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Finding Potential Sites for Small-Scale Hydro Power in Uganda: a Step to Assist the Rural Electrification by the Use of GIS.

A Minor Field Study

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Degree-thesis in Physical Geography and Ecosystem Analysis
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Abstract

Over 2 billion people, mostly in developing countries, have no access to modern fuels or electricity. The necessity of clean, efficient, reliable and affordable energy services is a crucial issue in developing countries, especially in the context of rural areas where the majority of the people lives. Renewable energy sources in shape of small-scale hydropower systems are a complement or alternative to grid extension. The purpose of this study was to develop a method in order to find potential sites for small-scale hydropower in our study area in southwestern Uganda, by using a Geographical Information System (GIS) and also to investigate the rural energy situation in the area. A GIS is a computerized information system for collecting and handling data in databases as well as a powerful tool for analysis and visualization of geographical data. The results indicate a generally positive attitude to electricity and all interviewees were in great need of its services. Almost all consider themselves to have some means to pay for the electricity even if it is more expensive than what the energy cost today. Our self-designed algorithm identified 250 potential sites for small-scale hydropower stations in the study area. A selection of 14 sites out of these was evaluated and resulted in only three sites fulfilling the defined requirements. All sites met the requirement regarding a certain slope, but the majority lacked a permanent flow of water. The outcome from the evaluation was a result of low quality of the watercourse input data. In conclusion, our method is swift and precise, presupposed reliable input data is available. Presupposed there is a need for electricity and good financing possibilities, small-scale hydropower is an appropriate alternative to assist rural electrification, which will lead to improved standard of living.

Sammanfattning

Mer än två miljarder människor, mestadels i utvecklingsländer, saknar tillgång till moderna energikällor eller elektricitet. Behovet av rena, effektiva, pålitliga och ekonomiskt överkomliga energitjänster är en viktig fråga i utvecklingsländer, särskilt för landsbygden, där merparten av befolkningen bor. Förnyelsebara energikällor i form av småskaliga vattenkraftverk är ett bra komplement eller alternativ till utbyggnad av befintligt elnät. Syftet med den här studien var att utveckla en metod för att hitta potentiella platser för småskaliga vattenkraftverk i vårt studieområde i sydvästra Uganda, genom användandet av ett Geografiskt Informationssystem (GIS), men också att studera landsbygdens energisituation i området. Ett GIS är ett datoriserat informationssystem för insamling och hantering av data i databaser, men också ett kraftfullt verktyg för analys och visualisering av geografisk data. Våra resultat visar en generellt positiv attityd till elektricitet och de intervjuade var i stort behov av dess tjänster. Nästan alla ansåg sig att i viss mån ha pengar till elektricitet, även om det skulle kosta dem mer än vad de betalar för sin energi idag. Vår egendesignade algoritm identifierade 250 potentiella platser för småskaliga vattenkraftverk i studieområdet. Ett urval av 14 av dessa utvärderades, vilket visade att bara tre platser uppfyllde uppsatta kriterier. Alla platser uppfyllde kravet på lutning, men merparten saknade ett permanent vattenflöde. Resultatet av utvärderingen berodde på låg kvalitet på inputdata innehållande vattendrag. Vår metod är sammanfattningsvis snabb och noggrann, förutsatt att pålitlig inputdata är tillgänglig. Förutsatt att det finns ett behov av elektricitet samt goda möjligheter till finansiering, så är småskaliga vattenkraftverk ett passande alternativ för att bistå distributionen av el till landsbygden, vilket kommer att leda till förbättrad levnadsstandard.

Acknowledgments

First of all, we would like to give special thanks to both of our Swedish supervisors: Assistant Lecturer Ulrik Mårtensson and Associate Professor Petter Pilesjö at GIS Centre, Department of Physical Geography and Ecosystem Analysis, Lund University for good advise and inspiration.

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This study could not have been performed if we had not received the Swedish International Development Cooperation Agency's (Sida) scholarship for Minor Field Studies, which was granted by the Department of Social and Economic Geography at Lund University and Högskolan i Kalmar. Thank you for giving us this opportunity to attain all this knowledge and experience.

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Students at the Department of Physical Geography and Ecosystem Analysis, friends and family.

Table of Contents

1 Introduction

This master thesis has been performed during the autumn of 2004, as a Minor Field Study (MFS) funded by a scholarship granted through Swedish International Development Co-operation Agency (Sida). The MFS Scholarship Programme is intended to give Swedish students the possibility to increase their knowledge about developing countries and development issues. It is also supposed to give the students, teachers and departments at Swedish universities the possibility to develop and strengthen contacts with departments, institutes and organisations in developing countries. The scholarships are administrated and granted through many different Universities throughout the country. This study was granted scholarships from both the Department of Social and Economic Geography at Lund University and Högskolan i Kalmar.

The study has been conducted by both Department of Physical Geography and Ecosystem Analysis at Lund University and the Technical Faculty of Makerere University, Kampala. The field study has been performed in the southwestern parts of Uganda.

1.1 Background

More than half of the world's population lives in rural areas, almost 90 percent of them, approximately 3 billion, in developing countries. Out of these nearly 1.6 billion are without access to commercial energy (UN, 2003; WEC, 2000). This means that these people are dependent on the traditional fuels of wood, dung and crop residue, often using primitive and inefficient technologies. For a lot of them, this combination just about allow them to fulfil their basic human needs of nutrition, warmth and light. There are small or no possibilities for them to utilize energy for productive uses, which might begin to permit escape from the cycle of poverty (WEC 1999).

There are immense efforts done by governments and organizations throughout the developing world, trying to connect people to electricity grids or to provide them with modern biomass and other commercial energy. Between the years 1993 and 2000 as many as 300 million people were given access to commercial energy (WEC, 2000). Despite this there are still, as mentioned above, a considerable amount of people in need of energy and according to WEC (2000) this number will increase with another 400 million up to the year 2020. So there is and will continue to be a great demand after energy resources in the developing world.

For the specific case of Uganda, a country of 24 million people, it is estimated that less than 4% of the population has access to electricity, and that only 1% of the rural population of 20 – 21 million enjoys its benefits. This situation results in hindrances, making everyday duties hard and time consuming, which in turn complicates the process of development. For example, particularly the women spend a great deal of time and energy on collecting wood or finding other solutions such as diesel generators or car batteries for satisfying their energy needs (www.sida.se). Furthermore, after sunset in Uganda, which is at 6 PM throughout the year, the rural population must rely on torches, candles or small kerosene lamps for light, which causes health and environmental problems. Work at night is not possible and economic development, even in daylight, is limited without electric power (ovonics.com).

Rural Electrification Agency's (REA) main approach to amend Uganda's prevailing energy situation is through extension of the grid to rural areas. This measure has been sporadic at best, due to the lack of available funds. Also the dispersed nature of the population, difficulties in billing and collection, continuing capacity shortages and the high cost of grid extensions contributes to the complicated situation and makes the grid extension impractical for much of the population for the foreseeable future.

An efficient, relatively cheap and one of the most environmentally friendly alternatives to the grid based electrification is small-scale hydropower stations. Small-scale hydropower systems capture the energy in flowing water and convert it to usable energy (www.small-hydro.com). The capacity for most stand-alone hydro systems not interlinked to the grid, and suitable for "run-of-the-river" installation reaches up to 500 kW, and the potential depend on the availability of a suitable water flow. Where the resource exists it can provide cheap, clean and reliable electricity. A well-designed small-scale hydropower system can blend with its surroundings and have minimal negative environmental impacts (www.small-hydro.com; Fraenkel et al., 1991).

Moreover, small-scale hydropower stations have a huge, as yet untapped potential in most areas of the world and can make a significant contribution to future energy needs. It depends largely on already developed and proven technology, yet there is considerable scope for development and optimisation (www.small-hydro.com).

1.2 Objectives of the Study

The facts regarding the energy infrastructure in the developing world are overwhelming. There is no doubt that the need for access to modern energy sources is great and that today's efforts to connect rural areas by grid extension is not sufficient. Renewable energy sources in shape of small stand-alone systems are a complement or alternative to grid extension, and small-scale hydropower systems is in particular a sustainable option.

This interdisciplinary study, which is on one hand based on GIS-analysis of our collected data and on the other quantitative and qualitative interviews, has the objectives to:

- identify potential sites for small-scale hydropower in the study area located in the south-western parts of Uganda
- develop a method for localization of potential small-scale hydropower sites in the developing world
- investigate the rural energy situation in Uganda

Reaching these objectives will hopefully help us to answer the following questions:

- Are there any potential sites for small-scale hydropower stations in south-western Uganda?
- Is GIS a suitable tool for localization of potential sites for small-scale hydropower stations?
- How important is the digital data quality in the matter of finding potential sites for small-scale hydropower stations?
- Is there a need for electricity in rural areas in Uganda and how can it assist a sustainable development?
- What governmental measures are taken to assist rural electrification in Uganda?

We believe that a swift and straightforward method of locating potential sites for small-scale hydropower systems could be by the use of a Geographic Information System (GIS). A GIS is a computerized information system for collecting and handling spatial and non-spatial geographical data in databases as well as a powerful tool for analysis and visualisation (Eklundh, 1999).

Our GIS-analysis for finding potential sites is based on four different criteria.
The potential sites must:

- have a permanent watercourse
- have a specified slope
- be in vicinity of a village (to avoid high distribution costs)
- not be in an unsuitable area (national parks and electrified areas)

To be able to fulfil these criteria we expected to receive the following digital data over our study area:

- Rivers and streams
- Elevation
- Administrative boundaries down to village level
- Land use

By analysing this information we should be able to receive data showing good, accessible and legitimate sites for small-scale hydropower stations in the vicinity of settlement.

2 Study Area

The main reason for us to choose Uganda as country to perform our study in is the good relations and the ongoing cooperation between Makerere University in Kampala and GIS-Centre at the University of Lund. Makerere University has good expertise within GIS, and could therefore be of assistance and guidance. Uganda is also a poor country, with a very limited access to electricity, and therefore in great need of assistance in their development.

2.1 Uganda

Uganda stretches between 4° N and 2° S latitude and 29° and 35° E longitude (go.hrw.com). It is a very fertile country located in East Africa, with an area about half the size of Sweden (241,139 km^2) and a population of 26.4 million people in 2004. The capital is Kampala with a population of 1.2 million. Other major cities are Jinja, Mbale and Mbarara, as can be seen in Figure 2.1 (www.cia.gov). The southern border of the country is located just south of the equator, but the main part is on the East African plateau (Johannesson, 2003). It is bordered by Sudan to the north, Kenya to the east, Tanzania and Rwanda to the south, and the Democratic Republic of the Congo, formerly Zaire, to the west.

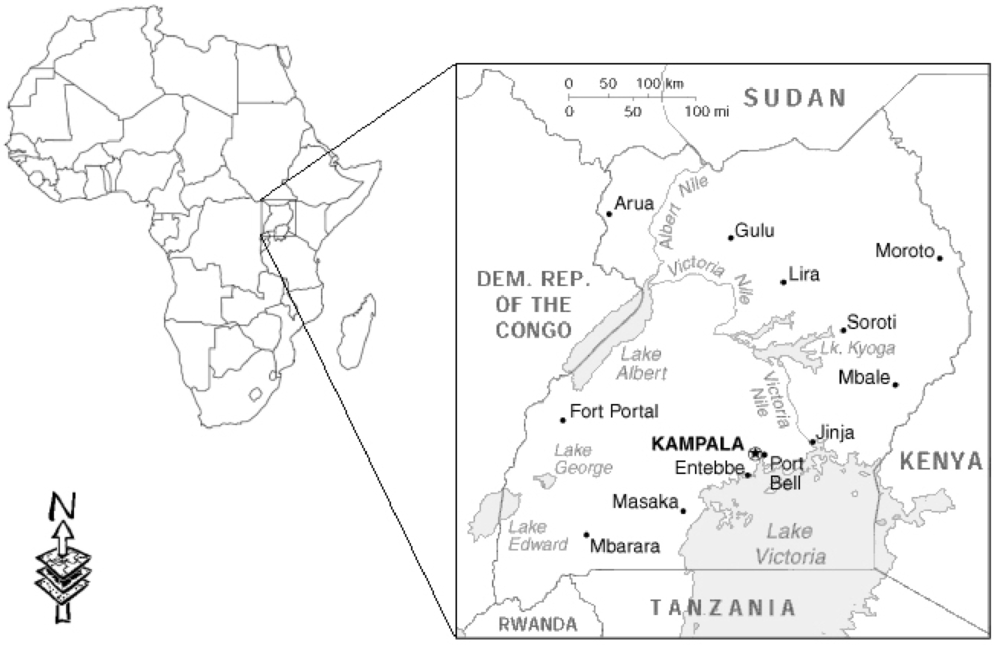


Figure 2.1 Uganda with major cities and lakes. Source: www.worldatlas.com; CIA.

Most of the Ugandan people live in rural areas; only 12% lives in larger cities. The population density is high but has major variations in certain parts of the country, depending on soil fertility. The main part of the rural population lives in the fertile half-moon along the Lake Victoria (Johannesson, 2003).

Uganda is divided into the administrative units: districts, counties, sub-counties, parishes and villages (www.ubos.org). The southern districts Kisoro and Kabale (see Figure 2.2), were chosen to be our study area because it's mountainous and precipitation rich conditions, which makes it an area with high potential for hydropower.

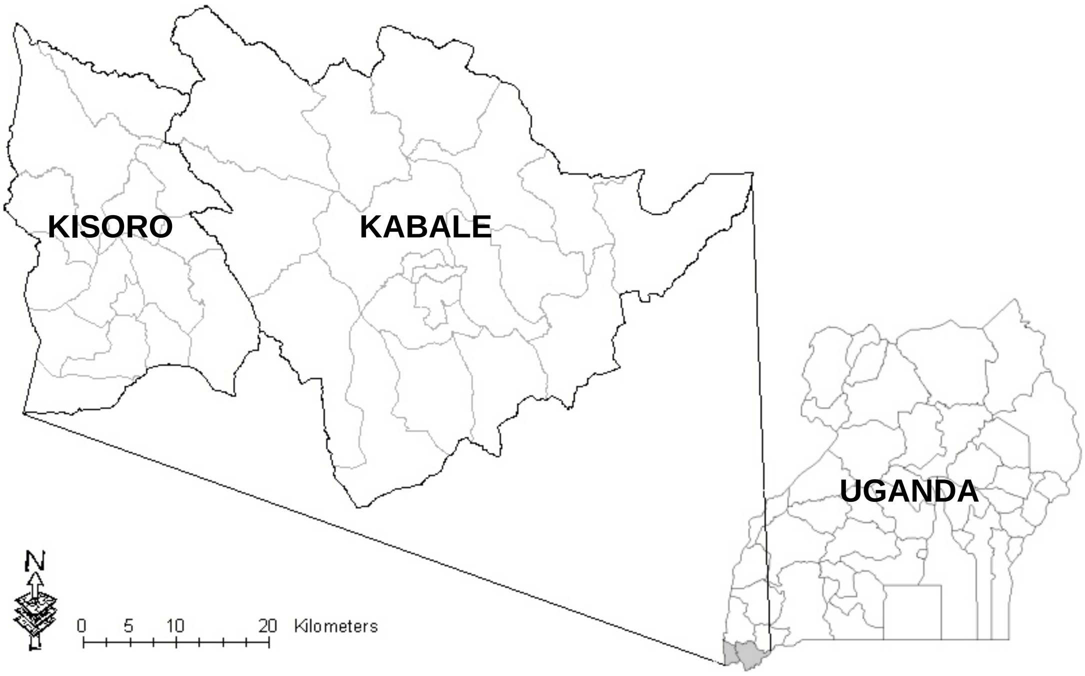


Figure 2.2 Uganda and the study area, showing the districts of Kisoro and Kabale with sub-counties.

2.1.1 Socio-Economy

Due to the favorable climate, fertile soils, rich natural resources and a relatively well-educated population, Uganda has good prerequisite for economic development. During the latest fifteen years, the country has showed a high economic growth due to the government's economic reform program. But the growth started from a very low level, and Uganda is still considered as a very poor country. A continued economic development is reduced by a number of problems, amongst others guerilla war in the north and a too strong dependence on a few export products, coffee in particular (Johannesson, 2003).

In the 1960's Uganda was one of the richest countries in Africa, with successful agriculture and a significant refining industry. The relative prosperity was destroyed during the rule of Idi Amin, not least because of the banish of the population with Asian background, which dominated the country's business world. A great contribution to the economic recovery was when the banished Asians, in 1991, were invited to return and reclaim their property.

The driving force in the development has been the private sector, which was stimulated by the deregulation of the governmental sector. After 1986 the mean growth rate was over 5% until 2003 and the industrial production had a significant growth of approximately 14%. The inflation decreased from three digit mean levels per year during the 1980's to 3% per year 1997-2002 (Johannesson, 2003).

The agriculture is the dominating sector within the economy and is equivalent to 40% of GDP. The industry is primarily concentrated on refining agricultural products. Larger factories produce tobacco-products, drinks and textiles and clothing. Almost all production is made for the local market and the industry is concentrated to Kampala and Jinja by Lake Victoria. The largest natural asset is the fertile soil, but the country has also large deposits of copper. Uganda was also in the late 90's Africa's second largest gold exporting country, although a large portion of this gold had been smuggled in from Congo Kinshasa. Agricultural products and fish are equal to about 90% of the export and the sector employs almost 80% of the population. The fertile soil and the favorable climate in southern Uganda makes it possible to harvest two times a year under normal precipitation circumstances and with irrigation three to four times a year. Staple crops consist of matoke, cassava, sweet potatoes and corn (www.cia.gov).

Firewood and charcoal represents 90% of the total energy consumption in the country. The remaining 10% are extracted from imported oil or nature gas or as electricity almost exclusively produced at the hydropower station at Owen Falls.

Uganda is one of the most aids ravaged countries in the world, but it is also the first country in Africa with a successful aids program. There has been a decrease from 30% of HIV positive adults in 1992 to less than 6% in 2003 (Johannesson, 2003).

2.1.2 Climate

According to Köppen's Climate Region System, Uganda is classified to have a tropical wet-and-dry climate (Aw). In difference to Köppen's tropical wet climate (Af) this region has a distinct dry season during a period of about two months, with monthly rainfall less than 60 mm (Ahrens, 2000).

The climate of Uganda is modified by elevation and, locally, by the presence of the lakes. The major air currents are northeasterly and southwesterly. Because of Uganda's equatorial location, there is little variation in the sun's declination at midday, and the length of daylight is nearly always 12 hours. All of these factors, combined with a fairly constant cloud cover, ensure an equable climate throughout the year.

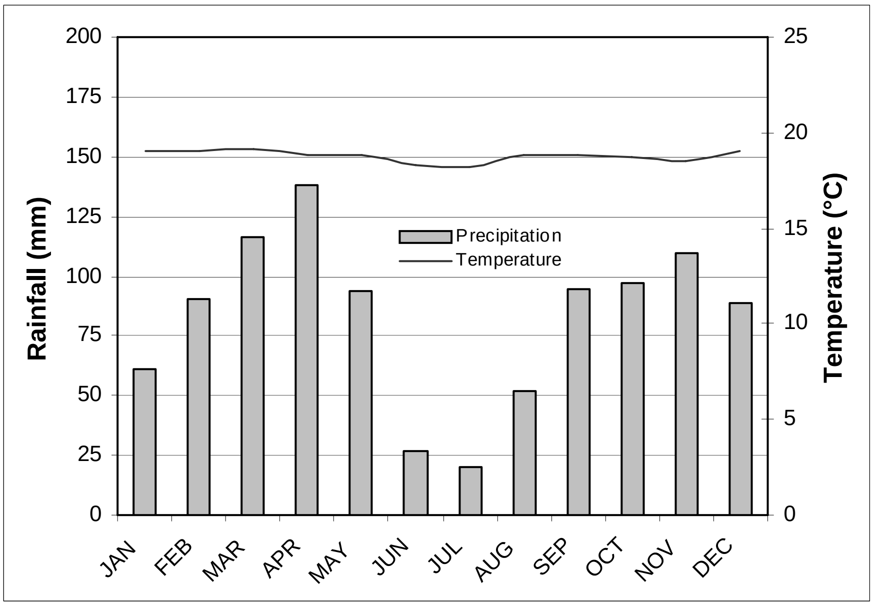


Figure 2.3 Kampala's monthly mean precipitation (mm) 1937-1981 and monthly mean of the daily 24-hour temperature (°C) 1931-1954. Source: cdiac.esd.ornl.gov.

Most parts of Uganda has a high amount of precipitation, annually ranging from less than 500 mm in the northeast up to 3,000 mm in the Sese Islands of Lake Victoria. Figure 2.3 shows annual variation of precipitation and temperature for Kampala. In the south two wet seasons, March to May and October to November, are separated by dry periods, although the occasional tropical thunderstorm still occurs. In the north a wet season occurs between April and October, followed by a dry season that lasts from November to March (Encyclopaedia Britannica, 1992).

2.1.3 Topography

Most of Uganda is situated on a plateau, a large expanse that drops gently from about 1,500 meters above sea level in the south to approximately 900 meters in the north. Mountains and valleys mark the limits of Uganda's plateau region.

To the west a natural boundary is composed of the Virunga Mountains, the Ruwenzori Range, and the Western Rift Valley. The volcanic Virunga Mountains rise to 4,125 meters at Mount Muhavura and include Mount Sabinio with a height of 3,645 meters, where the borders of Uganda, Democratic Republic of the Congo, and Rwanda meet. Further north the Ruwenzori Range rises to 5,115 meters at Margherita Peak, Uganda's highest point. Between the Virunga and Ruwenzori mountains lie Lakes Edward and George. The rest of the boundary is composed of the Western Rift Valley, which contains Lake Albert and the Albert Nile River.

The northeastern border of the plateau is defined by a string of volcanic mountains that include Mounts Morungole, Moroto, and Kadam, all of which exceed 2,750 meters in elevation. The southernmost mountain, Mount Elgon, is also the highest of the chain, reaching 4,321 meters. South and west of these mountains is an eastern extension of the Rift Valley, as well as Lake Victoria. To the north the plateau is marked on the Sudanese border by the Imatong Mountains, with an elevation of about 1,800 meters (Encyclopaedia Britannica, 1992).

2.1.4 Vegetation

Vegetation is densest in the south and typically becomes wooded savannah in central and northern Uganda. Where conditions are less favourable, dry acacia woodland, tropical African shrubs or trees and euphorbia occur interspersed with grassland. Similar components are found in the vegetation of the Rift Valley floors. The steppes and thickets of the northeast represent the driest regions of Uganda. In the Lake Victoria region and the western highlands, forest covering has been replaced by elephant grass and forest remnants because of human incursions. The medium-elevation forests contain a rich variety of species. The mountain rain forests of Mount Elgon and the Ruwenzori Range occur above 1,800 meters followed by transitional zones of mixed bamboo and tree heath and mountain moorland. Uganda's 14,500 km^2 of swamplands include both papyrus and seasonal, grassy swamp (Encyclopaedia Britannica, 1992)

2.2 Kisoro and Kabale

Because of their favorable environment regarding important factors for small-scale hydropower, such as climate and topography, the two districts Kisoro and Kabale was the choice of study area in Uganda. Another constraining factor for the selection of study area was the prevailing disturbances, caused by the rebels, Lords Resistance Army (LRA), in the northern parts of the country. Kisoro and Kabale districts are two, for Uganda, typical rural areas situated in the southwest of Uganda. In these districts, where Kisoro and Kabale towns are the administrative headquarters, the population is 220,312 and 458,318 respectively. The region has a population density of over 400 inhabitants per km^2, which is one of the most densely populated regions in the world (www.ubos.org).

The study area covers a mountainous region structured through numerous chains of hills and ridges, which lies approximately 2000 m above sea level (see Figure 2.4). The highest point of the mountain is in the volcanic ranges bordering Rwanda in the southern part of the District and includes Mgahinga (3475 m), Muhavura (4127 m) and Sabyino (3645 m). These volcanic ranges are interspersed by wide saddles with valleys occupied by extensive swamps. The volcanic mountains are part of six dormant and two active volcanoes of Virunga range extending into Rwanda and the Democratic Republic of Congo (NEMA, 1998).

The rocky system underlying most part of the study area was influenced by the volcanic actions formed by the upsurge of the Western Rift Valley during the Pleistocene age. It is much eroded and altered and consists of metamorphic largely granitoid rocks, schist and foliated granites, granochiorate and adamellite. The high relief in the southwestern parts of the study area has the characteristics of highly weathered and exposed granite rocks. The study area is underlain by three main rock systems, namely the Precambrian, Cenozoic and Mesozoic groups. The volcanic activity was characterized by the outpouring of a great variety of potash rich in alkaline lava (NEMA, 1998).

Figure 2.4 The highest volcano in Kisoro district, Muhavura and it's surrounding ridges and valleys. Photo: Bergström 2004.

Kisoro District like Kabale District experiences two rain seasons a year with heavy rains from March to May/June and from August to November. December to February and June to August are dry seasons. The mean annual rainfalls in the Districts are 1000-1250 mm (see Figure 2.5). The study area has a relatively low temperature where mean annual maximum temperature is 23°-25°C in the dry spell and mean annual minimum record of 10°-12.5°C (NEMA, 1998).

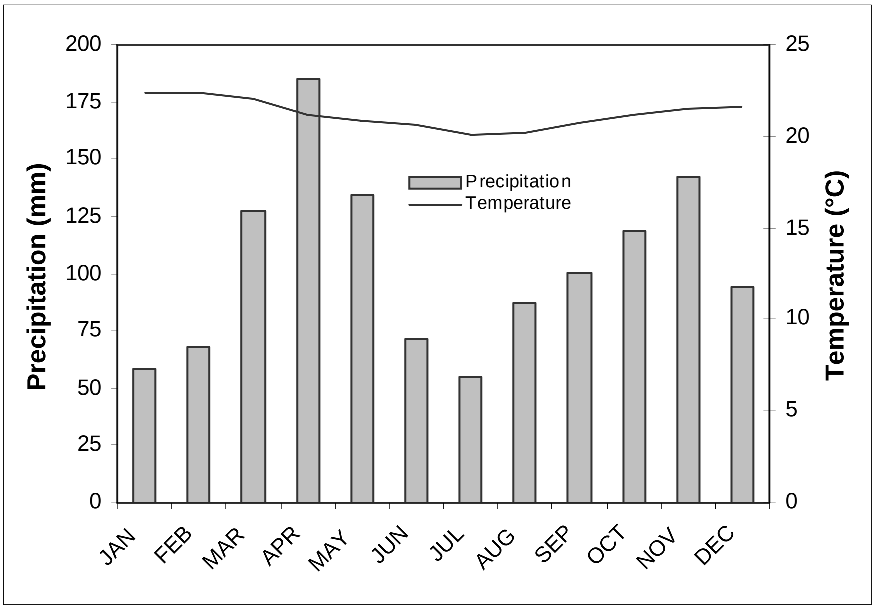


Figure 2.5 Kabale's monthly mean precipitation (mm) 1918-1974 and monthly mean of the daily 24-hour temperature (℃) 1952-1971 Source: cdiac.esd.ornl.gov.

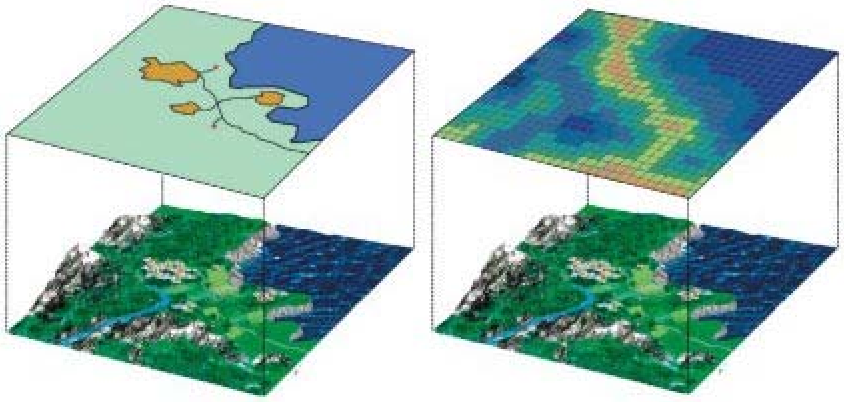
3 Theoretical Background and Rural Development

3.1 GIS

The definition of GIS according to Ekundh (1999) is:
“A computerized information system to handle and analyze geographical data.”

GIS stands for Geographical Information Systems and is simply a combination of maps and tabular information that is stored and handled in a computer. The system can handle data linked to a geographical position. This link means that every spatial object in the database has one or more coordinates in a system, which gives position on the earth surface (Eklundh, 1999).

Eklundh (1999) further states that the spatial objects are presented in either vector or raster format. Vector is a format where geographical objects in a coordinate system are linked to attributes stored in tabular form, which describe the geographical data (see Figure 3.1 a). A road can for example have information stored about its length and whether it is gravel or tarmac etc. Raster is a format where every picture element (pixel) or cell is given a numeric value. This format is most commonly used when analyzing continuous surfaces, for example elevation (see Figure 3.1 b).



(a) (b)

Figure 3.1Vector (a) and Raster (b) layers representing reality.
Source: www.giscentrum.lu.se.

The most common demands on a general GIS can according to Eklundh (1999) be concluded into a number of points:

- *Input and output of data:* The system should be able to read data from a number of different sources such as maps, satellite and aerial data, GPS receivers and tabular information from field surveys. In order to read the input data, 1) the user must be able to manually write the data, 2) the data should be able to be read from other digital systems and 3) the data should be able to be converted from maps or other documents (digitising). The data should also be able to be exported to other software, which often involves conversion of data formats.

- *Data handling:* This involves organization and maintenance of data in the system. Both spatial objects and their attributes must be stored in a way that simplifies search operations. Attribute data are handled in data base management systems, which facilitates modification and upgrading of the data.

- *Analysis*: Both attribute and spatial data must be searchable for analysis. Spatial relationships between different objects within and between different layers should be able to be analysed. This can be used by overlay operations of data layers to analyse spatial connections (see Figure 3.2).

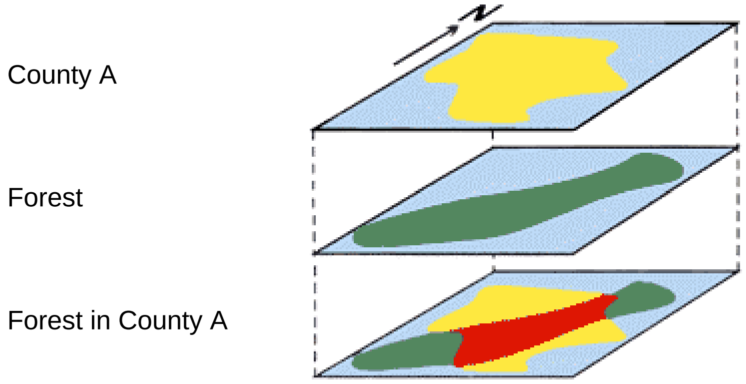


Figure 3.2 An example of an overlay operation of two data layers to get a third layer that contains information from both. The resulting layer in the example can be used to calculate the area of forest within and outside County A. Source: www.giscentrum.lu.se.

- *Presentation*: The end result from an analysis must be able to be presented in a educational way, such as maps, charts and concluding tables.

Examples of what a geographical information system can be a used for are:

- finding the shortest way between two points by using a map containing roads,
- mapping the potential customers for a planned enterprise by using population map,
- finding the optimal stretching for a new road building by combining maps containing properties, land use, slope etc and
- model environmental effects for a theoretical discharge by using climatic and soil data etc.

3.2 Small-Scale Hydropower

3.2.1 Characteristics

Being a renewable energy resource that never can be exhausted, and that it avoids the pollution associated with the burning of fossil fuels, makes hydropower a very attractive energy alternative. However, the larger hydro schemes involve massive dams, impounding enormous volumes of water in man made lakes, in order to provide year-round power by smoothing out fluctuations in river flow. These kinds of schemes are in many cases far from endless because the dams will gradually silt up and cease to function effectively as inter-seasonal storage reservoirs within a few decades. There are also numerous environmental problems that can result from interference with river flows, and many of the larger schemes have had adverse effects on the local environment (Fraenkel et al., 1991).

A well-designed small-scale hydropower scheme on the other hand, can blend with its surroundings and have minimal negative environmental impacts. It is one of the most environmentally favourable energy conversion options available, because unlike large-scale hydro these schemes tend to be "run-of-the-river", without significant damming or the creation of man-made lakes, (Fraenkel et al., 1991; IEA, 1998).

The definition of small-scale hydropower has no international consensus. In Canada "small" can refer to upper limit capacities of between 20 and 25 MW meanwhile it can mean up to 30 MW in the United States. However, a value of up to 10 MW total capacities is becoming more generally accepted as definition (www.small-hydro.com). Small-scale hydro is further classified in to small, mini, micro and pico hydropower based on the power output (Anderson et al., 1999; Maher & Smith, 2001). In this report we will refer to small-scale hydropower as schemes of 10 MW or less and use the definitions as follows in Table 3.1 The type of hydro schemes most suited for our study are the ones in the lower range of the "small-scale hydro"-concept, which according to table 3.1 are mini, micro and pico hydropower.

Table 3.1 Classification of hydropower. Source: Anderson et al., 1999.

Type	Capacity
Large hydro	> 100 MW
Medium hydro	10 - 100 MW
Small hydro	1 - 10 MW
Mini hydro	100 kW - 1 MW
Micro hydro	5 - 100 kW
Pico hydro	< 5 kW

kW (kilowatt) = 1000 watts, MW (megawatt) = 1 000 000 watts

Depending on the appearance of the site the small-scale hydropower schemes can be further subdivided into low and high-head systems. This is because the same level of power can be obtained from a large quantity of water falling a short distance (low-head), or from a smaller quantity of water falling a greater distance (high-head) (IEA, 1998).

Over the last few decades there has been a growing realization in developing countries that small-scale hydropower schemes have an important role to play in the economic development of remote rural areas, especially mountainous ones. Depending on the end-use requirements of the generated power, the output from the turbine shaft can be used directly as mechanical power or the turbine can be connected to an electrical generator to produce electricity. For many rural industrial applications, e.g. milling or oil extraction, carpentry workshop or for small scale mining equipment, shaft power is suitable, but many applications require conversion to electrical power. For domestic applications, like refrigerators, light bulbs, radios, televisions, and food processors electricity is preferred. This can be provided either:

- directly to the home via a small electrical distribution system, or
- by means of batteries which are returned periodically to the power house for recharging. This system is common where the cost of direct electrification is prohibitive due to scattered housing and hence an expensive distribution system (Anderson et al., 1999).

The basic physical principle of hydropower is that if water can be piped from a certain level to a lower level, then the resulting water pressure can be used to perform work. If the water pressure is allowed to move a mechanical component then that movement involves the conversion of water energy into mechanical energy. Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grain mill, or some other useful device (Fraenkel et al., 1991). Figure 3.3 shows the main components of a run-of-the-river small-scale hydropower scheme. Each of the components has been described more in detail below.

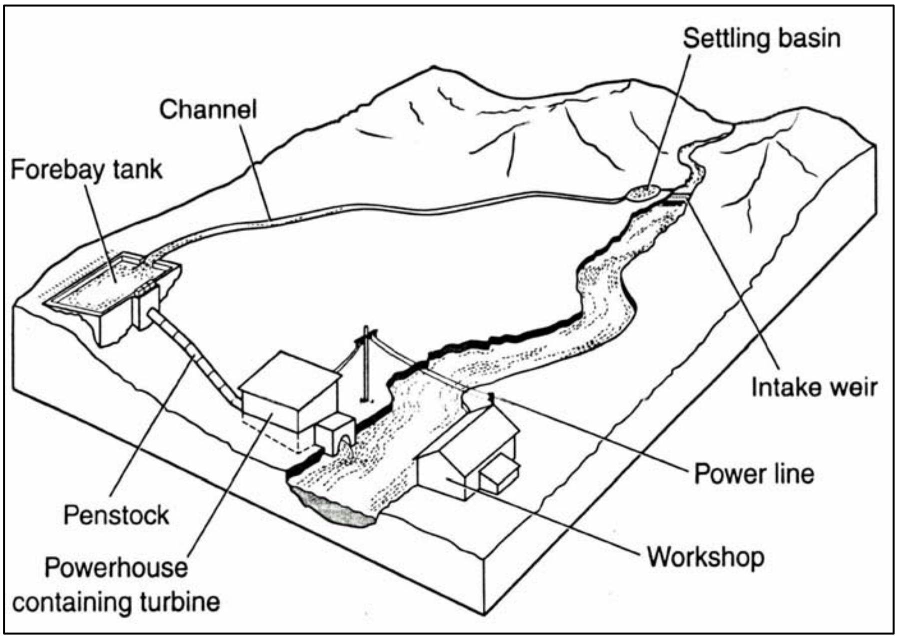


Figure 3.3 Layout and components of a typical small-scale hydropower installation. Source: Anderson et al., 1999.

- The source of water is a stream or sometimes an irrigation canal. Small amounts of water can also be diverted from larger flows such as rivers. The most important considerations are that the source of water is reliable and not needed by someone else. Springs make excellent sources as they can often be depended on even in dry weather and are usually clean. This means that the intake is less likely to become silted and require regular cleaning.

- Run-of-the-river schemes requires no water storage; the water is instead diverted by the intake weir into a small settling basin, where the suspended sediment can settle. A grid to prevent the flow of large objects such as logs, which may damage the turbines, usually protects the intake.

- The water can, when it is needed be channelled in, usually a concrete canal, along the side of a valley to preserve its elevation.

- The water is then led into the forebay tank, whose job is to hold a sufficient body of water to ensure that the penstock is always fully submerged to prevent suction of air to the turbine (www.esru.strath.ac.uk). The forebay tank can sometimes be enlarged to form a small reservoir. A reservoir can be a useful energy store if the water available is insufficient in the dry season.

- Then the water flows from the forebay tank or reservoir down a closed pipe called the penstock. The penstock is often made of high-density materials and exposes the water to pressure; hence the water comes out of the nozzle at the end of the penstock as a high-pressure jet. The recommended head, or the vertical drop from the beginning to the end of the penstock, for small-scale hydropower schemes should at least be 20 meters. A drop of 20 meters or more also means that the amount of water needed to produce enough power for the basic needs of a village is quite small.

- The power in the jet, called hydraulic power or hydropower, is transmitted to a turbine wheel, which changes it into mechanical power (see section 3.2.2). The turbine wheel has blades or buckets, which cause it to rotate when they are struck by water. Hydro-turbines convert water-pressure into mechanical shaft power, which can be used to drive an electricity generator, a grain mill or some other useful device. Via the tailrace in the powerhouse, the water returns back to the river from where it was taken.

- An electronic controller is connected to the generator. This matches the electrical power that is produced, to the electrical loads that are connected. The "load" is the appliances and machinery, which are energized by the hydro scheme. This is necessary to stop the voltage from going up and down. Without a load controller, the voltage changes as lights and other devices are switched on and off.

- The distribution system, or the power lines connects the electricity supply from the generator to the houses. This is together with the penstock, the most expensive parts of the system (Fraenkel et al., 1991; Maher & Smith, 2001; www.microhydropower.net)

3.2.2 Power

When discussing a hydropower project, the power concept can be divided into three different types, hydraulic, mechanical and electrical power, which will have three different values. The hydraulic power will always be more than the mechanical and electrical power, because some power is lost as it is converted from one form to another, as can be seen in Figure 3.4 (Maher & Smith, 2001). It is also important not to confuse the words "power" and "energy". Power is the energy converted per second i.e. the rate of work being done. Energy is the total work done in a certain time (Fraenkel et al., 1991).

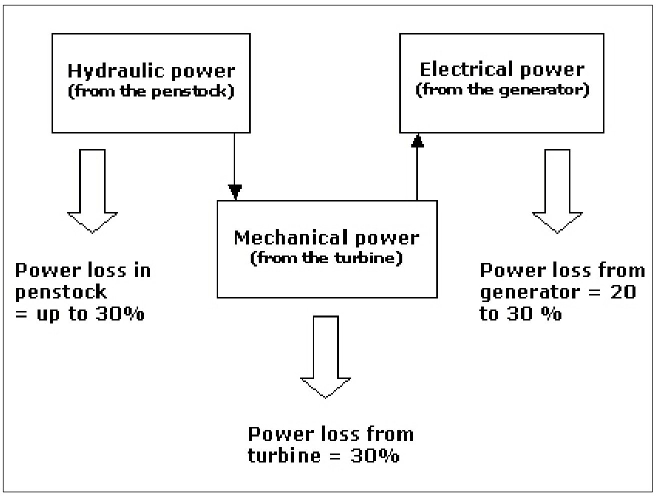


Figure 3.4. Some power is lost at each stage during the conversion from a water jet to electricity. Source: Maher & Smith, 2001.

About one third of the power is lost when the jet of water is converted into rotating, mechanical power by hitting the turbine wheel. There will also be a loss of around 20% - 30% in the generator when mechanical power is converted into electricity. The friction in the penstock will also cause power loss of another 20% - 30% (Maher & Smith, 2001).

To determine the power potential of the water flowing in a stream or a river, it is necessary to determine the flow rate of the water, the head through which the water can be made to fall and the system efficiency. (Anderson et al., 1999) Efficiency is the word used to describe how well the power is converted from one form to another. A turbine that has an efficiency of 70% will convert 70% of the hydraulic power into mechanical power and 30% will be lost. The system efficiency is the combined efficiency of all the processes together and is typically between 40% and 50% for small-scale hydro. The formula to calculate the hydraulic power is shown in Equation 3.1 below.

$$P = Q \cdot H \cdot g \tag{3.1}$$

Where:
P = Hydraulic power in Watts
Q = Flow rate in litres per second
H = Head or the vertical drop in meters
g = Acceleration due to gravity, 9.81 m/s^2
(Maher & Smith, 2001)

If we assume the following for a small-scale hydropower scheme; a head of 60 meters, a flow of 10 litres/second, a 25% power loss due to friction in the penstock, the turbine and generator is 65% and 80% efficient respectively, then the calculation to determine that schemes power potential will be as follows:

1. **Net head:**
   $0.25 \cdot 60 = 15\text{m}$
   $60 - 15 = 45\text{m}$

2. **Hydraulic power:**
   $45 \cdot 10 \cdot 9.81 = 4414\text{W}$

3. **Mechanical power:**
   $4414 \cdot 0.65 = 2870\text{W}$

4. **Electrical power:**
   $2870 \cdot 0.8 = 2295\text{W or } 2.3\text{kW}$

3.2.3 Environmental Aspects

Small-scale hydro is one of the most environmentally benign methods of power generation and the most significant environmental consideration is that it does not have any kind of emissions, which usually are associated with conventional energy resources. However, small-scale hydro is not totally without environmental problems (Fraenkel et al. 1991).

To begin with, even if the small-scale hydropower scheme itself does not generate any emissions, there are still some emissions associated with the technology during other life cycle stages. The chain of manufacturing processes required to manufacture and construct the generation and transmission equipment, e.g. penstocks, turbines, generators and cables, are a important source of emission (IEA, 1998). A study was performed in Northwest of America, to calculate emissions from the manufacture of materials used in construction of hydropower schemes. The study calculated the atmospheric emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and particulates per unit of material manufacture of steel, concrete, copper and aluminium for a site with a total capacity of 40.8 MW. The results show emission values of 8.6 g/kWh of CO_2, 0.025g/kWh of SO_2, 0.068g/kWh of NO_x and 0.005g/kWh of particulates (ORNL/RfF, 1994). These emissions are significantly less than those arising from conventional fossil fuel stations. For example, they have approximately half the direct emissions from a new build coal power station, with flue gas desulphurisation (EC, 1995). It should also be emphasized that the example is a relatively large project and is likely to represent the upper limit of emissions for most small-scale hydropower schemes (ORNL/RfF, 1994).

Further, the quality of the water in a river or stream connected to a small-scale hydropower scheme can be affected in numerous ways, amongst others through changes in suspended solids. Impounded water generally becomes sediment heavy, whereas discharge water is sediment deficient. The disruption of natural flow patterns may cause increased deposition or erosion, which can affect species and agriculture downstream (IEA, 1998).

The presence of small-scale hydropower has in many cases a negative influence of fish migration, in particular migratory salmonids, e.g. salmon and sea trout. The scheme can contribute to increased fish mortality both direct through creation of obstructions to the fish migration and indirect because the diversion also affects the invertebrate population in the river; this can reduce food sources for organisms up the food chain, including fish. The impacts on fish migration can be minimised in a number of ways, e.g. through the use of fish passes to allow the upward migration of fish or the installation of grids across water intakes and tailraces which prevents the entry of fish into the turbine (IEA, 1998).

There are several more environmental considerations such as; habitat change, impact on ecology and irrigation but most of these impacts are small, localised and often reversible and they can often be ameliorated or avoided by use of various methods or approaches (IEA, 1998).

3.2.4 Small-Scale Hydropower Status, Potential and Costs

To get small-scale hydropower into the context of total installed energy capacity it is suitable to first review the hydropower sector as a whole. In this section the reference WEC is abundantly used, even though it is rather old we consider the figures to be representative in order to get an opinion of the present conditions. According to WEC (1994) hydro plants accounted for a capacity of 627 GW, which is 22.9% of the world's total installed, electric generating capacity. The combined output was 2281 TWh, which is 18.4% of the world total electricity production. Industrialized countries account broadly for two-thirds and developing countries for one-third of this hydropower production. The statistics for regional small-scale hydropower capacity and production are given in Table 3.2. The estimated installed capacity of small-scale hydropower was about 19.5 GW in 1990, or 3.1% of world hydropower capacity. Annual output for small-scale hydropower is 81.7 TWh, which indicates that it accounts for 3.8% of hydro electricity production.

Table 3.2 Capacity and production of small-scale hydropower in 1990. Source: WEC 1994.

Region	Capacity (MW)	Production (GWh)
North America	4,302	19,738
Latin America	1,113	4,607
Western Europe	7,231	30,239
E Europe and CIS	2,296	9,438
Mid East and N Africa	45	118
Sub-Saharan Africa	181	476
Pacific	102	407
China	3,890	15,334
Asia	343	1,353
Total	19,503	81,709

The developing trend of small-scale hydropower up to the 1990's has been significantly increased in countries where the national policy is favourable regarding renewables, that is where aid encouragement to financially viable projects have been provided (WEC, 1994).

In WEC (1994) the total hydropower potential is used as a basis for estimations of the potential relating to small-scale hydropower. The reason for this is because total hydropower is much better defined and that inventories of small-scale hydropower sites are not yet complete for many areas of the world. The extent to which the currently estimated total exploitable hydropower potential has been developed is shown in Table 3.3.

Table 3.3 Development extent of world hydropower resources. Source WEC 1994.

Region	Net* exploitable (TWh/yr)	Exploited (% of exploitable)
North America	801.3	72.4
Latin America	3,281.7	11.9
Western Europe	640.9	63.2
E Europe and CIS	1,264.8	20.6
Mid East and N Africa	257.1	15.6
Sub-Saharan Africa	711.2	6.3
Pacific	172.0	22.5
Asia and China	1,165.6	44.8
Total	8,295.0	27.5

Notes:
* This is the economically feasible hydropower capability. The technically Feasible capability is approximately double the figures quoted here.

The table points in particular to the very large resources remaining available for future development. About 59% of the net exploitable hydro resources lie in the developing world. At the time of publishing of WEC 1994, hydro sources contributed by around 5%

of the worlds primary energy supply. The share of hydropower energy supply in industrialized countries was not expected to change significantly in the next 25-30 years but was thought to become more prominent in the developing countries, as illustrated in Table 3.4.

Table 3.4 Estimates of share of hydro sources in primary energy supply (% of primary energy). Source: WEC, 1994.

	Year 2005		**Year 2020**	
	Moderate growth	Low growth	Moderate growth	Low growth
Industrialized countries	6.0	5.8	6.5	6.2
Developing countries	6.8	6.2	9.7	8.5
World total	6.3	6.0	7.7	7.3

Figures for the exploitable small-scale hydropower potential can be no more than speculative, however WEC (1994) estimates that 5% of the total hydropower potential thought to be exploitable is perhaps of the right order of magnitude. This gives a net exploitable potential of 630 TWh of which just less than 10% has been developed.

Another way to point out the potential of small-scale hydro is by adapting the two scenarios: “current policies” and “favorable”. The current policies scenario is based on a projection of existing trends. Some of the circumstances leading to the “favorable” scenario are national commitments to support the development of renewables, minimization of development constraints, reasonable real interests rates and adequate financing for worthy projects in developing countries. Estimates of generation capacity and electrical output by region through 2020 are presented in Table 3.5 (WEC, 1994).

Based on the information given in Table 3.5, by year 2020, approximately 40% of the net exploitable potential or small-scale hydropower will be developed.

Small projects lack the advantage of scale and their cost per installed kW can therefore be quite high. According to WEC (1994) the investment costs for projects in the range of 500 to 10,000 kW can be expected to lie in a range of about USD 1,500 to 4,000 per kW.

Table 3.5 Small-scale hydropower capacity and generation potential by world regions to 2020. Source: WEC, 1994.

	Current policies case capacity (MW)			**Favourable case capacity (MW)**		
Region	**1990**	**2005**	**2020**	**1990**	**2005**	**2020**
North America	4,302	5,154	6,152	4,302	8,604	12,906
Latin America	1,113	2,607	5,751	1,113	2,937	6,557
Western Europe	7,231	9,704	12,587	7,231	14,462	21,692
E Europe and CIS	2,296	3,082	3,997	2,296	4,592	6,889
Mid East and N Africa	45	108	233	45	119	266
Sub-Saharan Africa	181	434	935	181	477	1,065
Pacific	102	137	177	102	204	306
China	3,890	9,331	20,101	3,890	10,264	22,915
Asia	343	823	1,772	343	905	2,021
Total	19,503	31,380	51,705	19,503	42,564	74,617

	Current policies case generation (GWh)			**Favourable case generation (GWh)**		
Region	**1990**	**2005**	**2020**	**1990**	**2005**	**2020**
North America	19,738	23,645	28,225	19,738	39,476	59,214
Latin America	4,607	11,050	23,805	4,607	12,155	27,138
Western Europe	30,239	40,580	52,636	30,239	60,477	90,715
E Europe and CIS	9,438	12,665	16,428	9,438	18,875	28,313
Mid East and N Africa	118	285	613	118	313	699
Sub-Saharan Africa	476	1,139	2,454	476	1,253	2,797
Pacific	407	562	730	407	838	1,257
China	15,334	36,780	79,235	15,334	40,458	90,328
Asia	1,353	3,243	6,987	1,353	3,567	7,965
Total	81,710	129,949	211,113	81,710	177,412	308,426

3.3 Rural Development

This section discusses what role energy and electricity has in the context of development and what measures regarding rural electrification are made in Uganda.

3.3.1 Millennium Development Goals

Adopted unanimously by the international community in 2000, the Millennium Development Goals (MDGs) are a list of development objectives to be achieved by 2015. The MDGs have been established to eradicate world poverty and address challenges in hunger, health, gender equality, education, and environ-mental sustainability.

Millennium Development Goals

1. Eradicate Extreme Poverty and Hunger
2. Achieve Universal Primary Education
3. Promote Gender Equality and Empower Women
4. Reduce Child Mortality
5. Improve Maternal Health
6. Combat HIV/AIDS, Malaria and other Diseases
7. Ensure Environmental Sustainability
8. Develop a Global Partnership for Development

While energy is not explicitly mentioned in any of the MDGs, there is a growing understanding that energy services play a crucial role to achieve the MDGs and in improving the lives of poor people across the world. Lack of access to affordable, reliable, and environmentally benign energy is a severe constraint on development (Porcaro & Takada, 2005).

3.3.2 Energy Services

Over the past few decades the number of people impoverished by a lack of modern energy services has remained unchanged. Today, almost 1.6 billion people in developing countries live without electricity in their homes, which make them dependent on dung, firewood, and agricultural residues for cooking and heating. The availability of energy services has a distinct impact on the lives of poor people. For women and their families, dependence on traditional fuels and fuel technologies barely allows fulfillment of the basic human needs, let alone the opportunity for more productive activities (Porcaro & Takada, 2005).

An energy service is defined as "the function for which energy is required" (Anderson et al., 1999) or as **"**the view of energy as a resource to perform a desired task to meet end-needs, such as illumination, human comfort, mobility etc" (Ramani et al., 1993). "Rural people in developing countries do not need micro-hydropower, they need milled flour. They do not need photovoltaic cells; they need lighting in their house. They do not need a biogasifier, they need to cook" (Andersson et al., 1999).

Generally the focus of rural energy has been concentrated on the technologies, while the end-uses of the energy have been given a lower priority. What is not considered is which services are actually required from various energy technologies (Anderson et al., 1999). According to Anderson et al. (1999), many energy projects have failed because energy technology was supplied to an area where no assessment of actual energy requirements has been made. Hence the technology in rural energy projects is seen to fail because:

- people have little or no need for the particular energy source
- people have no means to develop beneficial or income generating uses for power
- the energy supplied by technology is insufficient
- the energy is available at wrong time of the day or year to be used
- people do not possess the relevant skills to maintain and operate the installation

In cases like these, the technologies do not supply the required energy services. This approach often means that the technology is not economically viable, as it is under utilized, or it is so unreliable that the villagers stop using the technology and return to their traditional energy sources (Balla, 2003).

3.3.3 Role of Energy in Rural Development

According to Porcaro & Takada (2005) energy services are an essential input into each of the economic, social and environmental dimensions of human development. They help to facilitate economic development by making a foundation for industrial growth, enhancing productivity, and providing access to global markets and trade. Further Porcaro & Takada (2005) discusses that modern energy services contribute to social development by helping to fulfil the basic human needs of nutrition, warmth, and lighting, in addition to education and public health. Modern energy services can also protect the local and global environment by helping to control deforestation and by reducing emissions. The crucial role of energy in enabling development makes the provision of adequate, affordable, and reliable energy services absolutely necessary in order to achieve the Millennium Development Goals.

The findings in the report by Porcaro and Takada (2005), point out the following key conclusions:

- Energy services that can be used for agricultural, manufacturing, transport, and other livelihood activities are particularly important services for the poor. It helps free up women's time and enables local income generation through enhanced agricultural productivity and the formation of micro-enterprises. The report shows that the provision of mechanized agricultural services, such as grinding, milling, etc., has enabled women in Mali to increase their income from agricultural activities by an average of USD 0.32/day. The potential contribution to poverty reduction is significant when considering that 11-15 percent of the people in Mali are living on less than USD 1/day. Energy services are an indispensable part of stimulating development at the local level.

- Improvements in energy infrastructure, particularly electricity, are associated with industrialization and reductions in poverty. In the report, Brazil's northeast state of Ceará, has had a twofold increase in the number of electrified households during the past decade, which has coincided with the largest improvement in any Brazilian state's Human Development Index (HDI) ranking. This kind of distinct relationship between growth in electricity access and development is common to many countries.

- Energy services also play a critical role in improving education and gender equality. Porcaro and Takada (2005), shows that the provision of time and labor-saving energy services can dramatically help to improve girl-to-boy ratios in primary schools in rural Mali, close to doubling the ratio in some cases. The report further indicates that the odds of being literate are far greater for individuals with electricity than those without. Modern lighting and improved telecommunications enable people to study during evening hours and help attract and retain better-qualified teachers. While there is clearly a strong relationship between access to energy services and certain measures of education, it does not always yield equal benefits for both men and women. In rural areas, energy services that reduce everyday duties, like fetching water and collecting fuel wood, are often more effective at increasing girls' opportunities for schooling as well as for after-school study.

- Equally important is the impact energy services have on health. Child mortality and maternal health are two examples of health-related issues that are closely linked to energy services and the fuels and fuel technologies that make them possible. In certain rural regions of Mali it is access to time and laborsaving energy services that enable women to take better advantage of prenatal health care. The use of solid biomass fuels for cooking also has significant health implications for women, including the health of their children, as women are exposed to a disproportionately higher share of indoor air pollution.

In conclusion Porcaro and Takada (2005), writes that in order for countries to meet their development goals, key development issues such as economic productivity, education, health, and gender equality, need to be addressed simultaneously. Energy is an essential component to all of these issues, generating numerous and collaborating impacts on development.

However Holland et al. (2001), argues that the benefits of electricity, compared to other forms of energy, are its usefulness and convenience. Electricity can stimulate development that is already taking place, but it will not initiate development. “Communities, which are very poor, with very little economic activity, are unlikely to derive much economic benefit from an electricity supply, although they may derive substantial social benefits from better lighting and communication”. In addition Ramani (1993) discusses that there is no direct correlation between rural electrification and economic growth leading to rural development, though admits its role in promotion of economic growth. Rural electrification can result in greater impacts on productivity in combination with other factors and conditions regarding availability or creation of necessary infrastructure facilities.

3.3.4 Uganda’s Rural Electrification Strategy and Plan

In order to investigate and learn more about what actions the Government of Uganda takes to contribute to an increased development through rural electrification, we interviewed a newly founded institution in Uganda, called the Rural Electrification Agency (REA). This chapter is the result of that interview.

3.3.4.1 Background

Uganda’s Electricity Act, 1999, provides that the minister responsible for electricity shall prepare a sustainable and coordinated Rural Electrification Strategy and Plan for Uganda. The Strategy and Plan are designed to overcome the main barriers of rural electrification by the establishment of an appropriate framework composed of a Rural Electrification Agency, a Rural Electrification Board, a Rural Electrification Fund allowing provision of grants and subsidies on investment costs and a Rural Electrification Master Plan to provide information on investments opportunities. The Rural electrification Strategy forms an integrated part of the government’s wider rural transformation and poverty eradication agenda. Sustainable rural development with increase in rural incomes and quality of life hinges critically upon enabling small and medium rural enterprises as engines of economic growth and provision of basic social services to meet community needs such as health, education, water, telecommunication services and lighting.

The government owned electricity distributor, Uganda Electricity Board (UEB), has 170,000 costumers, of which 80,000 lives outside the urban Kampala-Jinja-Entebbe triangle. UEB has been adding new grid connections at a rate of roughly 8,500 a year mainly in urban and peri-urban areas, whilst the number of Ugandan households is growing at a rate of 100,000 every year, more than half of which are in rural areas. This illustrates the scale of Uganda's electrification needs and the limited scale of the progress made to date. According to REA, the requirement for a fundamental change of policy and approach will be provided by the Electricity Act of 1999.

3.3.4.2 Objectives

The primary objective of the Rural Electrification Strategy is to reduce inequalities in access to electricity and the associated opportunities for increased social welfare, education, health and income generating opportunities. The target is to reach a rural electrification rate of 10%, which means that 400,000 rural households are to be serviced by the year 2010, by promoting expansion of the grid and development of off-grid electrification and stimulate innovations within suppliers. The promotion of renewable energy is another important element of the governments Rural Electrification Strategy. At present, a part from the large hydropower plants, only a tiny fraction of Uganda's renewable energy potential, consisting of biomass, small-scale hydropower, solar, wind and geothermal resources, is being exploited, largely for self-generation by sugar and coffee producers. Renewable energy can provide a cost-effective method of electrification, especially in the many rural areas that are remote from the grid. In the past, key policy and other barriers have held back the potential of these indigenous and environmentally friendly energy resources. The new Rural Electrification Strategy aims to facilitate the rapid rise in the use of renewable energy by removing or reducing existing barriers, such as weak capacity for project sponsoring, technical capacity, high up front investment costs resulting in long payback periods and an overall weak financial sector, to mention some.

3.3.4.3 The New Approach

The fundamental elements of the new policy and approach are that it progressively will be demand-driven and based on decentralized private initiatives, whereby private companies, NGOs, local authorities and communities will establish and manage their own electricity supply arrangements. For areas that are not attractive to the private sector government will promote public private partnership to electrify them in a realistic time.

The Rural Electrification project types that qualify for subsidy assistance from REF can be grouped into three categories:

- Grid extension – Extending the transmission grid to cover a new community is the cheapest solution when the volume and value of demand justify the cost of the new lines through savings of diesel consumption. New concessions are being created for private investors, to further extend the existing UEB grid.

- Mini-grids – If demand is not large and the distance to the grid is great, a mini-grid may be more cost effective. The mini-grid may be based on; the expansion of agro-industrial generating capacity currently used for self-generation, diesel or renewable energy capacity.

- Photovoltaic (PV) units – PV technology is appropriate for isolated and dispersed electricity requirements. The major disadvantage of PV-systems is their limited capacity; they are only competitively able to satisfy household and small commercial requirements, like TV, radio, lights etc. Thus, PV-systems do not offer the same scope for rural income generation available from grid-based systems. However, PV may be the only option for isolated social centers, such as schools, clinics etc., and for communities that are far from the grid and do not have reliable hydro or biomass supplies.

There is also a possibility to receive subsidies from the REF for projects started on own initiative by for example private companies or village co-operations. The Rural Electricity Fund shall according to the Electricity Act of 1999, consist of significant money appropriated by the Parliament, any surplus made from the operations of the Electricity Regulatory Authority, a 5% levy on bulk transmission sales and donations, gifts, grants and loans from bilateral donors, such as Sida, Norwegian Agency for Development Cooperation (NORAD) and The World Bank.

4 Material and Method

As can be seen in Figure 4.1, this study consists of two major parts: a study of the rural electrification situation in developing countries in general and Uganda more specifically and a GIS analysis to find potential sites for small-scale hydropower stations. The first part consists of two different kinds of interviews performed in Uganda. One interview was performed during the time of collection of input data and the others, with the rural population in southern Uganda, when we evaluated our GIS analysis result.

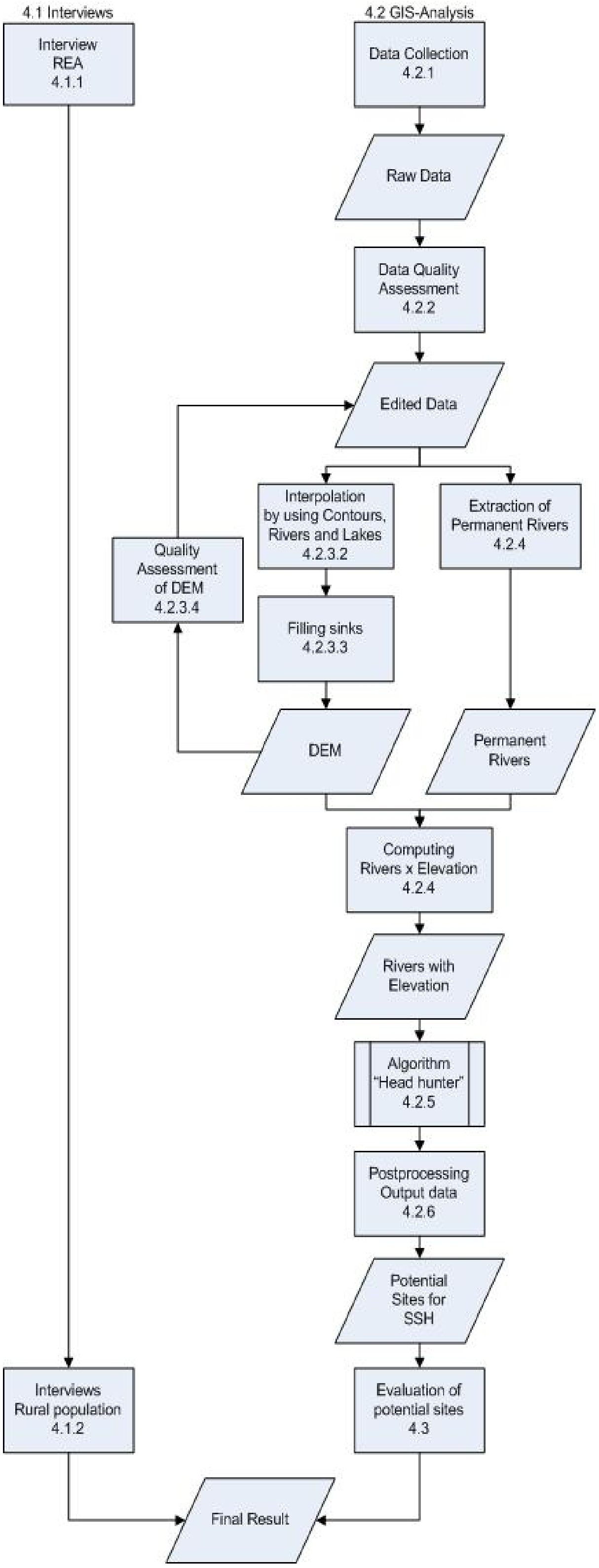


Figure 4.1 Chart over the different parts of the method. The numbers represent headings in method section.

4.1 Interviews

In our study we used two different interview techniques, structured and semi-structured interviews (Halvorsen 1992, Mikkelsen 1995). The structured interview has a formal questionnaire while the semi-structured interview does not and could be described more as a free discussion. The semi-structured interviews are performed using a list of open-ended questions to be discussed. Since the questions in a semi-structured interview are open-ended, the interview still has the character of a discussion, and one advantage of this is that the respondents usually feel more comfortable with the situation (Devereux & Hoddinott 1993).

The closer the interviewer is to the respondent, the better the interviewers understanding of the interview material becomes. Even if there is a need for an interpreter, the interviewer still has a fairly direct contact with the respondent. An advantage of having an interpreter is the possibility of he or she providing information about the area, the culture and practical things (Devereux & Hoddinott 1993).

4.1.1 Rural Electrification Agency

In order to find out more about how Uganda fights their problems with rural electricity, we visited the Rural Electrification Agency (REA). We used a semi-structured interview method, to get a discussion about the purpose of this newly started institution as well as information of how they work. We got help from our assistant field supervisor to get an interview. It took place at the 10th floor of the Workers House in central Kampala. The interviewees were a female spokesman from REA and an engineer, for more technical answers. A summary of the interview is found in section 3.3.4 and the questions can be found in Appendix 9.1.

4.1.2 Rural Population

When evaluating our result of our GIS-analysis, we also made numerous interviews with people in the countryside of our study area. Our intention with these interviews was to investigate the population's attitude to, and need for, electricity and small-scale hydropower. As mentioned earlier, Anderson et al. (1999) claim that many energy projects have failed because of a number of reasons (see section 3.3.2), which we based our questions upon. In contradiction to the semi-structured qualitative interview methods used before, the questions in a structured quantitative method are asked in a predefined way. All respondents are asked the same questions and no discussion is present. Since English is rarely spoken in the study area, an interpreter was used to perform the interviews and to guide us in the countryside. The sample population for the interviews was chosen along the way. The selection is not statistically valid, but we consider it to be representative with respect to the objectives of our study. Questions are attached as Appendix 9.2.

4.2 GIS Analysis

The following section describes the technical part of our method, where we describe a chain of processes with main focus on a specially designed algorithm. The main part of our work has been performed on a laptop computer with a 1.6 GHz Intel processor and by the usage of the following software:

- ArcGIS 8.3 & 9
- Matlab 7.0.1
- Microsoft Excel 2000

4.2.1 Data Collection

By the beginning of our study there were no digital data over the study area in Uganda available in Sweden. After some time we realized that the enormous bureaucracy and difficulties in contacting ministries made it impossible to receive data from a distance. Instead we had to wait until we were in Uganda to collect the needed data. One institution to collect data from is the National Forestry Authority (NFA) within the Ministry of Water Lands and Environment (MWLE), in Kampala. They are the former National Biomass Study who started in 1992, sponsored by NORAD, to do land cover stratification (vegetation mapping) of the whole country. They also produced digital data sets from 1:50,000 maps, covering administrative boundaries down to parish level, infrastructure down to motorable tracks, boundaries of all protected areas such as Forest Reserves and National Parks, rivers and land cover.

Uganda has not a well-organized cooperation for sharing data among the ministries. Often the same work is performed at different ministries, without knowing of each other's existence. NFA only had digital data over administrative boundaries down to parish level, but we found that village data in paper form were available at a different location, Ugandan Bureau of Statistics (UBOS) in Entebbe.

The data we received from NFA are either discrete physical objects, e.g. a road, continuous physical surfaces, e.g. land cover (use), or discrete virtual objects, e.g. administrative units. All data are digitised in Arc 1960 UTM Zone 36N projection. The Arc Datum 1960 is referenced to the modified Clarke 1880 ellipsoid, Transverse Mercator projection with coordinates on the UTM grid. The digital maps of Uganda are divided into a grid system (see Figure 4.2), where our study area falls in the cells 93/1-4 – 94/1-3.

Over this area we bought the following layers:

- Contours – 30 meter equidistance, vector shape file
- Administrative boundaries – down to parish level, vector shape file
- Infrastructure – roads and railways, vector shape file
- Rivers and Streams – seasonal and permanent, vector shape file
- Land Cover (use), vector, ArcInfo coverage

The data from UBOS consisted of 33 paper copies of sub-counties showing parishes and villages and in some cases even houses. The projection and reference system is the same as in the data received from NFA and the scale is 1:25,000. We also received population data from the 2002 Population and Housing Census, for all sub counties in the study area. A more specified list of all data used in our study is attached in Appendix 9.3.

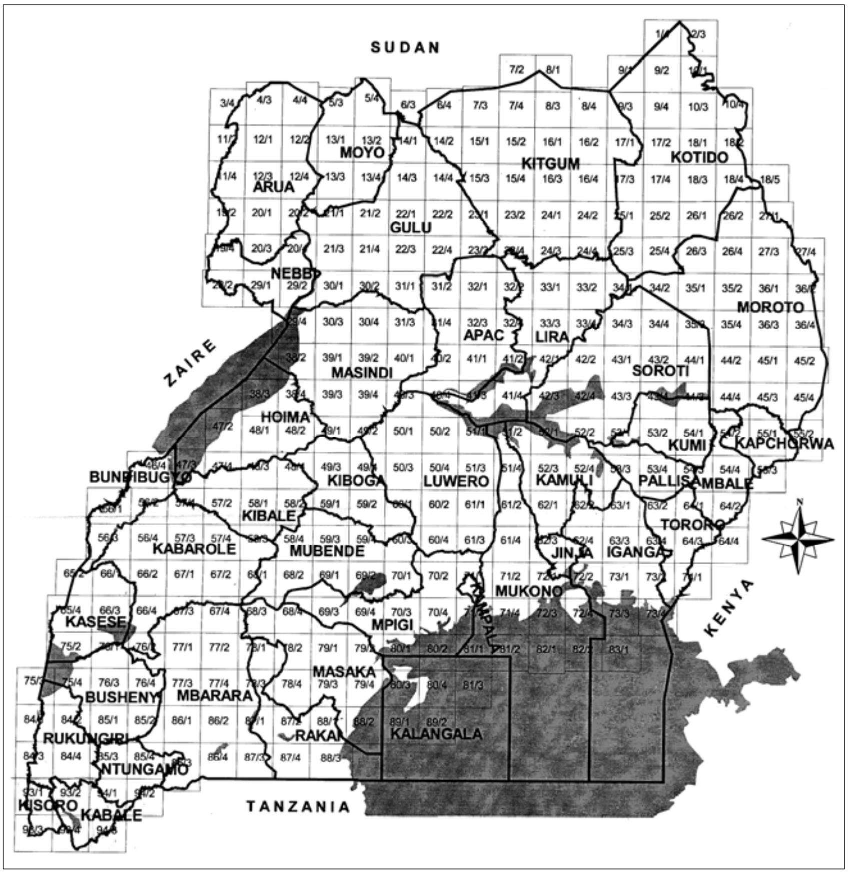


Figure 4.2 The grid system in which the digital data of Uganda is divided into. Source: NFA.

4.2.2 Quality Assessment of Elevation Data

Before the analysis could begin we had to make sure that all data were correct. The assessment of the contour data became subjective, since it was performed visually by using ArcScene. We found many elevation errors among the contour lines. Many of the errors probably arose when the contours were digitized. The contours were digitized from 1:50,000 maps in the same grid system mentioned earlier. Therefore when many grids were joined together there arose vertical edge errors, and it seems as if no correction between the layers were done. These errors were visually detected using a 3D enhancement function, called vertical exaggeration. The attribute table of the contour layer was corrected until we were unable to find any more errors.

4.2.3 Interpolation

In order to perform our analysis we needed a continuous surface with elevation (DEM) over our study area. This surface would later be used to calculate height differences in rivers to find potential sites for small-scale hydropower stations. What we had to do was an interpolation of our contour lines to produce the wanted surface. Probably the most important aspect when producing continuous topographic data with different interpolation methods is the accuracy in representation of terrain shape and drainage structure. The locally adaptive ANUDEM gridding procedure has proven to be able to produce representations with high quality from point, contour and streamline data. An example of input data can be seen in Figure 4.3. These data are particularly appropriate for producing DEMs with a cell ranging form 5 to 200 meters, where source contour data tend to accurately reflect reality (Gallant & Wilson, 2000).

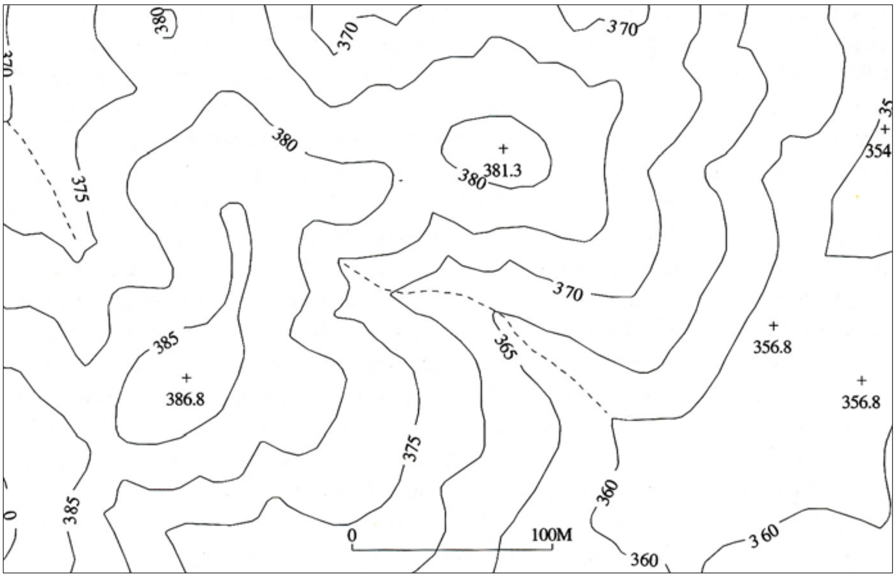


Figure 4.3 Contour with 5-meter equidistance, stream and point elevation data. Source: Gallant & Wilson, 2000.

The primary erosive force determining the general shape of most landscapes is water. For this reason, most landscapes have many hilltops and few sinks leading to a connected drainage pattern. This knowledge about surfaces is used in the ANUDEM technique in TOPOGRID, a command used in ArcGIS. It is used by imposing constraints on the interpolation process resulting in connected drainage structure and correct representation of ridges and streams (ARC/INFO).

The method consists of an iteration technique, which employs a nested grid strategy. It starts from an initial coarse grid and successively calculates grids at finer resolutions. It halves the cell size until the final user defined resolution is obtained. The initial values for the first coarse grid are calculated by using the heights of local maxima based on the surrounding contour height information, since no other information on the maximum height is available. The following finer grid resolutions are based on linear interpolation from the preceding coarser grid (Asserup & Eklöf, 2000).

The ANUDEM technique enables a drainage enforcement algorithm, which is designed to remove all sink points in the DEM that has not been identified as sinks in the input data. The sinks are being found by comparing the height of each grid point with the height of the eight immediate neighbors (ARC/INFO; Wahba, 1990).

The procedure of this interpolation has been designed to take advantage of the types of input data commonly available, and the known characteristics of elevation surfaces. It is optimised to have the computational efficiency of 'local' interpolation methods such as Inverse Distance Weighted interpolation, without losing the surface continuity of global interpolation methods such as Kriging and Splines (Hutchinson, 1989). Streamlines as well as contours are widely available from topographic maps and provide important structural information about the landscape. ANUDEM can use such streamline data, provided that the streamlines are digitised in the downhill direction (Wilson and Gallant, 2000).

The result from the example interpolation done with ANUDEM with the input data shown in Figure 4.3 can be seen in Figure 4.4. ANUDEM generates ridges and streamlines from points of locally maximum curvature on contour lines. This permits interpolation of the fine structure in contours across the area between them. This is done in a more reliable way than methods such as Kriging and Spline (Hutchinson 1988). The derived contours also show a close match with the contours in the input data in Figure 4.3 (Gallant & Wilson 2000).

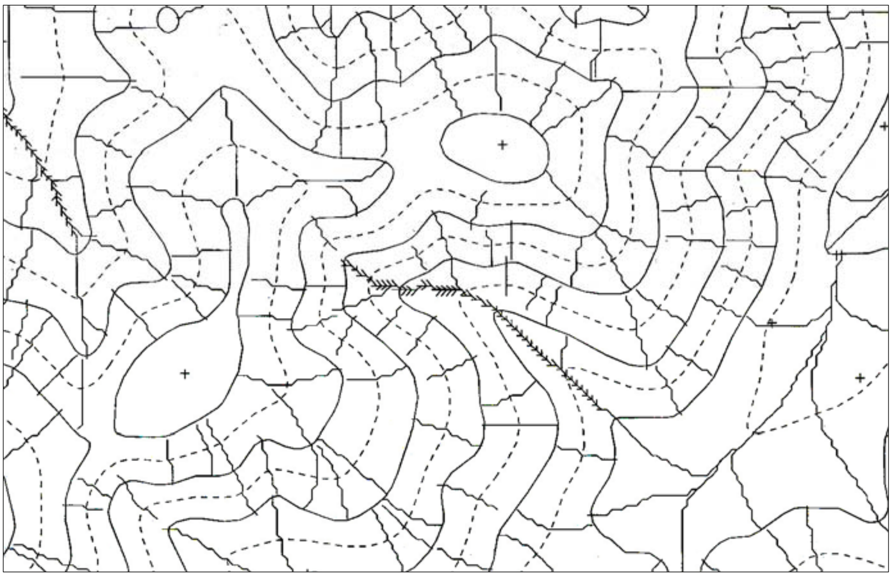


Figure 4.4 Result of using ANUDEM with Figure 4.3 as input data. Structure lines such as ridges are generated automatically by ANUDEM. All contours are derived from the interpolated DEM. Dashed lines are shown at elevations midway between the data contour elevations. Source: Gallant & Wilson, 2000.

4.2.3.1 DEM Input Data

When using the ANUDEM-method we used three input coverages: the contours, lakes and streams. Contour data is used for two purposes in TOPOGRID. It is first used to generate a generalized morphology of the surface based on the curvature of the contours. The contours are then used in their more traditional role as sources of elevation information. All output grid cells within a lake will be assigned the minimum elevation value of all cells along the shoreline. Stream data always takes priority over contour data, therefore elevation data which conflict with descending streams are ignored. Stream and lake data are a powerful way of adding additional topographic information to the interpolation, further ensuring the quality of the output DEM. If there are known sinks in the area of interpolation, there is a possibility to include a sink coverage (ARC/INFO).

4.2.3.2 Implementation

The ANUDEM interpolation we used is found in ARCGIS 9, under ArcInfo Workstation – Arc, with the function TOPOGRIDTOOL.

The choice of resolution of the DEM depends on several factors. Terrain representation, regarding both absolute measures of elevation as well as surface shape and drainage structure, is of major importance. Other factors of weight, especially when working with limited computer capacity, are time-efficiency and storage. To achieve the suitable resolution we tried interpolations with resolutions of 100, 30 and 10 meters.

There are a set of tolerances used to adjust the smoothing of input data and the removing of sinks in the drainage enforcement process. Tolerance number one (tol1) reflects the accuracy and density of the elevation points. Data points, which block drainage by no more than this tolerance, are removed. This should be set to half of the contour interval when using contour data (Johnston et al., 2001). Tolerance number two (horizontal_std_err) represents the amount of error inherent in the process of converting point, line, and polygon elevation data into a regularly spaced grid. It is scaled by the program depending on the local slope at each data point and the grid cell size. Larger values will cause more data smoothing, resulting in a more generalized output grid. Smaller values will cause less data smoothing, resulting in a sharper output grid, which is more likely to contain spurious sinks and peaks. The third tolerance (vertical_std_err) represents the amount of random error in the z-values of the input data. The default values for horizontal and vertical standard errors are very robust and have been tested with a wide variety of data sources. If the interpolation results are inferior, you should according to Johnston et al. (2001) check for errors in the input data before changing the default values. We therefore let the tolerances be default except for the first tolerance (tol1), which we set to 15 meters, half the input data contour interval.

4.2.3.3 Sinks

A sink is a cell or set of spatially connected cells whose neighbouring cells all have a higher elevation value, which means that there is no drainage from the sink. Naturally occurring sinks in elevation data with a cell size of 10 meters or larger are rare except for glacial or karst areas, and generally can be considered errors. As the cell size decreases, the number of sinks in a data set often increases (Johnston et al., 2001). Spurious sinks and local depressions in DEMs are a significant source of problems in hydrological applications. Sinks may be caused by incorrect or insufficient data, or by an interpolation technique that does not enforce surface drainage (Hutchinson and Dowling, 1991). To eliminate possible sinks in the interpolated DEM, we used the ArcGIS function “FILL”.

4.2.3.4 Quality Assesment of DEMs

The quality of a derived DEM can vary greatly depending on the source data and the interpolation technique. The desired quality depends on the application for which the DEM is to be used. Since most applications of DEMs depend on representations of surface shape and drainage structure, absolute measures of elevation errors do not provide a complete assessment of DEM quality.

A number of graphical techniques for assessing data quality have been developed. These are non-classical measures of data quality that offer means of confirmatory data analysis without the use of accurate reference data (Wilson and Gallant, 2000). The following two techniques have been used in the study:

- When deriving contours from a DEM, it can provide a reliable check on terrain structure since their position, aspect and curvature depend directly on the elevation, aspect and plan curvature respectively of the terrain. Derived contours are a useful tool to measure interpolation quality. (Wilson and Gallant, 2000).

- By computing shaded relief images of the DEM, it allows to do a rapid visual inspection of the DEM for local anomalies that show up as bright or dark spots. This technique can indicate both random and systematic errors, for example edge matching as well as terracing problems (Hunter and Goodchild, 1995, Wilson and Gallant, 2000).

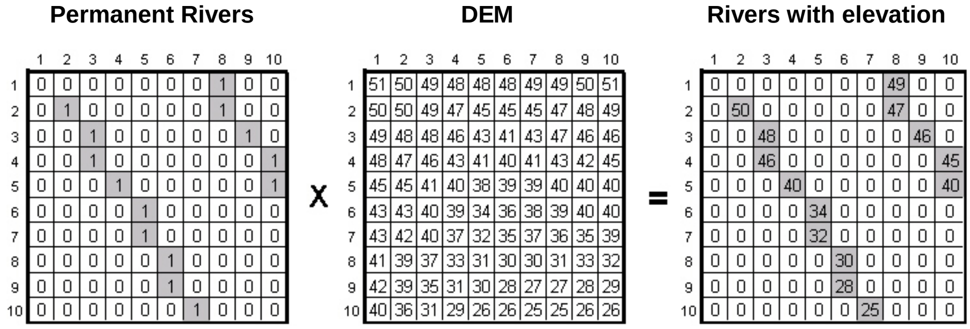
To create reference data to be able to evaluate the accuracy of the absolute elevation of the DEM, four contour lines, all containing approximately 300 vertices, from the contour layer were excluded before the interpolation. Two lines from a flat area and two from a steep were visually chosen in ArcGIS. We calculated Root Mean Square Prediction (RMS) error using the reference data and the interpolated DEM values as input in Equation 4.1. RMS-error indicates modeled points mean deviation from their origin by calculating the deviations of points from their true position, summing up the measurements, and then taking the square root of the sum.

$$\mathrm{RMS} = \sqrt{\frac{\sum_{i=1}^{n}(I_i - R_i)^2}{n}} \qquad (4.1)$$

Where *I* equals the interpolated values, R equals the reference values and *n* the number of values (Johnston et al., 2001).

4.2.4 Permanent Rivers with Elevation

Input data to our algorithm is a layer with rasterized rivers, where each river cell contains that position's absolute elevation values. In order to receive needed data, we extracted the permanent rivers, from the river layer, because our study is not applicable where rivers are seasonal, since the hydro power station will then not work during the whole year. The permanent rivers were then rasterized using the function LINEGRID in ArcWorkstaion. We classified all river cells to contain the value of one and all non-river cells a value of zero. The classified raster layer was then multiplied by the DEM to apply the height values of the DEM to the river cells by using Raster Caculator in ArcGIS - Spatial Analyst (see Figure 4.5).



Permanent Rivers

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	1	0	0
2	0	1	0	0	0	0	0	1	0	0
3	0	0	1	0	0	0	0	0	1	0
4	0	0	1	0	0	0	0	0	0	1
5	0	0	0	1	0	0	0	0	0	1
6	0	0	0	0	1	0	0	0	0	0
7	0	0	0	0	1	0	0	0	0	0
8	0	0	0	0	0	1	0	0	0	0
9	0	0	0	0	0	1	0	0	0	0
10	0	0	0	0	0	0	1	0	0	0

X

DEM

	1	2	3	4	5	6	7	8	9	10
1	51	50	49	48	48	48	49	49	50	51
2	50	50	49	47	45	45	45	47	48	49
3	49	48	48	46	43	41	43	47	46	46
4	48	47	46	43	41	40	41	43	42	45
5	45	45	41	40	38	39	39	40	40	40
6	43	43	40	39	34	36	38	39	40	40
7	43	42	40	37	32	35	37	36	35	39
8	41	39	37	33	31	30	30	31	33	32
9	42	39	35	31	30	28	27	27	28	29
10	40	36	31	29	26	26	25	25	26	26

=

Rivers with elevation

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	49	0	0
2	0	50	0	0	0	0	0	47	0	0
3	0	0	48	0	0	0	0	0	46	0
4	0	0	46	0	0	0	0	0	0	45
5	0	0	0	40	0	0	0	0	0	40
6	0	0	0	0	34	0	0	0	0	0
7	0	0	0	0	32	0	0	0	0	0
8	0	0	0	0	0	30	0	0	0	0
9	0	0	0	0	0	28	0	0	0	0
10	0	0	0	0	0	0	25	0	0	0

Figure 4.5 Raster Calculation of Permanent Rivers and the DEM in order to receive a layer with Permanent Rivers with height values. Grey cells represent river cells and the values in the DEM represents height values in meters.

4.2.5 Algorithm

To find the sites suitable for building small-scale hydropower stations we designed an algorithm in the software Matlab 7.0, see Appendix 9.4. It is designed to search a maximum of ten connected river cells (if a cell size of 10 meters is used), which approximately equals 100 meters, to see if the criterion of 20 meter accumulated head is fulfilled. These cells will then be saved into an output raster. According to Maher and Smith (2001) a head of 20 meters is recommended to produce enough power for the kind of small-scale hydropower stations that our study focus on. The distance of 100 meters corresponds to the length of the penstock in which the water flows down to the turbine. There is no absolute measure of how long the penstock must be, since it can vary greatly depending on the appearance of the terrain. However, the penstock is one of the most expensive parts in the construction of small-scale hydropower stations, which imply that a short penstock is preferable. Maher and Smith (2001) recommend a penstock of 100 meters, which together with a 20-meter head are set to be the criteria in our algorithm (see Figure 4.6).

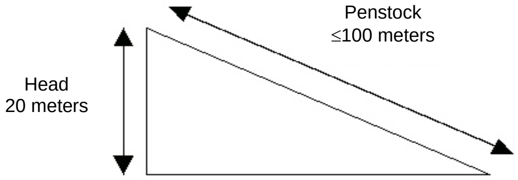


Figure 4.6 Head and penstock.

To get an overview of how the algorithm is designed, Figure 4.7 shows the different steps on which the algorithm is based on.

The needed input data for the algorithm is a raster in floating data format, containing river cells where the cell values illustrate absolute elevation. The algorithm begins by reading the input data into a matrix called "DATA", where the number of rows and columns depends on the resolution and the size of the area of interest. An example is shown in Figure 4.8a.

The next step in the algorithm is to extract all cells containing a value other than zero, and save them into the array "RIVERCELLS" (see Figure 4.8b). These values are then ranked by height and stored into another array called "ORDER", see the example in Figure 4.8c. The arrays consist of three columns, containing the river cell's coordinates and height values. The number of rows in these arrays is equal to the number of river cells in "DATA". This operation is done in order to make our algorithm more time effective, since sorting one column ("RIVERCELLS", z) is done much faster than alternative solutions.

In order to find a head of 20 meters over a distance of 100 meters, the algorithm locates ten in a row connected cells and calculates their accumulated height difference. It is possible for the river cells to connect diagonally, which means that the accumulated distance of ten cells can reach a maximum of 141 meters.

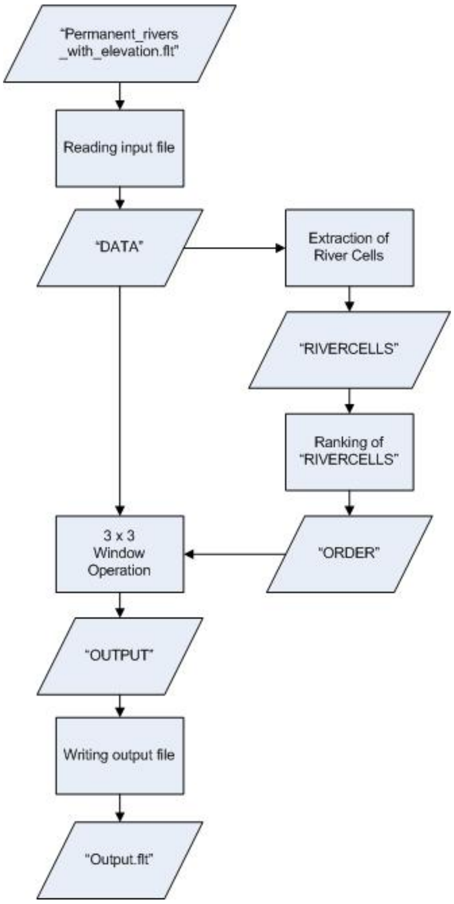
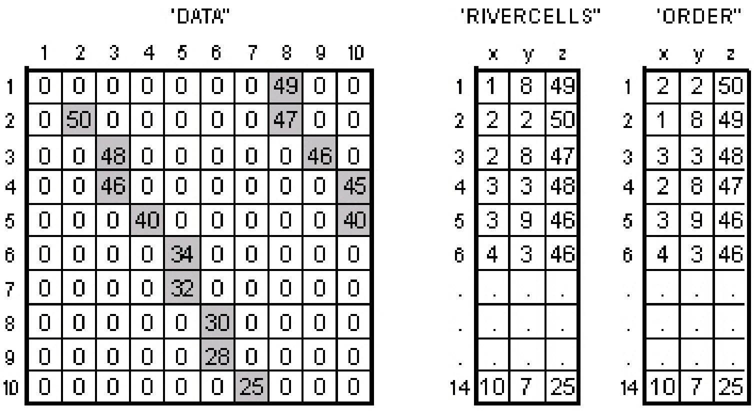


Figure 4.7 Flowchart showing the chain of processes in the algorithm.



'DATA'

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	49	0	0
2	0	50	0	0	0	0	0	47	0	0
3	0	0	48	0	0	0	0	0	46	0
4	0	0	46	0	0	0	0	0	0	45
5	0	0	0	40	0	0	0	0	0	40
6	0	0	0	0	34	0	0	0	0	0
7	0	0	0	0	32	0	0	0	0	0
8	0	0	0	0	0	30	0	0	0	0
9	0	0	0	0	0	28	0	0	0	0
10	0	0	0	0	0	0	25	0	0	0

(a)

'RIVERCELLS'

	x	y	z
1	1	8	49
2	2	2	50
3	2	8	47
4	3	3	48
5	3	9	46
6	4	3	46
.	.	.	.
.	.	.	.
.	.	.	.
14	10	7	25

(b)

'ORDER'

	x	y	z
1	2	2	50
2	1	8	49
3	3	3	48
4	2	8	47
5	3	9	46
6	4	3	46
.	.	.	.
.	.	.	.
.	.	.	.
14	10	7	25

(c)

Figure 4.8 An example showing the matrix "DATA" (a) and the arrays "RIVERCELLS" (b) and "ORDER" (c).

To locate these ten in a row connected cells the algorithm is designed to search pixels downstream by the use of a "3 x 3 pixel search window", which is illustrated in the example in Figure 4.9. It starts searching from the highest ranked pixel in "ORDER", which is also the cell with highest elevation, which in the example corresponds to the cell in the second row and second column in "DATA". From here it examines all eight surrounding cells, starting with the northwest pixel and then continuing clockwise.

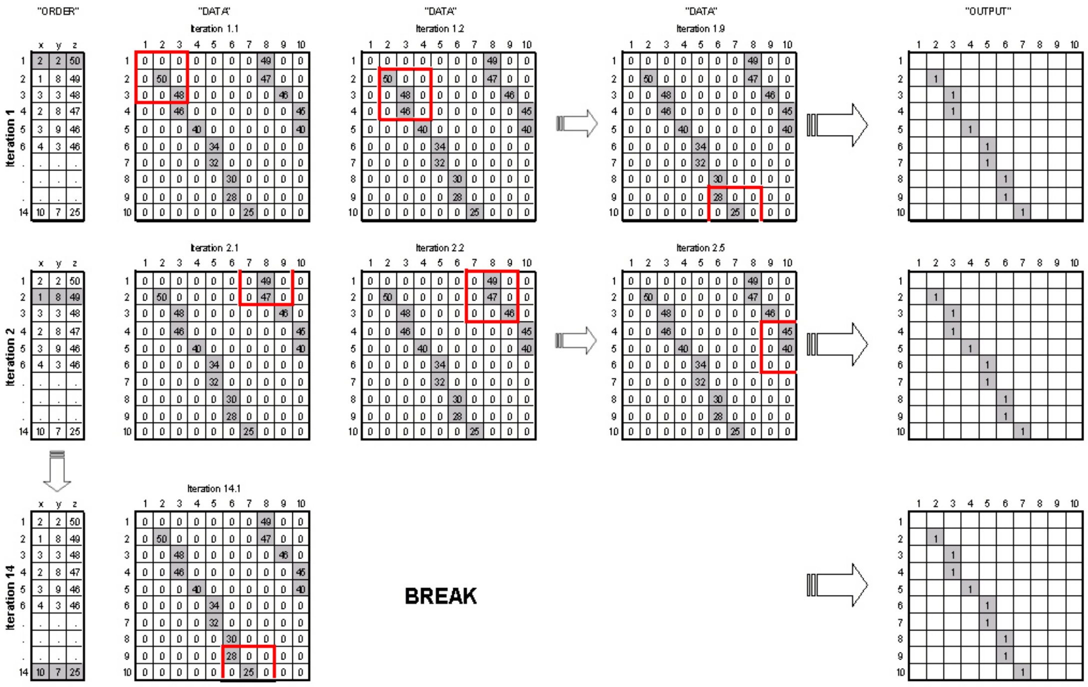


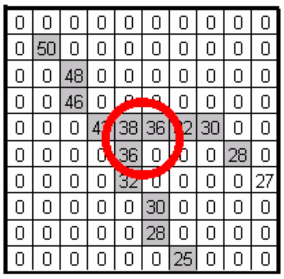
Figure 4.9 An example of how the "3 x 3 search window" operation works in a fictitious raster.

The eight pixels in the "3 x 3 search-window" are all examined to see:

- if their value is larger than zero - the algorithm should only examine cells containing rivers
- if the value is lower or equal to the current pixel's value - the search should not be able to proceed up-stream
- if the pixel has been examined earlier in the ten-pixel loop - in order not to get stuck in a loop between two cells with the same pixel value

The pixels, which fulfill these criteria, are then examined to calculate the best height difference from the current pixel, in order to know which pixel to go next. The calculated height difference is saved into a variable, which accumulates for each new cell. As can be seen in Figure 4.9, Iteration 1.2, the new pixel where to start from is at row three and column three. The whole process is repeated until ten connected cells have been visited or until the "river" ends, which is illustrated in Figure 4.9, Iteration 1.9. If the accumulated height value is 20 meters or more, the visited cells, which coordinates have been stored in a temporary variable, are stored into the matrix "OUTPUT", which can be seen in Iteration 1 in Figure 4.9. In the case of Iteration 2 in Figure 4.9, the river-cells accumulated height value does not reach the required value of 20 meters and are therefore not stored in "OUTPUT". Iteration 14 in Figure 4.9 illustrates the course of events when the search begins in the last pixel in a river. In this case there is only one connecting river cell in the "3 x 3 search window", but since it is upstream, the search will be aborted and no output is stored.

In order for the algorithm to present a correct result, an assumption that rivers or streams never branch off downstream in hilly areas has been made. The reason for this assumption is that our algorithm in such cases (see Figure 4.10) is limited since it only chooses the branch with the best height difference and leaves one branch unattended. If this branch individually has a height difference of 20 meter it will also be stored in "OUTPUT". In cases of same height difference the algorithm chooses the last found branch.



0	0	0	0	0	0	0	0	0	0
0	50	0	0	0	0	0	0	0	0
0	0	48	0	0	0	0	0	0	0
0	0	46	0	0	0	0	0	0	0
0	0	0	4[illegible]	38	36	[illegible]2	30	0	0
0	0	0	0	36	0	0	0	28	0
0	0	0	0	32	0	0	0	0	27
0	0	0	0	0	30	0	0	0	0
0	0	0	0	0	28	0	0	0	0
0	0	0	0	0	0	25	0	0	0

Figure 4.10 The unlikely phenomenon of down-stream branching off rivers

4.2.6 Post Processing of Output Data

The result at this stage contains numerous potential sites for small-scale hydropower that, for different reasons, are inaccessible or unusable. To exclude these areas we applied a mask-grid on the algorithm-output by using the ArcGIS raster calculator function. The mask-areas are:

- National Parks – derived from the Land use layer. The national parks are protected areas, mostly containing tropical rainforests.
- Electrified areas – derived from the Administrative layer. These areas are represented of major towns. They are already connected to the existing grid and are therefore in no need of small-scale hydropower.
- Surrounding Countries – derived from national borders in the Administrative layer. A number of potential sites are situated in the neighboring countries, because the geographical input data exceeds the borders of Uganda.

4.3 Evaluation of Potential Sites

When the GIS-analysis was finished, the result had to be evaluated in order to determine the quality. The evaluation was performed during three weeks in the study area, covering approximately 3000 square kilometres. Due to the inability to unhindered visit all sites in the terrain, we decided to evaluate sites in vicinity of roads and smaller villages. We estimated to be able to evaluate at least 25 sites. Due to our economic situation, the possibility to travel with a 4X4-car was excluded; instead we used a small Chinese-made motorcycle.

The purpose of the evaluation was to validate that the result coincides with reality. This was done by controlling a) that the stream had a head of at least 20 meters over a distance of 100 meters and b) that there was a permanent flow in the stream. To further estimate the power potential of the site, we measured the flow of the stream.

4.3.1 Head Measurements

To validate the required head of 20 meters over a distance of 100 meters, we used a hand-held sighting meter (see Figure 4.11). They are often called inclinometers or Abney levels and can be accurate if used by an experienced person, but it is easy to make mistakes and double-checking is recommended. Because they are small and hand-held, the error will depend on the skill of the user, but will typically be between 2% and 10%.

To measure the slope of a potential site one of us walked 100 meters either up-river or down-river, depending on our start point. To measure the distance we used a 20-meter tape measure. When reaching the 100-meter point, one of us used the inclinometer and took sight on the other person's eyes. The angles are then put into Equation 4.2 to calculate the height difference between us. At sites with very difficult terrain, we had to divide the measurements into steps, as can be seen in Figure 4.11.

$$h_n = L_n \sin \alpha_n \tag{4.2}$$

where h_n is head, L_n is distance between measuring points and α_n is the angle of inclination (Fraenkel et al., 1991).

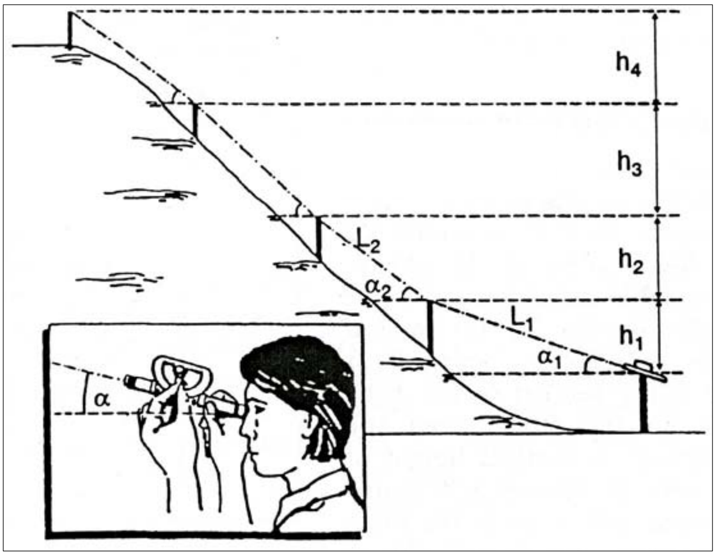


Figure 4.11 Inclinometer and measuring technique. Source: Fraenkel et al., 1991.

4.3.2 On-Site Measurements of Flow

When measuring the flow of the rivers in our evaluation, we used the principle of letting a cross-sectional profile of the streambed be charted for a known length of the stream (see Figure 4.12). We used a slightly modified approach compared to the described method, because of limited resources and time. Instead of charting the complete profile of the streambed, we let one measurement in the middle of the stream represent the height of a triangle-shaped cross-section (see Equation 4.3).

$$A = (b \cdot h)/2 \tag{4.3}$$

Where A equals the cross-sectional area and b is the width of the stream and h is the depth of the stream.

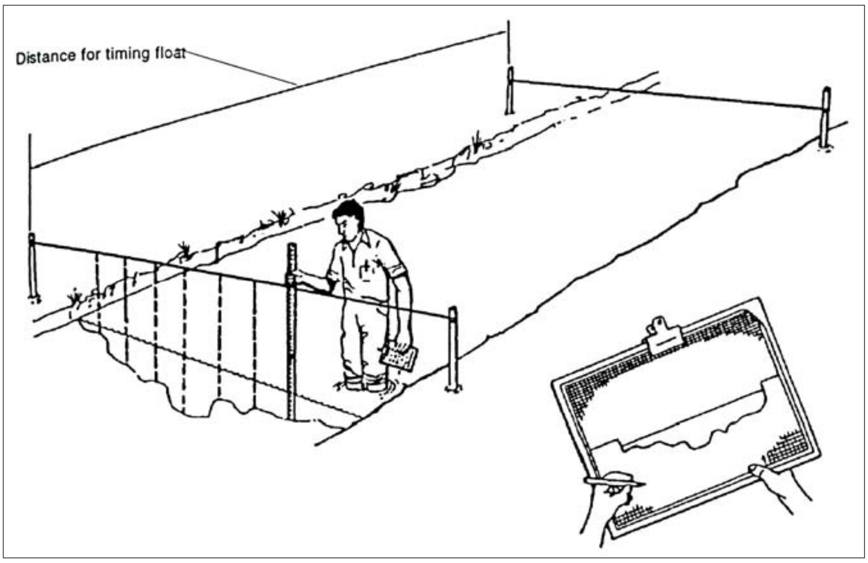


Figure 4.12 Charting the cross-sectional area of a stream.
Source: Fraenkel et al., 1991

To estimate the flow velocity, a series of floats, e.g. convenient pieces of wood, were timed over a measured length of stream. The results were averaged and a flow velocity was obtained. The velocity must then be reduced by a correction factor, which estimates the mean velocity as opposed to the surface velocity. Approximate correction factors to convert surface velocity to mean velocity are according to Fraenkel et al. (1991):

Concrete channel, rectangular, smooth	0.85
Large slow clear stream (>10 m^2)	0.75
Small slow clear stream (<10 m^2)	0.65
Shallow (<0.5 m) turbulent stream	0.45
Very shallow (<0.2 m) turbulent stream	0.25

By multiplying the average cross-sectional area A by the averaged and corrected flow velocity V_{mean}, the volume flow rate Q can according to Fraenkel et al. (1991) be estimated (see Equation 4.4).

$$Q = A \cdot V_{mean} \, (m^3 / s) \tag{4.4}$$

5 Result

5.1 Interviews

The structured interviews made among the rural population in the study area, showed generally a positive attitude against energy projects such as small-scale hydropower. To emphasize the importance of reaching a target group, which is as correct as possible, we chose not to interview persons living in any kind of population center. A sample population of 65 interviewees was randomly chosen, 33 women and 32 men. The distribution of occupation among the interviewees can be seen in Figure 5.1, which shows that there were a majority of farmers.

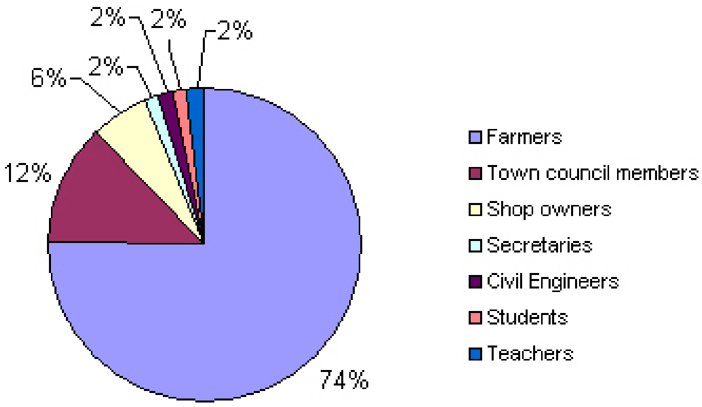


Figure 5.1 Distribution of occupation of interviewees.

One purpose of the interviews was to receive an understanding of the living standard in the area and what sources of energy that are most frequently used. Since no one of the sample population used electricity as energy source in their homes or at work, the energy supply was dominated by the use of biofuel and paraffin lanterns (see Figure 5.2).

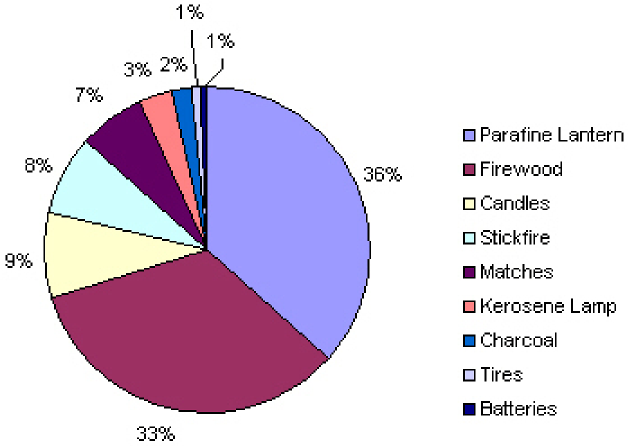


Figure 5.2 Distribution of energy sources in use.

Even though no one used electricity, three per cent of the sample population had access to electricity through the possibility to connect to a nearby grid, but was forced to relinquish because of too expensive connection fees. Despite access to traditional energy sources all interviewees agreed that there is a great need for electricity. Further, the interview results demonstrate that access to electricity would lead to the usage of modern energy services, such as lighting, domestic duties and entertainment. Figure 5.3 shows in detail what the interviewees would like to use electricity for.

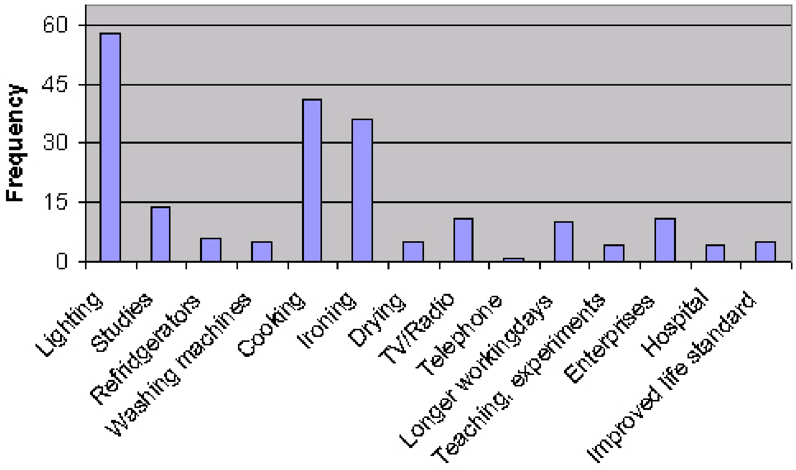


Figure 5.3 Desired Energy Services if access to electricity.

The most obvious disadvantage with electricity for the interviewees seemed to be the anxiety for accidents in form of electrocution, shortcuts and fire. Only a few were anxious not to be able to pay for their electricity usage, because of the uncertainty in income, while the remainder saw no negative effects at all.

When implementing small-scale hydropower projects a basic condition is that the major part of the cost is covered by subsidies and contributions from the Government, NGOs and aid-organizations. Remaining costs must be covered by the consumer’s own liquid assets. 83% of the interviewees consider themselves to have some means to pay for electricity and they are more than willing to pay more for electricity than they do for their current energy sources.

Another basic condition in order to attain a sustainable and economically viable small-scale hydropower project is non-profit participation and commitment by the consumers. 95% of the interviewees were positive to the thought of, without any kind of compensation, continually maintain and handle service of a possible future power station. Our experience, from visited parts of our study area, is that all land is cultivated and belongs to someone, which means that a certain degree of land sacrifice is necessary when constructing a small-scale hydropower station. The majority would be happy to sacrifice a part of their property in order to get electricity, while 5% says that such a sacrifice would bring a too high loss in harvest income generation.

5.2 GIS Analysis

5.2.1 Interpolation

The interpolation turned out to be a rather time consuming operation when working on a laptop computer. An interpolation of the study area with 100-meter resolution needed approximately 5 minutes to complete, the 30-meter resolution 30 minutes, while the 10-meter resolution interpolation needed almost 4 hours.

The output from all three interpolations contained a large amount of sinks. As can be seen in Figure 5.4 the majority of sinks were concentrated to areas of low slope angle, e.g. valley bottoms or areas between contours of same elevation. The areas often coincide with areas containing rivers.

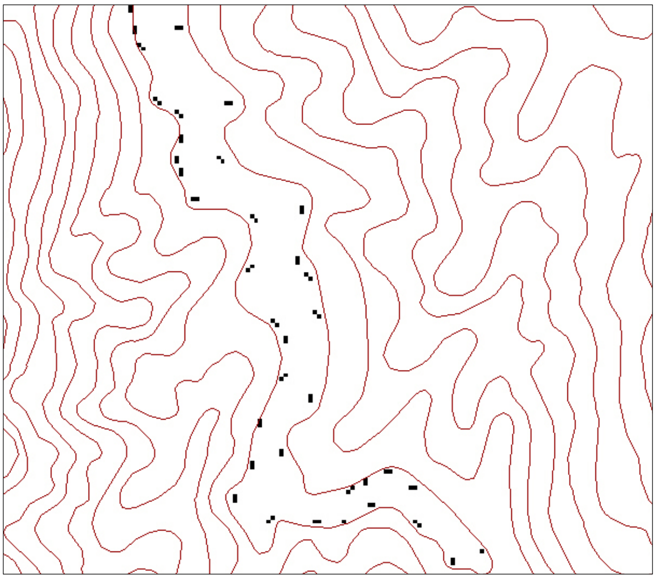


Figure 5.4 Original contours (brown lines) and sinks (black dots).

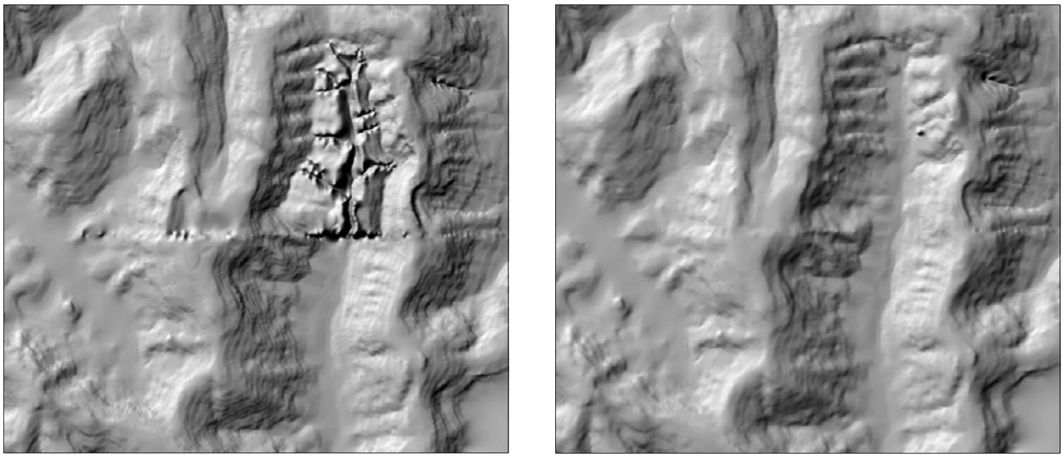
The sinks have no significant influence on our analysis, since their locations in the interpolated DEMs often are in irrelevant areas, such as valley bottoms. Despite this, we performed a fill sink-function, which removed all existing sinks, in order to receive a more accurate DEM.

The first step when performing the quality assessment of our interpolated DEMs was to compare derived contours from the three different resolutions with the original contours. As can be seen in Figure 5.5 the degree of agreement, regarding terrain structure, increases with increased resolution.

(a) (b) (c)

Figure 5.5 Derived contours from DEMs in different resolutions. a) 100 meters, b) 30 meters and c) 10 meters. Red lines representing original contours and black lines the derived contours from the interpolated DEM.

The second step in the quality assessment was to visually inspect shaded relief images of the interpolated DEMs. This step made it possible to locate a number of anomalies that showed up as very contrasting areas. It was possible to detect both geometrical displacement and attribute errors. An example of geometrical displacement is vertical edge errors, which can be seen in Figure 5.6 below. These errors were edited by correcting the attribute table and the interpolation repeated until a satisfying result was obtained. A certain degree of terracing can also be noticed along the slopes in the figure.



(a) (b)

Figure 5.6 Shaded relief of DEM with 10-meter resolution. a) Showing digitised errors leading to vertical edge error problems and (b) same area after editing of input data.

To evaluate accuracy of the absolute elevation of the DEMs, we calculated the RMS-errors at four different reference locations. The result, which can be seen in Table 5.1 shows that the lowest RMS-errors occurs at steep areas in the DEM with 10-meter resolution. At flat areas the RMS-error are within the same range of values, regardless of resolution. There is a noticeable increase in RMS-error with increased cell-size in steep areas.

Table 5.1 RMS-error for the DEM at the references lines, in three different resolutions.

Resolution	Flat 1	Flat 2	Steep 1	Steep 2	Mean RMS
100 meter	14.64488	14.32897	29.07937	43.40787	25.36527
30 meter	12.84792	14.78252	16.47471	23.72902	16.95854
10 meter	12.83892	15.45371	7.22123	7.36828	10.72054

The outcome of the quality assessment points to that the 10-meter resolution DEM is a good choice for our analysis. It has the highest degree of accuracy regarding both terrain structure and absolute elevation. Figure 5.7 shows the digital elevation model over our study area.

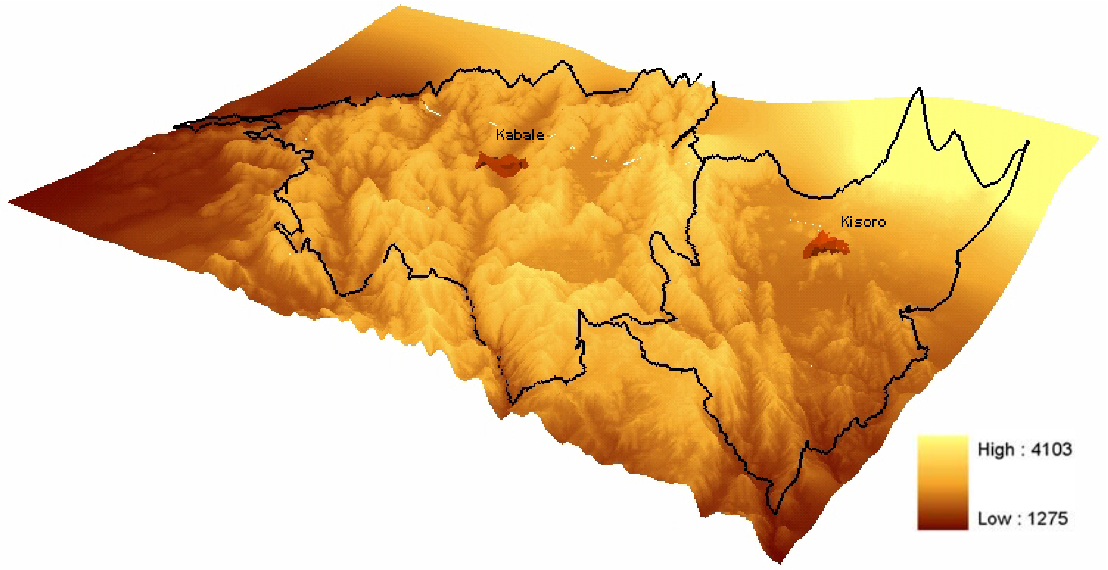
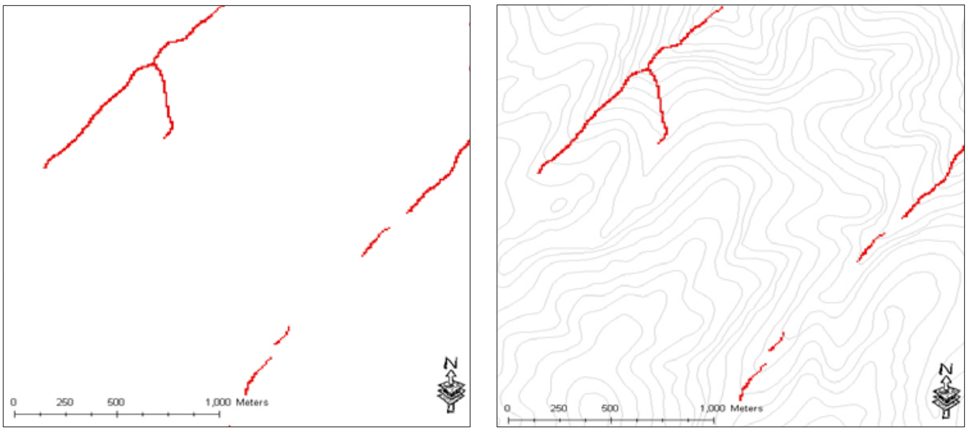


Figure 5.7 A 3-D image of the DEM with 10-meter resolution over the districts Kisoro and Kabale. A five-time vertical exaggeration factor has been used to highlight the shapes of the landscape. Lighter areas represent high elevation and darker low.

5.2.2 Algorithm

The first unprocessed output data, for the entire study area, is produced by the algorithm within a couple of minutes. A selection from the output data can be seen in Figure 5.8a. A first look at the output gives a rather vague impression of what the result actually represent, but when applying the contours (see Figure 5.8b) the potential sites appear more obvious in their geographic context. To visualize the whole study area at once in this way would not be illustrative, because the high resolution makes the output unclear and confusing. The result after post processing the output gives us a total amount of 250 potential sites for small-scale hydropower stations within Kisoro and Kabale.



(a) (b)

Figure 5.8 a) Showing raster output containing potential sites for small-scale hydropower (red lines) and b) the same output with contours.

5.2.3 Visualization

A basic but illustrative way of visualizing the potential sites derived by the algorithm is to display the number of sites per sub-county in a map (see Figure 5.9). It does not display the exact location of each site, which would make it too difficult to interpret, but it shows areas presumed to be of most interest for small-scale hydropower prospectors.

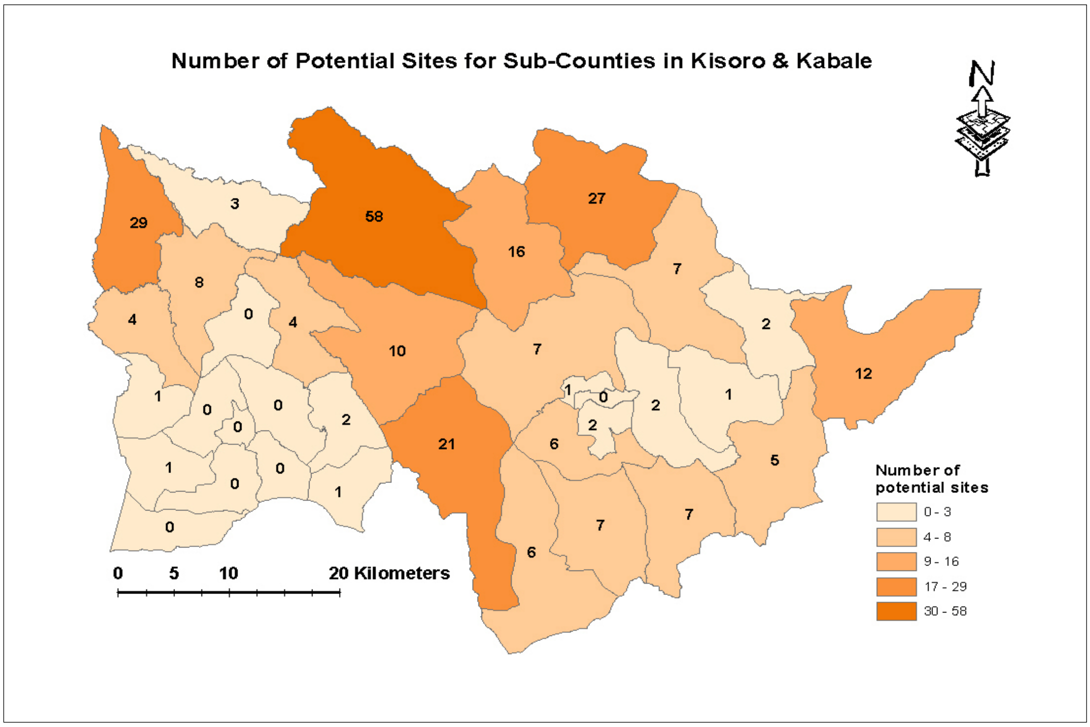


Figure 5.9 Overview map showing distribution of potential sites per sub-county.

A more advanced way of presenting the result would be to take more factors of interest into account. Such factors could be population density and distances between roads and potential sites, which can be seen in Figure 5.10.

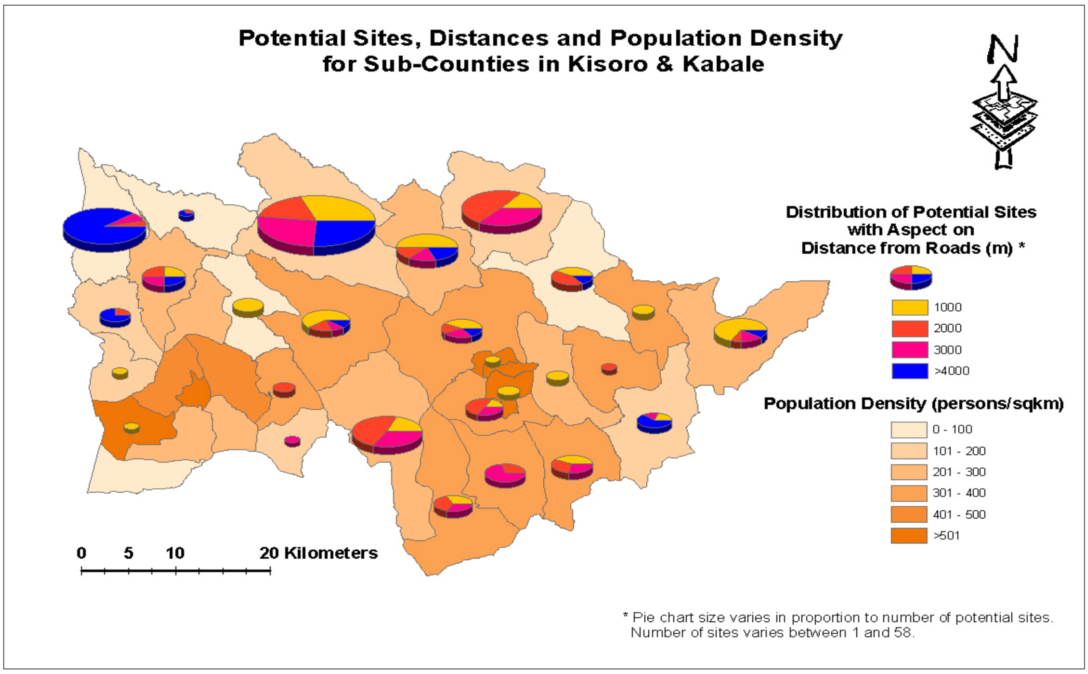


Figure 5.10 Overview map showing distribution of potential sites per sub-county. The segments in the pie chart diagrams represent the proportion of sites within a certain distance from a road. The sizes of the pie chart represent the number of potential sites in the sub-county. The colors of the sub-counties symbolize the variation of population density.

This figure helps to decide which areas that have a high population density as well as high number of potential sites and their distances to roads. As in Figure 5.9 above, the degree of detail is rather generalized; therefore if the exact position is desired, a more detailed map over a smaller area can be used (see Figure 5.11).

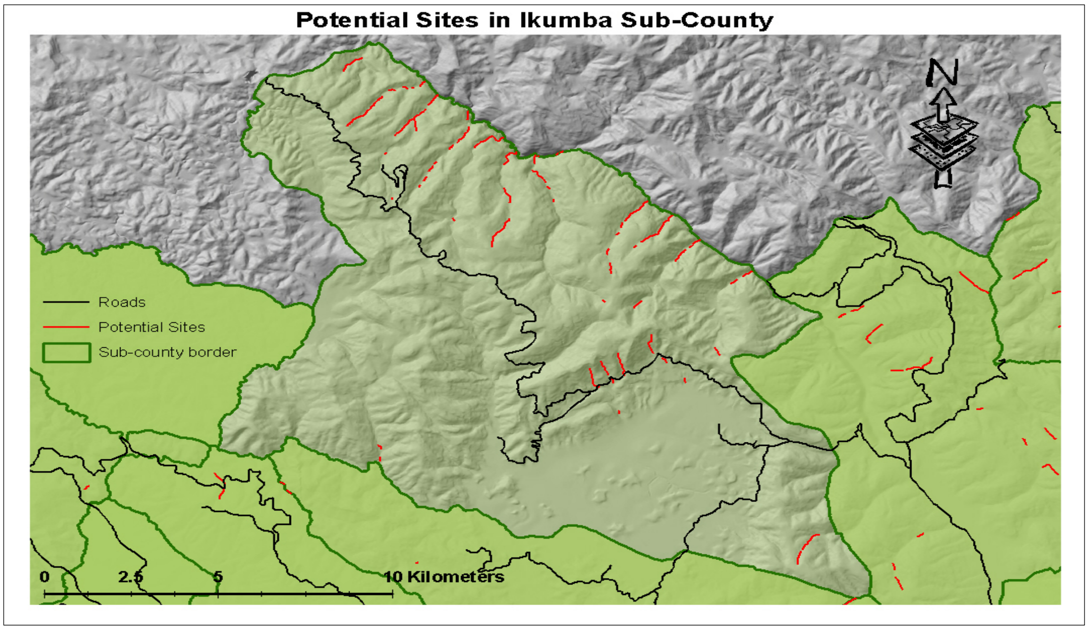


Figure 5.11 Geographic position of potential sites in Ikumba sub-county. Each red line, regardless of its length, indicates one potential site for a small-scale hydropower station.

By using a smaller area it is possible to visualize more details e.g. roads and administrative units. A shaded relief image of elevation set as background emphasizes the geographical surroundings of the potential sites, which facilitate the understanding of their position in reality.

5.2.4 Evaluation of Potential Sites

When performing the evaluation our goal was to evaluate 25 sites, but we were only able to visit 14 of them. All sites are marked as red dots in Figure 5.12 below. The result of our evaluation showed that all visited sites met the requirements of 20-meter head over a distance of 100 meters and showed noticeable traces from streams and rivers. However there were only three sites containing a permanent flow, which strongly contradict the input data, where all these rivers should be permanent. The sites where a permanent flow exist are sites 2, 19 and 25 in Figure 5.12

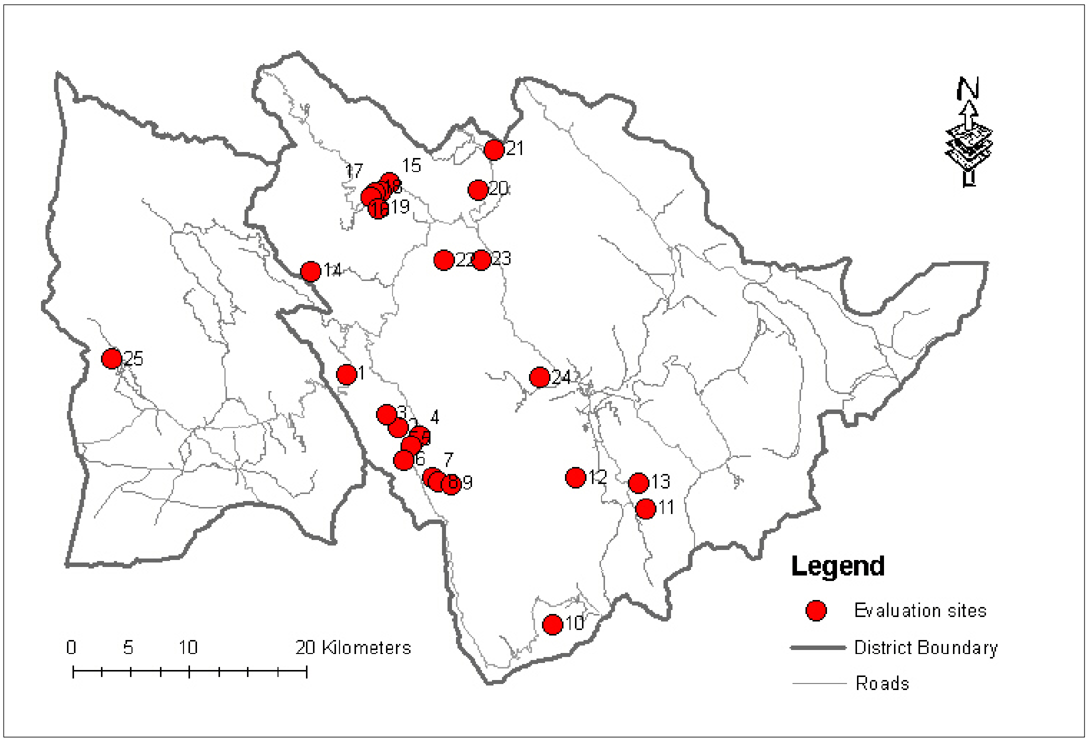


Figure 5.12 Evaluation sites in the study area.

To determine the electrical power potential of site 19, in vicinity of the village Nyambare in Nyamabare parish, the following steps were made:
To calculate the electrical power we first need to calculate cross-sectional area, flow and head. This is done by using equations 4.3, 4.4 and 4.2.

- **Area:**
  $(0.3\,\mathrm{m} \cdot 0.5\,\mathrm{m})/2 = 0.075\,\mathrm{m}^2$

- **Flow:**
  $0.075\,\mathrm{m}^2 \cdot (1\,\mathrm{m/s} \cdot 0.65) = 0.04875\,\mathrm{m}^3/\mathrm{s}$
  Where 0.65 is a correction factor for a small slow clear stream

- **Net head:**
  $100\,\mathrm{m} \cdot \sin 15^{\circ} = 25.9\,\mathrm{m}$
  25.9 m – 25% = 19.4 m
  Where 25 % equals the loss of power due to penstock friction.

By using equation 3.1 we then calculated the hydraulic power.

- **Hydraulic power:**
  $19.4\,\mathrm{m} \cdot (0.04875 \cdot 1000)\,\mathrm{l/s} \cdot 9.81 = 9283\,\mathrm{W}$

As stated in section 3.1.2, there is a power loss of 35% in the turbine when the hydraulic power is converted to mechanical power. There is also a loss of power when converting to electrical power. As in the example in section 3.1.2, we have calculated with a generator efficiency of 80 %, which gives the site at Nyambare the potential electrical power of 4.8kW.

- **Mechanical power:**
  9283 x 0.65 = 6034 W

- **Electrical power:**
  6034 x 0.8 = 4827 W or 4.8kW

The same calculations as above have been applied on the sites 2 and 25 to estimate their electrical power potential. Site 2 near the village Nyamatembe in Kacherere parish has an electrical power output of 1.9 kW and site 25 near the village Rusiza in Busengo parish, 48.4 kW. Information about all evaluated sites is attached as Appendix 9.5.

5.3 Summary of Results

- The general attitude to electricity is positive and all interviewees were in great need of its services. Almost all consider themselves to have some means to pay for the electricity even if it is more expensive than today's energy costs. If a small-scale hydropower project was to be implemented, they would happily sacrifice land for building it and handle service and maintenance for free.

- The outcome of the quality assessment point to that the 10-meter resolution DEM is a good choice for the analysis.

- The method identified 250 potential sites for small-scale hydropower stations. A selection of 14 sites out of these was evaluated, which resulted in three sites fulfilling all requirements. All sites met the requirement regarding a 20-meter head over a distance of 100 meters, but the majority lacked a permanent flow of water.

6 Discussion

6.1 Interviews

The answers from our interviews show a most concordant result, in that almost everybody is in great need of electricity, and consider themselves to have some means to pay for the associated costs. According to Halvorsen (1992) all units in the population, which in our case is the rural population of the Study area, should have equal chance to be selected when using an unbound random sample method. By limiting our sample population to only randomly choose interviewees along the way when performing the evaluation, the sample is not statistically correctly selected. Halvorsen (1992) also argues that the larger the size of the sample population is the higher the probability is that the sample population resembles the population and that the size of the needed sample population is dependent on how similar the population is. With the size of 65 interviewees, our sample can be considered fairly small, but we consider it to be representative. A Minor Field Study is performed under limited time and resources, which is why the interviews could not be performed in a, according to Halvorsen (1992), statistically correct manner.

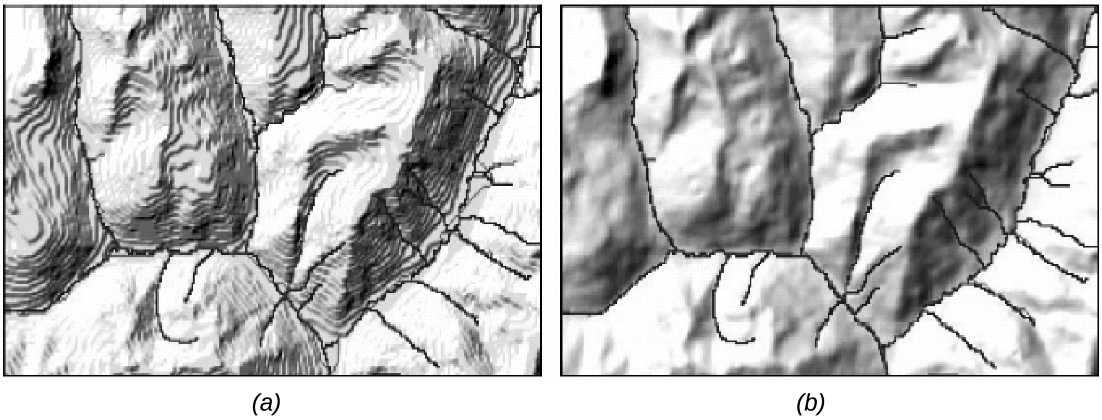
Devereux and Hoddinott (1993) argue that the use of an interpreter can bring advantages when performing an interview, such as information about the area, the culture and practical things. In our case, our interpreter helped us: to announce our presence and intentions, to arrange meetings, with guidance in the area and to understand the local customs, which made him indispensable for the study. The interpretation can naturally be a source of error, because of the interpreter's subjectivity and misunderstandings. One example of this from our interview is the question regarding what energy sources the interviewees were using at home and at work. By analysing the answers from this question, you can make the assumption that the interpreter sometimes more likely asked what sources of light they were using instead of what sources of energy.

Something we expected from the answers on the question regarding what the interviewees would use electricity for was that they would use electricity to begin small enterprises and use it in their farming. Surprisingly only 20% of the interviewed intended to either start an enterprise and/or expand their working days beyond dusk. A possible reason for this could be that the awareness of what the electricity could be used for is very low.

We have chosen not to take the economic aspects of small-scale hydropower projects into consideration, since we consider this to be outside the framework of our study. The projects are supposed to be financed by subsidies from the government, NGOs and aid organizations, but the remaining part must come from the rural population itself. Since it is hard to quantify these costs, we asked the question in a way that gave us information if the interviewees had any liquid assets at all to buy electricity for. The question does not answer how much money they have, instead it lets us know if they have any money or if they just trade goods or use self-catering.

6.2 Interpolation

When interpolating a DEM, the best result is usually received when the data points are evenly distributed throughout the interpolation area. Contour lines are practical when visualizing a landscape, but they do not represent the surface in a statistically correct way since points along the lines are over-represented compared with the ones perpendicular to them (Eklundh, 1999). This over-representation of data points can lead to terracing problems as can be seen in Figure 6.1a. A slight occurrence of terracing can be discerned in our DEM (see Figure 5.6) but in a comparison to the relief in Figure 6.1a we consider our terracing problems to be of minor importance. Our method is designed to find a 20-meter height difference over a distance of 100 meters, which means that smaller variations, such as terraces, within this distance are leveled out. Eklundh and Mårtensson (1995) argue that contour lines can only be used if a sophisticated interpolation algorithm, such as ANUDEM is available, otherwise the terracing problems will be too pronounced, see Figure 6.1.



(a) (b)

Figure 6.1 Contour interpolation using a) Inverse Distance Weighted and b) ANUDEM. Source: Peralvo.

In order to create a DEM a number of different techniques are available, such as Kriging, Spline and Inverse Distance Weighted (IDW) interpolation. In ArcGIS it is not possible to use contour lines as input data when interpolating with these methods. To be able to use our received data in these methods we either had to digitize a new layer with evenly distributed elevation points or to convert the lines to points and use a generalization routine that reduces the over-representation of points along the lines. Since the study was performed under limited conditions, there was no possibility to try these different methods, therefore we used the ANUDEM based interpolation method TOPOGRID in ArcGIS. Asserup and Eklöf (2000) say that when the highest possible accuracy is needed, advanced algorithms like ANUDEM offer more flexibility and higher precision, due to its drainage enforcement algorithm and the possibility to incorporate streamline data into the interpolation. Also Peralvo (www.crwr.utexas.edu) found, when performing a quantitative comparison measurement, that TOPOGRID outperformed IDW, Kriging and Radial Basis Functions (RBF) when creating hydrologically correct DEMs. TOPOGRID consistently produced high quality results for both areas with steeper slopes and well-defined valley bottoms as well as river junctions, which substantiate the appropriateness of the locally adaptive approach used in the algorithm.

When using contours as input data in the interpolation method ANUDEM the result is of course dependent on the quality of input data. As can be seen in Figure 5.6a, the bad quality of digitalisation could have caused the loss of potential sites for small-scale hydropower stations. Bigger errors arisen by incorrect digitalisation and by outliers with high amplitude is likely to be detected and edited and therefore not causing much problems. Hence, bad quality of contours can be critical for the outcome, but errors are relatively easy detected and eliminated through a visual inspection and editing of the data.

In our study we tried interpolations with 100, 30 and 10-meter cell size in order to reach a suitable resolution. The reason for choosing the 10-meter resolution DEM is that it has the best accuracy regarding both terrain structure and absolute elevation, compared to the 100 and 30-meter resolution. A reason not to choose the 10-meter resolution would be the slight occurrence of terracing, which is not as noticeable in the other resolutions. After studying the shaded relief images, we found that in most cases there is no terracing where there are rivers and they have therefore no or little influence on our further analysis of locating potential sites for small-scale hydropower. A reason for this is the drainage enforcement function that we used in the ANUDEM interpolation, which forces the interpolation to be as hydrological correct as possible. Our intention was also to interpolate with a 5-meter resolution, but the large amount of data that the contours over Kisoro and Kabale involve, made it impossible to perform. The computational capacity required in virtual memory for an operation like this could neither be met on our laptop nor on one of the most powerful computers at the Department of Physical Geography and Ecosystem Analysis.

Sinks are a reoccurring problem when performing interpolations. ANUDEM with its drainage enforcement algorithm is designed to remove all sink points in the DEM. Despite the use of ANUDEM in our interpolation, there are sinks occurring in the output data. We believe this is due to that the rivers used as input data in the interpolation were incorrectly digitalized. In order for ANUDEM to work properly, the rivers must be digitalized downstream, that is that the every arc's "from-node" in the river layer must be at a higher elevation than the "to-node". The interpolation strives to always let the rivers flow in downstream direction, which sometimes forces the terrain to lift up in an unnatural way. The sinks tend to arise along the sides of these elevated areas. The area containing sinks in Figure 5.4 is an example of this, where the valley bottom should be a flat area but has been elevated to a low ridge where the river flows. We assumed that the watercourse data we used was digitized in a correct way, but when detecting the sinks we realized that this was not the case.

6.3 Algorithm

The algorithm produced a generally satisfying result, but we have discovered some occurrence of noise, as can be seen in Figure 6.2. The noise consists of one up to five connecting pixels where the accumulated height difference reaches only a few meters, instead of the criteria of 20 meters.

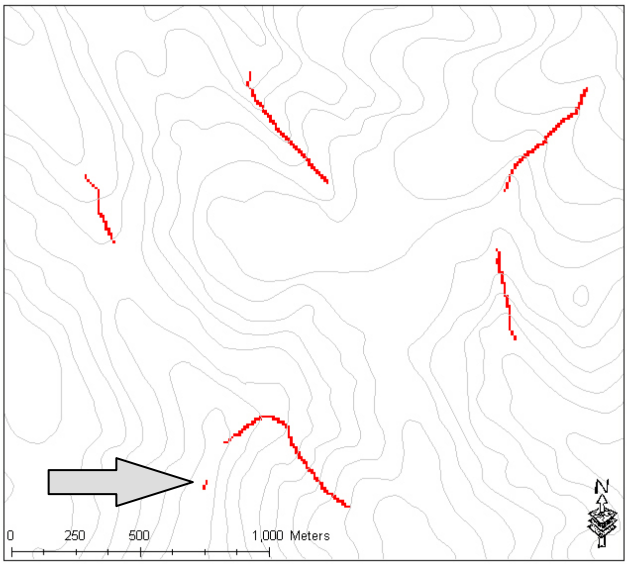


Figure 6.2 Showing an example of the inexplicable occurrence of noise in the algorithm output. Grey lines represent contours and red lines the potential sites.

Throughout the development phase of the algorithm we used a smaller training area, which produced a noise free result, but when the algorithm was completed and we used the whole study area as input data, we discovered the noise. After weeks of searching for an explanation with support from competent personnel, the phenomenon is still unexplainable for us. In order to avoid the noise, a split of the input data is necessary, because of some reason the noise does not occur when using smaller areas. These outputs can then be merged together to form a mosaic of the complete area. The problem with this solution is that when dividing the area into smaller areas, the watercourses could get cut off and cause loss of potential sites. Because of this problem we chose to use the whole study area as input data, despite the occurance of noise.

Our criterion for rivers to be a potential site is to have of a height difference of 20 meters over a distance of 100 meters. The algorithm is today designed in a way that makes it possible for the ten connection pixels to exceed the 100-meter criterion. This happens if the river pixels in the data set connect diagonally. If all cells should connect diagonally the distance would be 141 meters instead of 100, since the hypotenuse is 14.1 meters if the pixel size is 10 meters. To avoid this problem, it would have been preferable to change the syntax to stop after 100 meters instead of 10 pixels. Because of the limited time and that the criterion of a 100-meter distance only is a recommended approximate measure, we decided to use the algorithm in its present state.

6.4 Post processing

Our method was expected to be based on four different criteria, mentioned in the Introduction. The sites should have a permanent watercourse, have a specified height difference, be in vicinity of a village and not be in an unsuitable area. We succeeded to fulfill these criteria, except for the sites to be in vicinity of a village. There are two reasons for this and one is that there were no digital data covering villages available. The second and most important reason is that the village pattern has a completely different composition, compared to Sweden. What we expected was that clusters of houses would represent the villages. Instead the Ugandan countryside consists of evenly scattered houses, with only theoretical village boundaries separating one village from another. The reason for having this criterion was to receive a selection of rivers in direct vicinity of villages, but because of the actual village pattern, all rivers are in vicinity of villages. When this criterion appeared to be superfluous we chose to present the result as potential sites coupled to population density data at Sub-County level (see Figure 5.10).

6.5 Evaluation of Potential Sites

A reason to why we only evaluated 14 potential sites was our unfamiliarity to the coordinate systems in Uganda, which resulted in that we could not use our GPS in the process of locating evaluation sites. All used digital maps over Uganda are in Arc 1960

UTM Zone 36N projection. The study area is located in UTM zone 35, but is in all maps extrapolated to be in same zone as the rest of the country. When using a GPS in the study area, you will receive coordinates in zone 35, which therefore differs from the coordinates in the maps. The knowledge about this was received later and therefore we abandoned the use of GPS, which reduced the pace of our evaluation.

The fact that the use of GPS no longer was an alternative to find the potential sites and the inability to unhindered visit all sites in the terrain, we decided to evaluate sites in vicinity of roads and smaller villages. This was done despite the knowledge that a certain degree of tarmac bias could occur, which would make the selection of evaluation sites statistically incorrect. On the other hand, there is no interest in potential sites far away from roads, since it will make transportation of construction material more complicated and expensive.

The reason to why not more than three sites fulfilled the required criteria of head and permanent flow, at the evaluation, was not our algorithm, but incorrect input data. When performing the evaluation we found that all watercourses, except these three, were seasonal and not permanent as supposed to in the input data. This probably arose as a classification error when digitizing the watercourse layer. Despite that we did not find permanent watercourses, every visited site clearly showed signs from water activity, which means that the data is correct regarding location. Of course this should have been critically questioned before performing the analysis. We should also have asked the NFA what the requirements are for a watercourse to be classified as permanent. None of this was done, instead we committed the mistake of assuming that the data was correct.

We interpreted the conditions in the study area mentioned earlier, regarding precipitation and topography to be favorable for watercourses suitable for small-scale hydropower. The result from the evaluation showed the opposite since we hardly found any watercourses at all in the area, which surprised us. The reason for this is partly because of the incorrect classification but also because of the properties of the volcanic geology. According to Nyiraneza and Hoellhuber (2002) the absence of surface water is caused by high and inhomogeneous permeability of soil and underlying geological formations. Something we came across when evaluating the potential sites, which also can explain the absence of surface water, is the construction of subsurface water pipes. The water is led through pipes from springs down to the village center, where it supplies the villagers with drinking water.

From this we can draw the conclusion that the quality of watercourses as input data is of major importance. As the result from the evaluation show, almost 80 percent of the sites do not qualify to be a potential site for small-scale hydropower, because of low quality of input data. There are two different errors that can contribute to the low quality of data. The first and most obvious is the classification error mentioned above, but also the accuracy that the watercourses have been digitalized with can be of importance. If the watercourses have been imprecisely digitized, this can result in rivers located at the wrong position in the DEM, when making the overlay. This can result in loss of potential sites or gain of false sites.

6.6 Lesson Learned

From our study we conclude that the result is largely dependent on the quality of watercourse input data. In order to avoid errors such as incorrect classification and low digitalization precision and to receive a more accurate result, one option is to use self-produced input data over rivers and streams. This can be attained by using the produced DEM to calculate catchment area and flow accumulation. To make the input data even more reliable, factors concerning precipitation, infiltration and evaporation can be taken into consideration. This is an extensive task, which demands a thorough investigation of the geology and climatology of the area. Although this is time consuming, the result should be rivers at exact position and also knowledge about its volume flow rate and temporal variation. A better, faster and more reliable approach would be to use our method with available watercourse data and perform a field survey in the area of interest in order to ensure which sites that really have a potential for small-scale hydropower.

6.7 End Discussion

As mentioned, there were only three sites in the evaluation that fulfilled the criteria of a suitable small-scale hydropower site. To put these into context, the site with smallest potential electrical output of 1.9 kW would according to Fraenkel et al. (1991) be suitable for a battery charging station, as it is not economic to transmit electricity over longer distances because the cost of the cables will be out of proportion to the value of the power. Further Maher and Smith (2001) argues that a small-scale hydropower station with a potential electrical output equal to the site in Nyambare (4.8 kW) is enough to supply a village of up to 100 households with common devices such as; light bulbs, radios, televisions, refrigerators and food processors. The largest potential site found in the evaluation, with a capacity of 48.4 kW, would be suitable for income generating businesses, such as small-scale industries or workshops as well as for household energy.

As described in chapter 3.3.3 all referenced authors conclude that energy and electricity plays an important role in economic growth and rural development. As Porcaro and Takada (2005) writes, the most evident impacts of modern energy services are that they stimulate income generating businesses at local level, improve education, gender equality and health. Even though Holland et al. (2001) argues that electricity will not initiate development, it can stimulate development that is already taking place. In order for development to take place through access to electricity, we believe that some kind of basic economic condition as well as knowledge about the field of application is a necessity. The electricity would be of no use in a village where there are; no means to buy applications such as light bulbs or refrigerators or no knowledge of for example tool upgrading (electrical trimmers, lathes etc.), which will increase productivity.

When interviewing the Rural Electrification Agency we found that the Rural Electrification Strategy and Plan does not contain any plans or projects to assist rural electrification through implementation of small-scale hydropower stations. Instead their main approach is to extent the existing grid, but also mini-grids and photovoltaic units. We consider the grid extension to be a good strategy although it might take a long time to electrify all of Uganda, since it seems to be a rather time-consuming process and also difficult and expensive to reach remote areas. In order for the development to progress, we therefore believe that the REA should use small-scale hydropower as a complement, both during and after the grid extension, since it is efficient, reliable, relatively cheap and environmentally friendly.

The performed interviews identify an existing need for electricity among the rural population in Uganda. This need is a foundation for projects such as small-scale hydropower to be successfully implemented. Even though the people concerned have some means to pay for the projects, another prerequisite that must be fulfilled is that a proper financing system is available. This could be arranged through either governmental support, such as the grants from the Rural Electricity Fund, subsidies from aid organizations or private investors and micro credits.

7 Conclusions

The objectives of this study were to identify potential sites for small-scale hydropower in our study area, to develop a method for localization of potential small-scale hydropower sites in the developing world and to investigate the rural energy situation in Uganda. By reaching these objectives we can now answer the questions in the introduction:

- The result from our algorithm was 250 potential sites, of which we intended to evaluate 25. Because of time limitations, we were only able to evaluate 14 sites, which resulted in three approved potential sites, where the potential electrical output ranged between 1.9 and 48.4 kW.

- By developing our method we have realized that the use of a GIS is a swift and precise way to identify potential sites for small-scale hydropower stations.

- The importance of data quality is of weight in the matter of contour data, but errors can relatively easy be detected and edited. The quality of watercourse input data is of major importance, since imprecise digitalization and classification errors would result in a totally misleading output. We therefore recommend to our method with available watercourse data in combination with a thorough field survey in order to ensure which sites that really have a potential for small-scale hydropower.

- The result from our interviews point to an existing need for electricity in our study area, which we consider to be a general opinion in rural areas of Uganda. Energy and electricity plays an important role in economic growth and rural development. The most evident impacts of modern energy services are that they stimulate income-generating businesses at local level, improve education, gender equality and health.

- The governmental action in Uganda made to assist rural electrification consists of the Rural Electrification Strategy and Plan. The main approach is to extend the existing grid, implement mini-grids and photovoltaic units, but there is also a possibility for private initiators to receive subsidies from the Rural Electrification Fund.

In conclusion, our method for locating potential sites for small-scale hydropower is swift and precise, presupposed reliable input data is available. If there is a need for electricity and if good financing possibilities are available, small-scale hydropower is an appropriate alternative to assist rural electrification, which hopefully will lead to development and improved standard of living. If this method should be practically implemented, it is first of all intended to act as basic data for decision makers in developing countries, such as the Rural Electrification Agency, aid organizations and private investors.

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9 Appendix

9.1 Interview: Rural Electrification Agency

General discussion questions

Your organisation

Current energy situation

Figures of people connected to the grid

Private/local energy sources

Import of electricity from neighbouring countries

Energy production in Uganda

Ratio between production and consumption and blackouts

Contract between Uganda and Kenya, regarding power supply

Cost for grid connection

Price per kWH and other costs

Development of electrification in general in Uganda

Rural discussion questions

Actions to improve the rural electricity situation

Cheap and effective alternatives

Ongoing projects - Time plans and budgets

Financing - private investors - cooperation

Micro financing

Payment possibilities in rural areas

Meters and readings

Priorities when expanding

Maintenance

Illegal connections

9.2 Interviews: Rural Population in the Study Area

- What is your occupation?
- What kind of energy sources do you use at home and at work?
- Do you have access to electricity?
  If so, how is the electricity produced?
- Are you in need of electricity?
- What would you use the electricity for?
- What disadvantages do you think electricity would bring you?
- With electricity comes also some expenses for you; are you able to pay any money for that service?
- Are you willing to pay more money for electricity than for your current energy sources?
- If you get electricity from a small Hydro Power Plant, would you be interested in learning how it works and then for free take care of maintenance 1 hour every day?
- Do you think it is worth to sacrifice a part of your land to build a power plant, which will give you electricity?

9.3 Digital Data

All data layers are digitised in Arc 1960 UTM Zone 36N projection. The Arc Datum 1960 is referenced to the modified Clarke 1880 ellipsoid, Transverse Mercator projection with coordinates on the UTM grid. Following layers are divided into classes and sometimes sub-classes:

Watercourses (Line Shapefile)

- Permanent watercourses
  - River: normal permanent
  - River: small permanent
- Seasonal watercourses
  - River: small normal
  - River: small

Administrative units (Polygon Shapefile)

- District
- County
- Sub-county
- Parish
- Forest reserve
- National park

Infrastructure (Line Shapefile)

- All weather, tarmac with more than 2 lanes
- All weather, tarmac with 1 to 2 lanes
- All weather, eroded tarmac
- All weather, loose surface
- All weather, eroded loose surface
- Dry weather, loose surface
- Motorable track
- Bridge, cars
- Railway
- Railway, abandoned

Contours (Line Shapefile)

- Elevation contours with equidistance of 30 meters.

Land Cover/Use (PC ArcInfo Polygon Coverage)

- Deciduous plantation or woodlot
- Coniferous plantation or woodlot
- Tropical High Forest, fully stocked
- Tropical High Forest, depleted
- Woodland (trees and shrubs, average height > 4 meters)
- Bushland (bush, thickets and scrubs, average height > 4 meters
- Grassland, Rangelands, Pastureland, Open Savannah (with or without scattered trees, bush, scrub or thicket)
- Wetland (swampy areas with or without papyrus or reeds)
- Subsistence farmland (mixed, in use or fallow)
- Uniform farmland (e.g. tea or sugar estates)
- Urban or rural built-up area
- Open water (large rivers, ponds or lakes)
- Impediments (e.g. bare rock or barren soil)

9.4 Algorithm Syntax

HEADHUNTER
the software

made by Christoffer Malmros & David Bergström
Master Thesis in Physical Geography March 2005

This algorithm is developed to search through Rasterized Rivers, in order to find a height difference (head), of 20 meters over a distance of 100 meters. It is designed to search a maximum of ten connecting cells, which equals 100 meters. If the criteria of 20 meter accumulated head is fulfilled, these cells will be saved into a output raster.
Needed indata:

> a Matrix showing rivers where each river cell contain absolute elevation, extracted from an Digital Elevation Model.
> All values not containing elevation are set to zero.

```
clear;
%clears variables
clf;
%clears figure
clc;
%clears command window
time1=clock;
time3=clock;
```

Input of data

```
fin=fopen('rivers_elev.flt','r');
%opens a file in read mode.
data = fread(fin,[8254 5495],'float32');
%reads the data into a matrix with 4 byte real values.
data = data';
%flips the matrix to right angle.
fclose(fin);
%closes the input data file.

[row,col] = size(data);
%number of rows and columns are given as the variables "row" & "col".
```

Frame creation

This is made in order to avoid pixel values along the edges.
The algorithm must not calculate cells exceeding x-min/max or y-min/max.

```
for a=1:1;
%loop only the first row
   for b=1:col;
   %loop every column
      data(1,b)=0;
      %set the cell values to zero, to create a border above the data
   end
end
for c=1:row;
%loop every row
   data(c,1)=0;
   data(c,col)=0;
   %set the cell values of the first and last column to zero, to create
   %borders to the left and right of the data.
end
for d=row:row;
%loop only last row.
   for e=1:col;
   %loop every column.
      data(row,e)=0;
      %set the cell values to zero, to finalize the frame.
   end
end
```

Creation and definition of variables and matrices

```
cells = sum(data(:)>0);
%counts the number of cells in "data" greater than zero.
output=zeros(row,col);
%creates a matrix to write the output into.
rivercells=zeros(cells,3);
%creates a matrix of 3 x "cells" and fills it with zeros.
%It will soon contain all values and coordinates from "data".
order=zeros(cells,3);
%creates a matrix of 3 x "cells" and fills it with zeros.
%It will soon contain ranked coordinates from "rivercells".
%Highest elevation is ranked as number 1 in "order".
rivercells_row=0;
```

```
rivercells_col=0;
%the variables "rivercells_row" & "rivercells_col" are set to zero.
row_number=0;
%the variable "row_number" is set to zero.
highest_value=0;
%the variable "highest_value" is set to zero.
next=zeros(1,2);
%creates a array "next" and fills it with zeros.
prev(1,1)=10000;
prev(1,2)=10000;
%the array "prev" is filled with 10000.
x=0;
y=0;
%the variables "x" & "y" are set to zero.
```

Extraction and ranking of height values of input data

```
f=1;
%sets the counter "f", used in loop below, to one.
for g=1:(row);
%loop from 1 to number of rows.
   for h=1:(col);
   %loop from 1 to number of columns.
      if data(g,h) >0;
      %if value of cell is greater than zero ->
         rivercells(f,1)=g;
         rivercells(f,2)=h;
         %sets row "f" & column 1 & 2 in "rivercells"
         %to current row and column.
         rivercells(f,3)=data(g,h);
         %sets row "f" & column 3 in "rivercells" to current cellvalue.
         f=f+1;
         %adds 1 to the counter "f".
      end
   end
end

order= sortrows(rivercells,3);
% sorts the matrix "rivercells" in ascending order into the matrix "order".

execution_time1=etime(clock,time1)
%stops clock 1.
```

```
time2=clock;
%starts timer on clock 2.
```

Searching for height difference in a 3 X 3 cell window

The search begins in the cell with highest elevation. From there it examines all eight surounding cells to find the next cell to go to. The first cell to examine is the upper left ((x-1),(y-1)), seen from the highest elevation cell (x). Then it continous to search counter clockwise untill all eight are examined. The neighbouring cell with greater slope than any other of the neighbouring cells, is the next cell, from where to continue the search. The next cell must not be the previous cell, have the value of zero and have a value greater than current cell. After the first ten iterations have been performed, it starts again at the cell with the second highest elevation. This is done repeatedly until all rivercells have been a starting point.

```
for l=cells:-1:1;
%loop from 1 to number of "cells".
   x=order(l,1);
   y=order(l,2);
   %variables "x" & "y" are given the coordinates from row "l" in "order".
   cell_height=0;
   %the variable "cell_height" is set to zero.
   height=0;
   %the variable "height" is set to zero.



   for m=1:10;
   %loop from 1 to 10.
      temp1=0;
      %the variable "temp1" is set to zero.
      highest_value=data(x,y);
      %the variable "highest_value" is set to the height value of current
      %coordinates in "data".
      done=0;
      %sets the variable "done" to zero. Done is an indicator showing if
      %a logical exression has been performed.

      if data((x-1),(y-1))>0 & data((x-1),(y-1))<=highest_value...
      & any([(x-1),(y-1)]~=[prev(1,1),prev(1,2)]);
      %if the examined cell value is greater than zero, lower or equal to
```

```
%"highest_value" and if the cell coordinates are not the same as
%previous ->
    temp1=((highest_value-(data((x-1),(y-1))))/(sqrt(200)));
    %sets the variable "temp1" to the slope to the examined cell.
    next(1,1)=(x-1);
    next(1,2)=(y-1);
    %writes the coordinates of the examined cell into "next".
    cell_height=(highest_value-data((x-1),(y-1)));
    %sets the variable "cell_height" to the height difference
    %to the examined cell.
    done=1;
    %logical expression is performed.
end

if data(x,(y-1))>0 & data(x,(y-1))<=highest_value...
& (y-1)~=prev(1,2);
%if the examined cell value is greater than zero, lower or equal to
%"highest_value" and if the cell coordinates are not the same as
%previous ->
    temp2=((highest_value-(data(x,(y-1))))/(10));
    %sets the variable "temp2" to the slope to the examined cell.
    if temp2>temp1;
        temp1=temp2;
        %if the newly examined cell ("temp2") has greater slope
        %than the former ("temp1"), the variable "temp1" is set to
        % the value of variable "temp2".
        next(1,1)=(x);
        next(1,2)=(y-1);
        %writes the coordinates of the examined cell into "next".
        cell_height=(highest_value-data((x),(y-1)));
        %sets the variable "cell_height" to the height difference
        %to the examined cell.
        done=1;
        %logical expression is performed.
    end
end
% the following if-statements are as above.
if data((x+1),(y-1))>0 & data((x+1),(y-1))<=highest_value...
& any([(x+1),(y-1)]~=[prev(1,1),prev(1,2)]);
    temp2=((highest_value-(data((x+1),(y-1))))/(sqrt(200)));
    if temp2>temp1;
        temp1=temp2;
        next(1,1)=(x+1);
```

```
        next(1,2)=(y-1);
        cell_height=(highest_value-data((x+1),(y-1)));
        done=1;
    end
end

if data((x+1),(y))>0 & data((x+1),(y))<=highest_value...
& (x+1)~=prev(1,1);
    temp2=((highest_value-(data((x+1),(y))))/(10));
    if temp2>temp1;
        temp1=temp2;
        next(1,1)=(x+1);
        next(1,2)=(y);
        cell_height=(highest_value-data((x+1),(y)));
        done=1;
    end
end

if data((x+1),(y+1))>0 & data((x+1),(y+1))<=highest_value...
& any([(x+1),(y+1)]~=[prev(1,1),prev(1,2)]);
    temp2=((highest_value-(data((x+1),(y+1))))/(sqrt(200)));
    if temp2>temp1;
        temp1=temp2;
        next(1,1)=(x+1);
        next(1,2)=(y+1);
        cell_height=(highest_value-data((x+1),(y+1)));
        done=1;
    end
end

if data(x,(y+1))>0 & data(x,(y+1))<=highest_value...
& (y+1)~=prev(1,2);
    temp2=((highest_value-(data(x,(y+1))))/(10));
    if temp2>temp1;
        temp1=temp2;
        next(1,1)=(x);
        next(1,2)=(y+1);
        cell_height=(highest_value-data((x),(y+1)));
        done=1;
    end
end

if data((x-1),(y+1))>0 & data((x-1),(y+1))<=highest_value...
```

```
& any([(x-1),(y+1)]~=[prev(1,1),prev(1,2)]);
    temp2=((highest_value-(data((x-1),(y+1))))/(sqrt(200)));
    if temp2>temp1;
        temp1=temp2;
        next(1,1)=(x-1);
        next(1,2)=(y+1);
        cell_height=(highest_value-data((x-1),(y+1)));
        done=1;
    end
end

if data((x-1),(y))>0 & data((x-1),(y))<=highest_value...
& (x-1)~=prev(1,1);
    temp2=((highest_value-(data((x-1),(y))))/(10));
    if temp2>temp1;
        temp1=temp2;
        next(1,1)=(x-1);
        next(1,2)=(y);
        cell_height=(highest_value-data((x-1),(y)));
        done=1;
    end
end

if done==1
%if any of the above if-statements are true ->
    prev(1,1)=x;
    prev(1,2)=y;
    %gives the array "prev" the coordinates of current cell.
    height=height+cell_height;
    %the current height difference is added to the accumulated
    %height difference in the variable "height".
    height_value(m,1)=x;
    height_value(m,2)=y;
    %the current coordinates are saved in the matrix "height_value"
    %at row "m".
    x=next(1,1);
    y=next(1,2);
    %gives "x" & "y" the coordinates of the next cell to go to.

else
    break
    %if none of the above if-statemnets are true, the loop will end
    %and continue at the cell next in order.
```

```
        end

    end

    if height>=20;
    %if the accumulated height difference is greater/equal to 20 meters->
        for n=1:10;
        %loop from 1 to ten.
            output((height_value(n,1)),(height_value(n,2)))=1;
            %gives the matrix "output" a value of one at the coordinates
            %corresponding to the coordinates in the matrix "height_value".
        end
    end
end
clear('data');
%clears the variable "data" from the virtual memory, in order to free space
%to transpose "output".

potential_cells = sum(output(:)>0)
%prints the number of potential cells.

fout=fopen('output.flt','w');
%opens/creates the file "output.flt" to write into
fwrite(fout,output','float32');
%writes the matrix "output" into "output.flt"
fclose(fout);
%closes the file
execution_time2=etime(clock,time2)
%stop clock 2
%finished
execution_time3=etime(clock,time3)
```

9.5 Evaluated Sites

The coordinates are in Arc 1960 UTM Zone 36N projection. The Arc Datum 1960 is referenced to the modified Clarke 1880 ellipsoid, Transverse Mercator projection with coordinates on the UTM grid. The sites are given with approximate coordinates and can be seen in Figure 5.12.

Site 1 (144711,62948)
LC1 Kagano
LC2 Karengyere
12 degrees over 100 meters
No permanent water

Site 2 (149434,58522)
LC1 Nyamatembe
LC2 Kacherere
12-13 degrees over 100 meters
Permanent water
Depth: 0.3 m Width: 0.5 m Flow: 0.5 m/s.

Site 3 (148075,59518)
LC1 Nyaruchea
LC2 Kacherere
Not evaluated

Site 4 (150899,57389)
LC1 Rwabahundam
LC2 Kichange
25 degrees over 100 meters
No permanent water

Site 5 (150321,56814)
LC2 Kichange
25 degrees over 100 meters
No permanent water

Site 6 (149642,55333)
LC1 Muchange
LC2 Kachacha
12-15 degrees over 100 meters
No permanent water

Site 7 (151259,52530)
LC1 Kirimbi
LC2 Kachacha
8-12 degrees over 100 meters
No permanent water

Site 8 (151501,52133)
LC1 Nyakabungo
LC2 Kachacha
8-12 degrees over 100 meters
No permanent water

Site 9 (151722,51585)
LC1 Nyakabungo
LC2 Kachacha
8-12 degrees over 100 meters
No permanent water

Site 10 (162636,42001)
LC1 Nyamijoma
LC2 Kibuga
Not evaluated

Site 11 (170321,51332)
LC1 Kyaseb
LC2 Buhara
Not evaluated

Site 12 (164610,54110)
LC1 Kashenyi
LC2 Kitumba
Not evaluated

Site 13 (169505,53547)
LC2 Muyebe
Not evaluated

Site 14 (143474,71369)
LC1 Katatzya
LC2 Kaara
Not evaluated

Site 15 (148454,79110)
LC1 Kachvamuhoro
LC2 Nyamabare
20 degrees over 100 meters
No permanent water

Site 16 (147486,78619)
LC1 Nyambare
LC2 Nyamabare
22 degrees over 100 meters
No permanent water

Site 17 (147024,78470)
LC1 Nyambare
LC2 Nyamabare
20 degrees over 100 meters
No permanent water

Site 18 (146623,78157)
LC1 Nyambare
LC2 Nyamabare
20 degrees over 100 meters
No permanent water

Site 19 (147379,77045)
LC1 Nyambare
LC2 Nyamabare
15 degrees over 100 meters
Permanent water
Depth: 0.3 m Width: 0.5 Flow: 1m/s

Site 20 (156072,78680)
LC1 Hakitooma
LC2 Mpungo
Not evaluated

Site 21 (157216,82000)
LC1 Rugyendabar
LC2 Mpungo
Not evaluated

Site 22 (154710,73958)
LC1 Hamurwa
LC2 Hamurwa
Not evaluated

Site 23 (156681,72831)
LC1 Karukara
LC2 Hamurwa
Not evaluated

Site 24 (161760,63482)
LC1 Karambazi
LC2 Kagarama
Not evaluated

Site 25 (124521,64142)
LC1 Rusiza
LC2 Busengo
12 degrees over 100 meters
Permanent water
Depth: 1 m Width: 3 m Flow: 0.6m/s