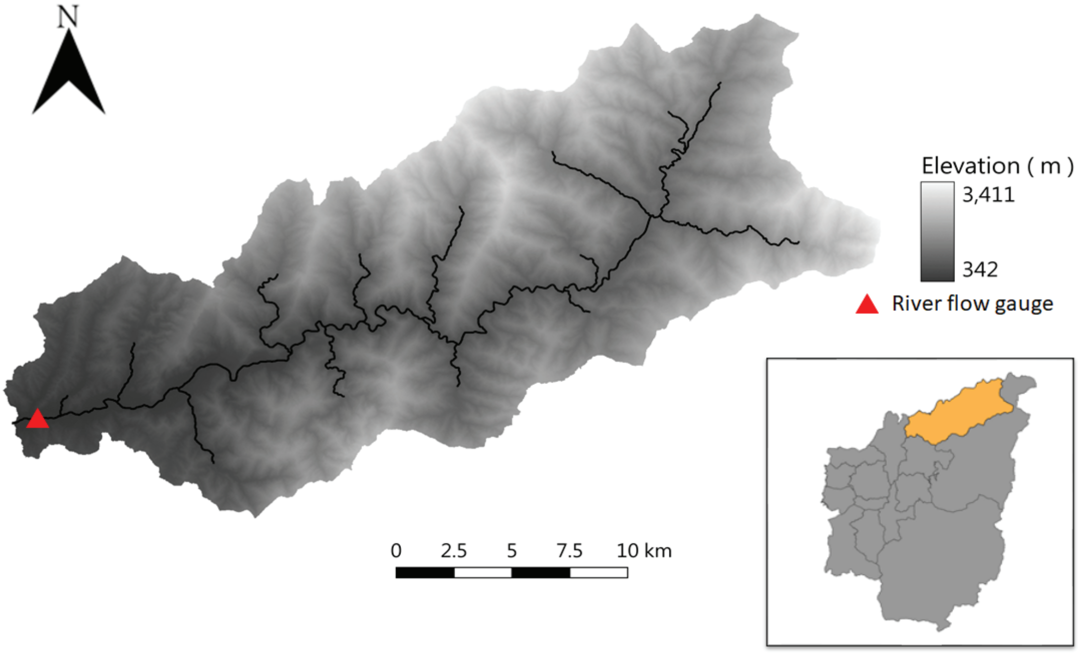

Figure 1. Digital Elevation Model (DEM) of the Beigang river basin and location of river flow gauges.

3. METHODOLOGY

The potential of run-of-river hydropower is determined by the river flow Q and drop head H. Q is evaluated by the rainfall-runoff hydrological model, and H is obtained from DEM by calculating the elevation difference. The theoretical power potential is estimated by Eq. [1]:

$$P = \rho * g * Q * H \qquad [1]$$

where P is the generated power in watt, ρ is the density of water (1000 kg/m^3), g is acceleration due to gravity (9.81 m/s^2), Q is the river flow rate (m^3/s), H is falling height (m).

The potential estimation procedure will be carried out in 3 steps. The flow chart of determining the river flow rate and drop head is shown in Figure 2.

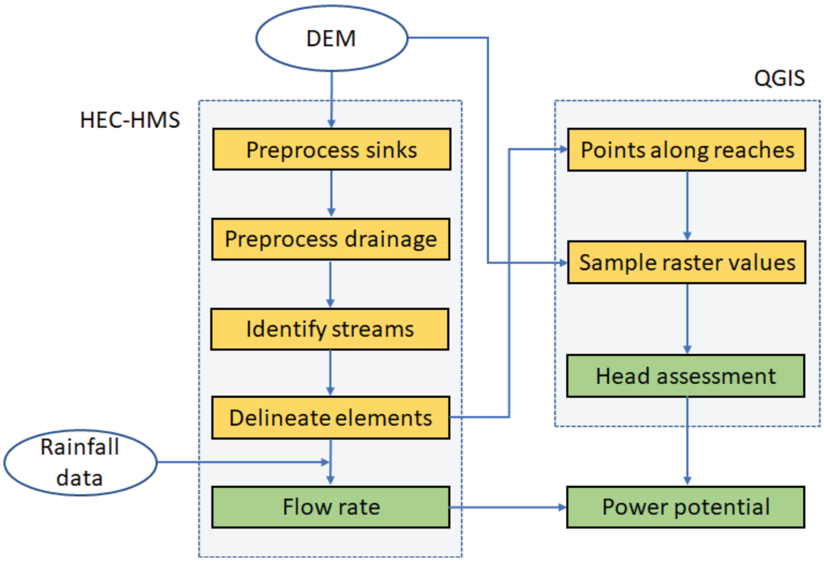

Figure 2. The process of assessment for hydropower potential.

3.1 DEM processing

HEC-HMS version 4.8 includes GIS tools that allow users to delineate elements, compute subbasin and reach characteristics, and the output layers can be applied in QGIS. The subbasin and river network established in HEC-HMS are shown in Figure 3.

i. Preprocess sinks: It may have an error in modeling surface runoff with DEM files have sinks in it. Preprocess sinks algorithm will remove the pit and produce a new, hydrologically-corrected DEM.
ii. Preprocess drainage: This algorithm determines the flow direction and flow accumulation for each grid cell in the terrain data raster.
iii. Identify streams: In this step, the drainage accumulation threshold will be set, defined where the stream start and build the stream network.
iv. Delineate elements: Delineate the subbasin and reach, and calculate the area of each subbasin and the length of each reach.

Figure 3. Subbasins and reaches extracted from HEC-HMS.

3.2 Flow Rate Assessment

As mentioned in chapter 2, the annual average rainfall is assumed to be 2300 mm/year which is about 6.5 mm/day. In HEC-HMS, use a 10-years long series of positive random number that average is 6.5 as rainfall data input. The final output from HEC-HMS is the discharge of each subbasin and reach in m^3, it is then divided by 315,360,000 (total second in 10 year) to get the unit in m^3/s. The discharge evaluated in this step will be linearly interpolated based on the area to determine the flow rate at each points created in next step.

3.3 Head Assessment

By specific tools in QGIS, the drop head can be determined according to the criteria. The river network has been created in chapter 3.1 and it can be used in QGIS.

i. Points along reaches: Create points along the reach generated in HEC-HMS in fixed distance, it is started from the lowest elevation to the highest of each reach.
ii. Sample raster value: This algorithm extracts raster values at the point locations, makes the points created in step 1 have the elevation data from DEM.

The river network is divided into several segments in this step, in each segments, the higher end is regarded as water inlet and the lower end is regarded as power plant. With the flow rate at the higher end and the elevation difference between both ends, the potential of hydropower can be evaluated by Eq. [1].

4. RESULT AND DISCUSSION

According to the chapter 3.3, the points have been created along the river network in every 100 m, 300 m, 500 m and 1000 m respectively. The hydropower potential map of these four plans are shown in Figure 4., the maps show that the power hotspots of each plan are in the same location. This results indicated that, by considering the flow rate and head drop only, the potential sites of small hydropower are nearly the same. Table 1. shows the comparison between the statistical index, the maximum capacity of single site is higher with the distance is higher, and the total capacity doesn't change significantly in four plan.

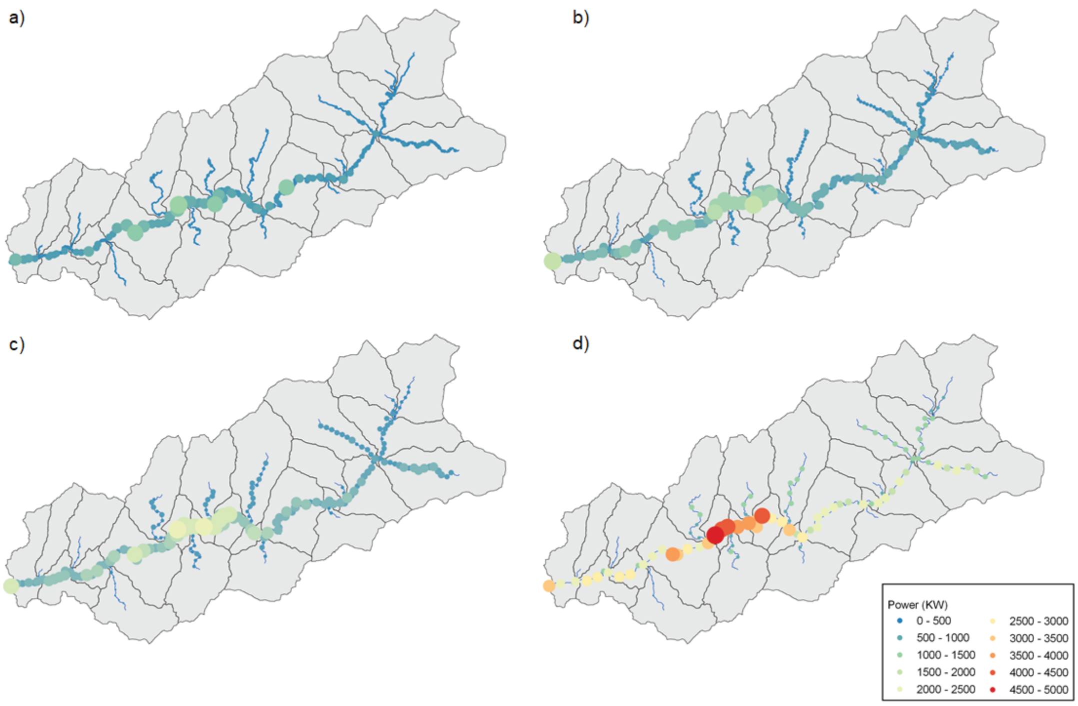

Figure 4. Maps of hydropower potential sites: (a) power plants every 100 m along river network; (b) power plants every 300 m along river network; (c) power plants every 500 m along river network; (d) power plants every 1000 m along river network.

Table 1. Statistics of hydropower potential of each plan.

	100 m	300 m	500 m	1000 m
Max. Capacity (KW)	1532.6	2014.1	2628.1	4614.5
Total Capacity (MW)	191	187	185	184

5. CONCLUSION

In this study, the potential for small hydroelectric power generation in the Beigang river basin was analyzed using QGIS and HEC-HMS. The theoretical power generation for all sites in the catchment was clearly presented through visualized graphs. The results of the study show that for the drop type turbines, the total power generation in the basin is not sensitive to changes in the calculated intervals. However, in addition to the drop type, the flow type is also used for small hydropower generation. This study only uses the drop type for evaluation at present, but in the future, if the river flow speed is calculated, the flow type will be included in the generation calculation. The calculation process proposed in this study will allow for a quick assessment of the potential sites in the catchment area, and the visualization of the results will help investors understand their location and investment feasibility.

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