Environmental Suitability Analysis for Geothermal Development: A Case Study for Suswa Geothermal Prospect, Kenya

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Environment, GIS, geothermal, Suswa

ABSTRACT

Geothermal development is a phenomenon that entails targeting and drilling of geothermal wells and eventual construction of geothermal power stations. For this to happen, certain environmental factors have to be considered. In the Suswa geothermal prospect area, available data were categorized into two datasets; physical (slope, hydrology and faults), and socio-economical (population centers, cultural sites and access roads). Geographical Information System (GIS) analysis tools were used to identify and generate environmental dataset that contains restrictive data layers and classification of these layers are taken into account for future development of geothermal. A knowledge-driven weighted overlay integration method within a GIS was used, to determine the spatial association between physical and socio-economical and technical evidences to determine potential areas for geothermal development.

1. Introduction

Geothermal energy is recognized as an environmentally friendly energy source compared to the use of fossil fuels. The terminology "environmentally friendly" is used in comparison with other sources but a degree of friendliness of an impact on the environment depends on the point of view of the impacted community.

Geothermal projects involve heavy civil and infrastructure activities in terms of construction of access roads, drilling pads and power plants. These activities can adversely affect land stability in the surrounding region and may consequently lead to landscape modifications, alteration of natural features, vegetation change and losses, soil erosion, surface water pollution and cultural interest.

One of the goals of the Suswa geothermal project is to demarcate environmental restrictive areas and identify extents for possible geothermal development with the lowest impacts on the surrounding environment. The Kenyan Integrated National Land Use Guidelines (NEMA, 2011) are customized and used in this analysis.

ArcGIS 10.1 was used as an effective tool for the analysis and visualization of environmental data using computerized approach. In lieu of identification and demarcation of environmental suitable sites for geothermal development, technical and environmental data were contributed and the GIS (ArcMap 10.1) was utilized as a decision support system tool for performing environmental suitable site identification. These data were categorized in two datasets; Physical (slope, hydrology and faults) and socio-economical (population centers, land use and access roads). The model builder tools in ArcGIS were used as a graphical environment to develop a diagram of the multiple steps required to complete complex geo-processing tasks to determine the spatial association between physical and socio-economical evidences to determine potential environmental suitable geothermal sites in Suswa prospect.

2. Project Area

Suswa is the southernmost Quaternary volcano in the axis of the Kenyan rift bounded by latitudes 1.00 S and 1.18 S and longitudes 36.13 E and 36.33. It contains a 12 x 8 km caldera with the rim at an altitude of 1890 m. Suswa is the closest active

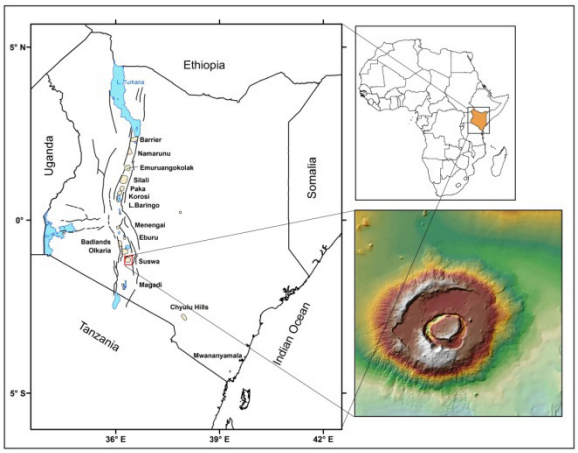

Figure 1. Location Map of Suswa.

volcano to Nairobi, the capital of Kenya (50 km). The project area is about 750 km^2.

The location of the study area is shown in Figure 1.

3. Methodology

GIS was employed to carry out a suitability analysis and site selection process because it can handle a large amount of data, is a powerful tool to visualize new and existing data, can help produce new maps while avoiding human errors made during decision-making and allows the effective management of the GIS data (Noorollahi et al., 2007).

The environmental suitability analyses were performed by overlaying environmentally important data layers and suitable areas selected. This resulted in identification of an environmentally suitable area for geothermal development activities. Suitability analysis involved the combination of the physical and socioeconomical datasets and then merging them after initial processing and analysis, applying weighted distance analysis and finally weighted overlay. The process is outlined in the figure below; GIS uses the commonality between multiple layers to search their relationships. This is done through geoprocessing and spatial analysis to discover their relationship. Spatial analysis in GIS is mainly used to identify associations between data sets that are otherwise unknown.

Selection of areas demarcated as environmentally suitable in the Suswa geothermal prospect were done using weighted overlay method. This method is described below:

Environmental Evidence Layers

Environmentally suitable areas for geothermal development activities in the Suswa geothermal prospect were identified by using available digital data layers categorized in two datasets including physical and socioeconomic. Each dataset includes some data layers. These data layers were used to make factor maps that were applied to demarcate environmentally suitable areas for geothermal development. The data layers introduced in the model are spatial distribution of slope, rivers, faults, population centers, access roads and cultural sites (caves etc.)

Physical Dataset

Physical data includes changes on the earth's surface such as mountains valleys, faults as well as features such as rivers and roads. Detailed information about terrain and surface features is essential for the planning and construction of any major civil engineering or construction projects. Physical information can also be used in the development stage for geothermal projects. The duration and cost of development can be minimized by physical siting program.

Slope

Slope represents an important terrain parameter from the land utilization point of view and also in environmental impact analysis. Natural slope of a geothermal prospected area is important for construction of well sites and accompanying structures. The land with a greater slope may pose difficulty in the construction and may need leveling and cause more environmental disturbance. The following criteria were used in delimiting suitable areas for geothermal development with respect to slope. (modified from NEMA, 2011).

Table 1. Criteria for delimiting suitable areas with respect to slope.

Slope (percentage)	Suitability
<12%	Most suitable for geothermal works
12 – 55%	Moderately suitable, such areas will require an integration of appropriate soil conservation measures. This will incur enormous costs during rehabilitation
>55%	Not suitable. Development is restricted and such areas are deemed protected.

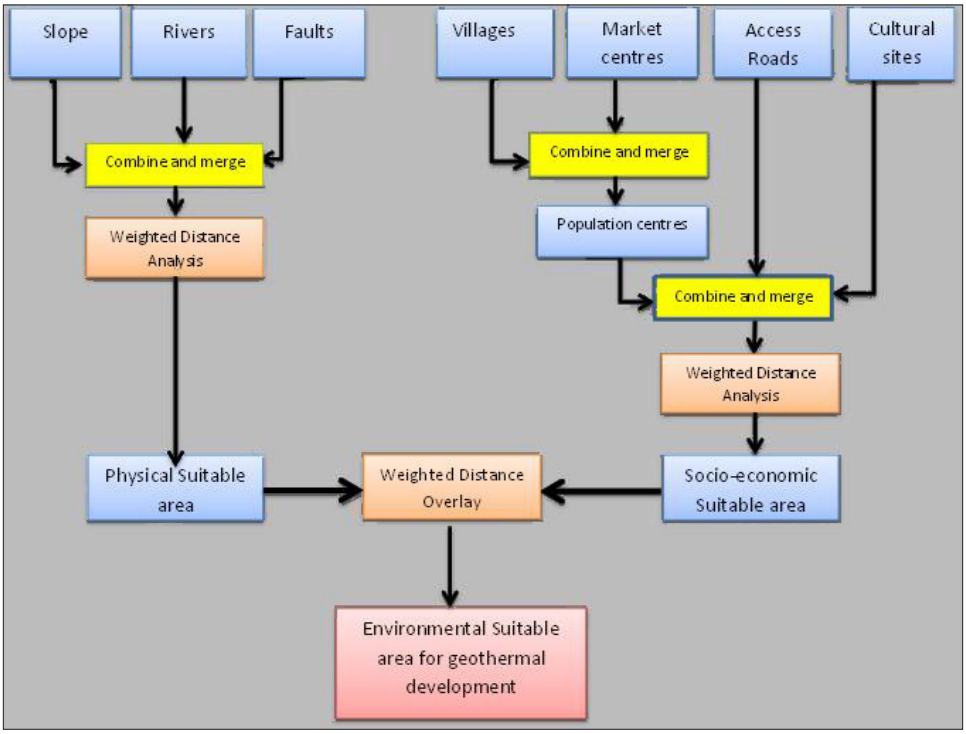

Figure 2. Schematic diagram for weighted overlay model.

The slope map of the study area was created from Digital Elevation Model (DEM) data and using the Spatial Analyst of ArcMap. The output raster map was asked to generate the percent of slope. To prevent surface disturbances, works like construction of geothermal drill sites, should be done where the slope is less than 12%. Environmental impact will be severe if the slope is greater than 12%.

For minimizing the environmental effects in the Suswa geothermal prospect, work on proposed geothermal well sites are required to be assigned in the less steep area. The prospect area was divided into two features; less than 12% and more than 12% of slope. The areas with the slope of

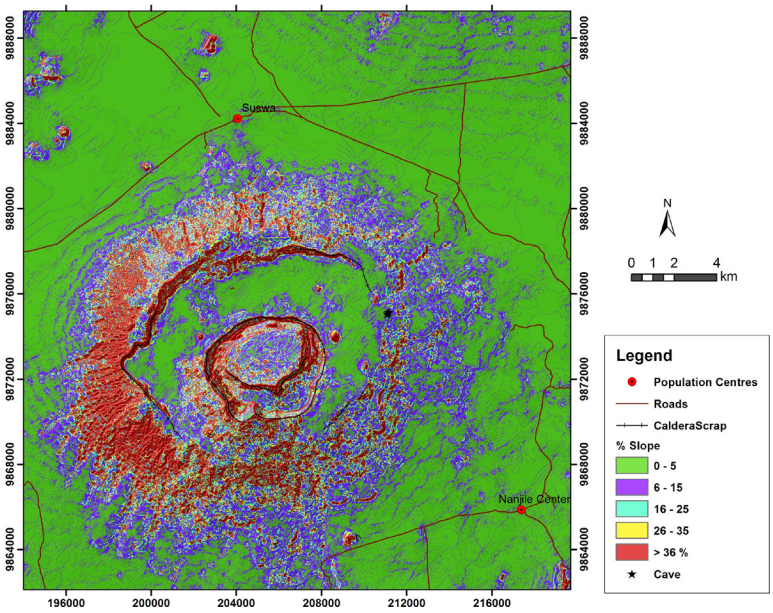

Figure 3. Slope for the Suswa geothermal prospect.

less than 12% inside the caldera were calculated to approximately 30km^2. This was selected as environmental suitable areas for geothermal development activities based on slope evidence. Areas with slope more than 12 % were discarded as shown in Figure 3.

Rivers (Water Drainage)

Data on the location of rivers provide information on the potential for flooding by rivers around the prospect area. The areas covered by water drainage system are not suitable for civil or infrastructures works for well sites due to the high possibility of water overflow and high flooding risk. According to the Kenyan Environmental Management and Co-ordination (Water Quality) Regulations, 2006 – Legal Notice No. 121 and the Water Resource Management Rules (2007)**,** development is restricted at 30m from the highest water/flood level within a riparian land. The criterion herein therefore restricts a buffer zone of 200m. In environmental suitability analysis the drainage system and movement ways of water across a surface is an important factor. The water drainage of the study area was derived from DEM data using Spatial Analyst tool and a 100 m buffer carried out to define the high risk area. The high risk area is cast-off from any future geothermal development undertakings. Buffer zones for areas without rivers are mapped as environmentally suitable for geothermal development.

Faults and Fractures

In most geothermal fields, fractures and faults play a big part in transportation of geothermal fluids from one point to another, in other words, from the geological perspective; geothermal plumbing systems might be controlled by fault planes. Geothermal fluids are known to flow through fractures in the reservoir rocks. Due to the of risk of encountering faults in the Suswa geothermal prospect, a proximity distance map with an interval of 500 meters was produced using the ArcMap spatial analyst tool. Proximity distances of 500 m and below were classified as potential hazard areas based on faults and fractures (Figure 4).

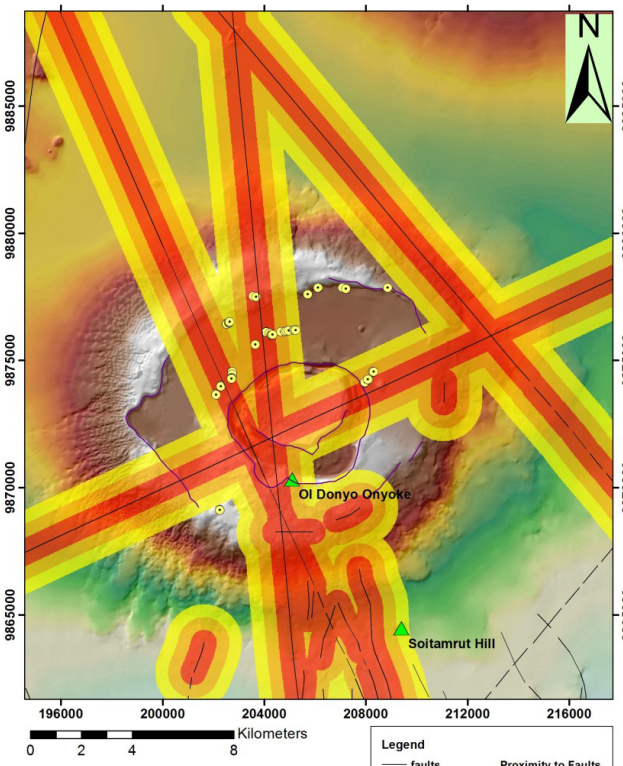

Figure 4. Distances to Faults.

Socioeconomic Dataset

Socio-economics data layer involves a combination of social and economic factors. Socioeconomic conditions are associated to humankind and their individualities, which usually contrast extensively within the same community and from one community to another. The socioeconomic datasets considered in the Suswa geothermal prospect area include population center, access road and cultural sites,

Population Centre

Population centres are basically where a lot of people live. Geothermal development activities should not be carried out near residential, recreational and cultural sites. The more reaction often grows against landscape modifications and alteration of natural features of cultural or historical interest, caused by civil and construction work and changes in the use of public areas resulting from project activities. There are several villages and several trade centres around the Suswa geothermal prospect. ArcMap was used to produce a factor map displaying distances to centres and villages. Distance zones within 5000 m buffer were discarded from further analysis for identification of potential sites for geothermal development.

Access Road

Good road networks positively impacts every socioeconomic aspect of a prospect area. The location of roads can play a significant role in reducing costs and limiting environmental impacts in the course of geothermal development activities. From an environmental perspective, it is recommendable that geothermal

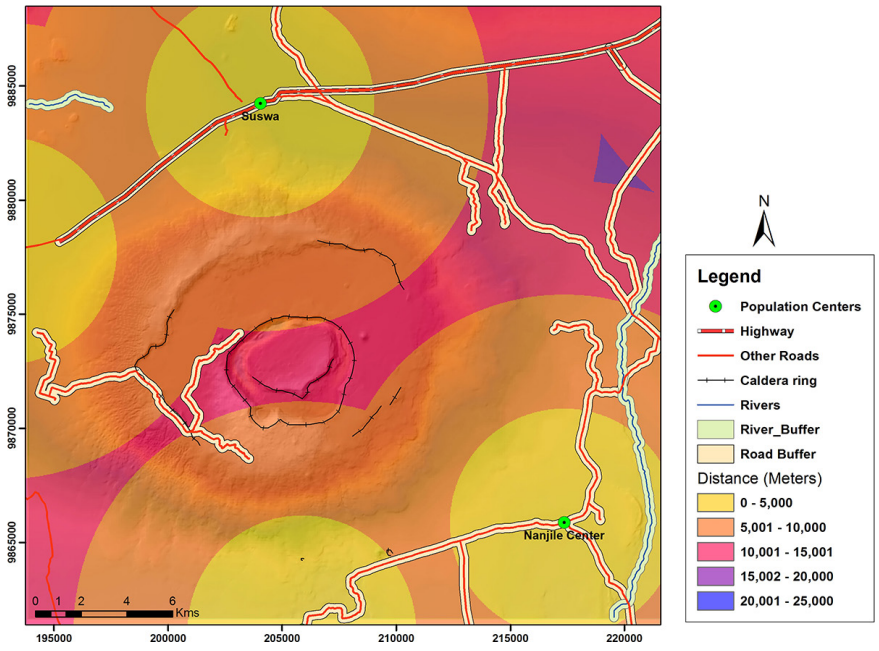

Figure 5. Distances to population centres and buffer zones on roads and rivers.

development activities take place near existing road networks. This will minimize the construction of new roads during civil works and for maintenance purposes. Environmentally, this will also reduce opening up of new and pristine areas thus decreasing land degradation and associated rehabilitation costs. Using ArcMap, a buffer size of 100m was generated to produce a restricted road network map.

Cultural Sites

A cultural site refers to an area that has been set aside due to its cultural significance. This place is known to have a legacy of physical artifacts and other elements of the society that have been inherited from past generations**.** In the Suswa geothermal prospect area, cultural sites exist in the form of special caves and other artifacts. Such areas were disregarded as suitable for geothermal development in line with the United Nations declaration on respect for indigenous people. A map showing distances to cultural sites was produced for the prospect area.

4. Data Integration Method

To determine areas with environmental suitability in the Suswa geothermal prospect, the weighted overlay integration model was used. The model entails applying a common scale to the datasets, and the higher values are given attributes that are considered suitable. The datasets were weighted giving each a percentage influence. The higher the percentage, the more influence a particular dataset will have in the model.

For performing weighted overlay model, a tool found in ArcToolbox, called raster calculator, was used to integrate the datasets in the prospect area. Raster calculator builds and executes a single Map Algebra expression using Python syntax in a calculator-like interface.

Table 2. Criteria for assigning higher weights for data layers integration.

Data Set	Evidence Layers	Suitable Zones
Physical layer	Slope	< 12 degrees
	Faults	>500 m
	Rivers	>200 meters
Socio-economic Layer	Population Centre	>5000 meters
	Access Roads	<100 meters
	Cultural Sites	>1000 meters

Raster maps on slope, faults and rivers were integrated to produce areas with a physical suitability map. Based on integration of factor maps on population centers, cultural site and access roads, areas with socioeconomic suitability were identified and mapped. The three layers were superimposed and the selected areas were combined using the union tool in ArcMap, to determine the socioeconomic suitable area

Table 2 shows the evidence layers and criteria which were used in environmental suitable site selection process.

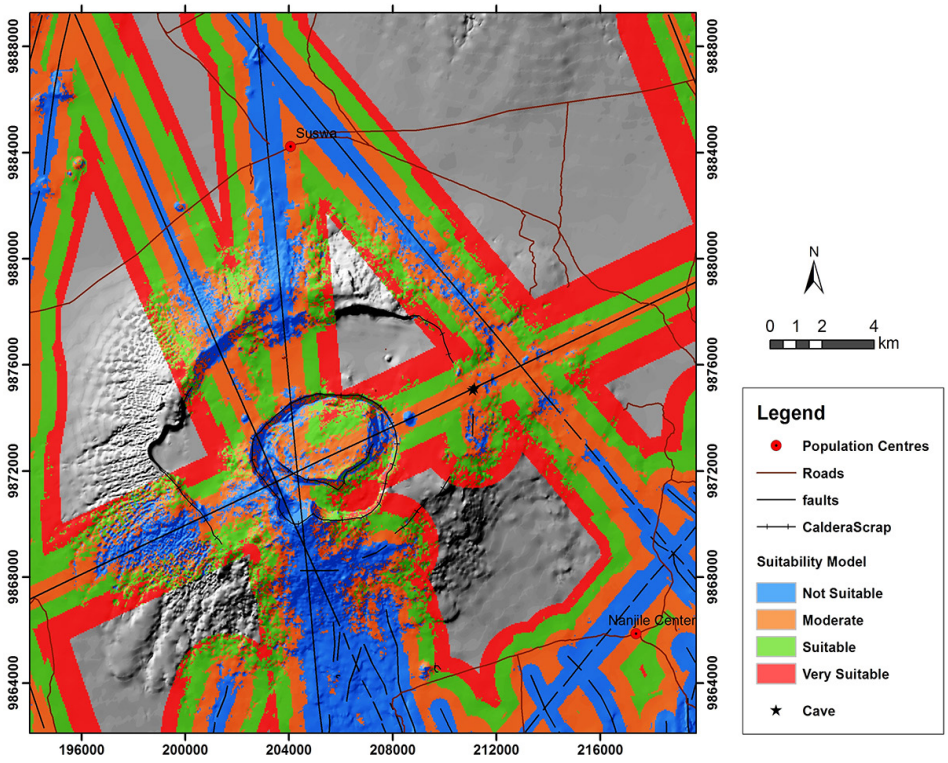

Figure 6. Environmental Suitability Model.

5. Conclusion

Environmentally suitable site selection for geothermal development in the Suswa geothermal prospect site selection was identified by using available physical data including slope, river and faults. The socioeconomical data that was used included population centers, access roads and cultural sites. Weighted overlay methodology was used to integrate the evidence layers in a GIS environment.

Finally, environmentally suitable sites for prospect area were determined. Figure 6 shows a map displaying suitable areas for geothermal development in the Suswa geothermal prospect area.

GIS models are dynamic and can be improve by adding new data layers or changing the criteria.

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