Use of a GIS in reconnaissance studies for small-scale hydropower development in a developing country: a case study from Tanzania

YOUNIS A. GISMAILLA
Hydraulic Research Station, PO Box 318, Wad Medani, Sudan

MICHAEL BRUEN
Centre for Water Resources Research, Civil Engineering Department, University College, Earlsfort Terrace, Dublin 2, Ireland

Abstract Small-scale hydropower schemes, used to produce either direct mechanical or electrical energy, are attractive for remote small towns, villages or small industries. Expensive ground investigations must be carefully targeted to the areas which are most likely to yield viable and useful sites for hydropower development. A reconnaissance study, using GIS techniques, identifies areas in Tanzania likely to yield useful sites for small-scale hydropower development and thus suitable for further on-the-ground investigation. Information about hydrological, demographic and economic factors are combined to yield a map representing an overall index of potential for small-scale hydropower development. The study’s main value however is both that it highlights a number of other areas worthy of more detailed ground investigation and also that it eliminates large parts of the country from further consideration.

INTRODUCTION

Tanzania is one of the largest countries of East Africa. It covers an area of almost a million km$^2$ (1-12°S, 29-41°E). In a large developing country faced with the task of rural development with scarce resources any scheme for developing an existing natural resource at a small and sustainable scale is welcome. Small-scale hydropower schemes, used to produce either direct mechanical or electrical energy, are attractive for small towns, villages or small industries in areas far from the national electricity grid and unlikely to be connected to it for the foreseeable future.

Identifying a suitable site for such a small-scale hydropower development and designing and constructing the unit requires a detailed ground survey by a specialist team. However because of cost and manpower constraints, it is not practical for such teams to survey all, or even most, of a country or region. Therefore their search must be carefully targeted to the areas which are most likely to yield viable and useful sites. This paper describes a reconnaissance study, using GIS techniques, to identify the areas in Tanzania likely to yield useful sites for small-scale hydropower development and thus suitable for further study by an on-the-ground survey team. The problem is not a trivial one. Although there has been some small-scale hydropower in some areas of Tanzania, for example in the Usambara mountains, the question remains of what other areas are suitable for this type of development.
THE PROBLEM

Sites for large-scale hydropower development, require relatively large flows and/or high hydraulic heads. In addition, the value of the energy produced is generally so great that, even if the site is remote, it is still worthwhile to build a transmission line to connect the site with the national grid. Identifying suitable sites requires essentially a linear search since it can be confined to regions close to the major rivers. It is quite likely that all candidate rivers have been accurately mapped.

In contrast, identifying sites for small-scale hydropower development in a developing country does require a truly two-dimensional, spatial approach. This is because large flow rates are not necessarily required and thus the search is not confined to the major rivers. Small rivers and streams, particularly mountain streams, may provide sufficient power to justify a small-scale development. All of these may not appear, or be well defined, on the available maps in a developing country and the focus of search thus must be changed from looking for specific promising streams to rather looking for the areas in which promising streams are likely to be encountered. Once such areas are identified, the ground survey team will select the best stream and site. It is this spatial character which can be tackled using a GIS.

There are a number of factors which must be considered when selected suitable areas for further investigation. In the following sections the paper describes the production of thematic maps for each of these factors from the available maps and other sources of information.

HYDROLOGICAL FACTORS

The power available at a given location is directly proportional to the product of discharge and available hydraulic head:

\[ p = \eta \rho ghq \]  

where \( p \) is power (Watts), \( \eta \) is the overall efficiency of the installation, \( \rho \) is the density of water (kg m\(^{-3}\)), \( g \) is the acceleration due to gravity, \( h \) is the hydraulic head difference available (m) and \( q \) is the discharge through the turbine(s) (m\(^3\) s\(^{-1}\)).

Thus, suitable areas for further investigation are those with a large runoff potential and/or with large ground slopes and coverages relating to both were developed and combined to generate a coverage of an index of likely available power.

Runoff

Runoff is related to climatic factors, such as rainfall, evaporation and transpiration which themselves are related to temperature and humidity. It is also related to catchment factors, such as soil type, topography, channel network structure and density and vegetation.

In this study runoff per unit area was taken as proportional to the product of net rainfall, i.e. rainfall less evaporation, and landscape. Net rainfall was estimated by subtracting potential evapotranspiration from rainfall.
Rainfall

A coverage of mean annual rainfall was compiled from a 1:3 000 000 scale map prepared by the Department of Geography, University of Dar es Salaam and based on an earlier map of mean annual rainfall of East Africa (Niewolt, 1973, 1977) (Fig. 1). It shows that vast areas of Tanzania are relatively dry, receiving less than 1000 mm of rainfall per year on average. However, there are very many small areas which receive considerably more rainfall, e.g. the northern tip of Lake Nyasa, the Uluguru and Usambara mountains, the southern and eastern slopes of Mount Kilimanjaro, the southern highlands near Mahenge, near Bukoba west of lake Victoria and the islands of Zanzibar and Pemba. In most cases, it is the topography, orographic lifting, which causes the increased rainfall, in some cases it is caused by convergence of the monsoon air currents. In Bukoba, Pemba and Zanzibar it is local wind systems, lake or sea breezes which are the main factors.

Fig. 1 Mean annual rainfall for Tanzania.
A coverage of potential evapotranspiration was prepared from maps produced by the Global Resources Information Database (GRID) in Nairobi.

Land slope

A coverage of average land slope was prepared by analysing contours on the Tanzania Y-503 series maps, drawn at a scale of 1:250 000. This series covers Tanzania with 63 sheets of which 49 were available for this study. Average land slopes for the missing sheets were calculated from 1:3 000 000 scale topographic map.

DEMOGRAPHIC FACTORS

One important feature particular to small-scale hydropower concerns its distribution to users. It is rarely economical to construct a special power line to distribute small-scale hydroelectricity over any appreciable distance. Thus the power must be used close to where it is generated, or else it must be generated close to an access point to the national grid. In a developing country the first condition is the most important. Thus a coverage relating to potential users of any power must be included in the analysis. Here again, there are two cases to be considered. Firstly, existing industries and/or towns and villages may use any newly developed hydropower capacity, substituting it for other energy sources. Hydropower may, for instance, replace oil as an energy source and this can be attractive especially if the oil must be purchased with external currency. Secondly, the availability of a source of cheap power may attract new industries to its source. In small-scale hydropower the former is generally more likely than the latter. Since the distribution of both existing industry and private consumers can be closely related to population distribution, it can be assumed that where there are greater densities of population the opportunities for using the power are greater than for areas with low population densities. Thus a coverage of population distribution was used in this study.

Population

A population distribution coverage was generated from maps based on the results of the 1967 population census of Tanzania (Thomas, 1973). Unlike rainfall patterns and land-slope, population distribution can be expected to vary as time goes on and dramatic changes can occur. Thus population distribution maps can go out of date rapidly, especially in a developing country. The 1967 census maps were the only ones available at the time of this study and are a weakness of this study. However a more recent census has been undertaken and it would be interesting to compare the differences between the two.

ECONOMIC FACTORS

Economies of scale dictate that hydroelectricity generated from large-scale plant is cheaper than that from small-scale plant. Thus areas of the country already serviced by the National Grid should not be a high priority for consideration for small-scale
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hydropower development, unless the power is to be sold directly into the National Grid. In this study a map of the National Grid is used as a "mask" to exclude such areas from consideration. However, not all the areas through which the national grid lines pass are actually serviced by it. Thus only areas in which there was a sub-station distributing electricity to a local low-voltage network were excluded.

METHODOLOGY

A simple raster type geographical information system was written for this study in the BASIC language and was run on an MS-DOS PC with an 80286 CPU. The original study used the results from this program. Subsequently, the study was transferred to a

Fig. 2 Potential for small-scale hydropower development.
commercial GIS system running on a 80486-based PC with much improved image processing facilities.

Because of the limited resolution of the available information this study used a relatively coarse discretization. The pixel size was chosen to give six pixels per degree both of latitude and of longitude. Pixels are thus rectangular rather than square and each represents an area of approximately 340 km².

The coverages of rainfall, land slope and potential evapotranspiration were combined to produce a single coverage representing the areal distribution of hydrological factors favouring hydropower potential. The combination is multiplicative, with net rainfall and land slope being multiplied together.

The hydrological potential coverage is then combined with the population distribution coverage to identify areas where high hydropower potential coincide with high population densities. The resulting coverage is masked and areas already served by the national grid are removed to give the final map of small-scale hydropower potential (Fig. 2).

The greatest small-scale hydropower potential is in areas of Kilimanjaro Region, Tanga Region (Usambara mountains), Mtwara Region and Ziwa Magharibi Region (near Bukoba). Some of the areas are adjacent to large towns which already have a national grid supply. Some are away from towns but in fertile areas where there is a naturally high but relatively uniform population distribution.

Not surprisingly the Usambara and Bukoba areas where small-scale hydropower has already been developed scored highly on this index and this supports the value of the methodology used. The study’s main value however is both that it highlights a number of other areas worthy of more detailed investigation. An additional and important result of this study is that large regions unlikely to be suitable for developing small-scale hydropower are identified.

The authors consider GIS to be an important tool in studies of this type because the work can be easily updated as new information becomes available. In a developing country, in particular, the quality and relevance of existing data can change rapidly, particularly in relation to population distribution and its consequences. The methodology requires relatively standard GIS features and could easily be applied to other developing countries.

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REFERENCES

