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POTENTIAL FOR SMALL SCALE DIRECT APPLICATIONS OF GEOTHERMAL FLUIDS IN KENYAS RIFT VALLEY – AN UPDATE FROM GEOPOWER AFRICA PROJECT

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ABSTRACT

Satellite and ground-based studies of the East African Rift (EAR) system reveal active magmatic and/or aqueous hot fluid movement beneath 40% of the volcanoes. Kenya and Ethiopia are already tapping geothermal fluids to generate electrical power. The GeoPower Africa project is currently investigating and mapping small but multiple geothermal manifestations (medium to low enthalpy resources of between 70^0-150^0C) in Kenya, Ethiopia and Tanzania and identifying new forms of applicable economic activities that can be introduced to utilise the geothermal resources along the rift. The project has so far employed an inter-disciplinary approach including using data from geology, volcanology, hydrogeology, fluid geochemistry and geophysics. A database was established from literature surveys and a sizeable number of sites have been visited in the three countries. In Kenya, data has been collected from Magadi in the south through Eburru in centre and Baringo in the northern parts of the rift and Homa Hills in western Kenya, including field controls and measurements of the geothermal manifestations and employing a systematic socio-economic approach through community interviews as well as observing the environment and economic activities of the communities around the geothermal sites. Results from the GeoPower Africa efforts indicate that a good number of the geothermal sites already visited can support small size units combining power generation and heat applications. Direct heat applications include green-housing, food drying, food preservation, thermal bathing and green tourism. These activities are expected to eventually contribute to improved socio-economic life of communities around the sites. This paper presents an update on the existence of small scale geothermal sites along the Kenyan part of the East African Rift and determination on which of these sites are suitable for immediate development, considering resource characteristics and the present socio-economic activities of the local population and its future needs.

1. INTRODUCTION

The East African Rift Valley is endowed with plenty of geothermal resources due to its being geo-dynamically active and characterized by regional anomalous mantle uplift with related extensional tectonics and shallow magma injections (Peccerillo *et al*., 2003; Biggs *et al*., 2009; Ebinger *et al*., 2010; Varet *et al*. 2012). The region encompasses more than 30 active volcanoes, and hundreds of hot springs and fumaroles, a situation which is particularly appropriate in providing sites of hydrothermal activity (e.g., hot-springs, fumaroles, hot and wet ground, etc) in which geothermal energy can be harvested at relatively shallow depths resulting in both big and small-sized development initiatives (Omenda, 2002 and 2012; Mnjokava, 2012; Teklemariam, 2006).

Population growth, a growing economy and aspirations to achieve some level of GDP growth requires that the Eastern Africa countries to almost treble their electrical power capacity in the coming decade. Peak demand has outstripped available capacity. These countries need to more than double their power supplies in the coming few years if their target of having at least half the population accessing power supplies is to be realised (KenGen Annual report, 2007; KenGen Business plan 2007; Porter, 2007). These countries will need also to kick-start future projects that will bring significant capacity on-line over the next decade, in order to alleviate current "fire fighting" to meet demand and create sustainable growth for Kenya, including the right to explore regional expansion opportunities. Much of this is expected to come from geothermal resources. In a region where the availability of jobs is a problem, the exploitation of geothermal energy, aimed at electricity generation and direct uses can become a source of employment and hence a pillar for raising the living standards of the local people and trigger social and economic development.

The Eastern Africa countries are addressing energy development issues by focusing on electrification through major grid systems supplied by large geothermal power plants capable of producing over 50 MWe each (e.g., Olkaria and Menengai, Kenya or Tendaho and Langano, Ethiopia). However, not all areas are connected yet to the grid, and there is a need to serve energy to presently isolated sites. In addition, not all geothermal waters are warm enough to be used to generate electricity by direct steam flash, but they are and can be valuable nevertheless because they all contain heat energy. Hence, there is a need to develop, in parallel, smaller size production units serving far-flung areas, away from main supply lines. Resources of low to moderate temperatures (50^0-150^0C) can be used for a wide variety of applications in the residential, commercial and industrial sectors. The direct uses include swimming, bathing, balneology, agriculture, and aquaculture. It is also possible now to produce electricity from fluids at temperature of 90 to 150^0C using small-size ORC plants. The cost per kWh produced is higher than conventional large size geothermal systems, but remains much cheaper than the kWh produced diesel generators.

Exploration efforts for geothermal energy have been carried out in the rift valley for several decades now. These investigations have identified both high enthalpy geothermal systems associated with young volcanic centres and low enthalpy systems associated with extremely weak surface manifestations. Models obtained from these data analysis suggested that the hot magmatic bodies resulted in the development of geothermal systems under these centres. Besides this, several hot springs occurrences are found along faults and open fissures. Hence a sizeable amount of data exists from all these kinds of thermal manifestations within the rift valley, but there had been, until now, no significant effort to investigate/confirm and compile all the available information on low or medium temperature resources and their current or potential uses. As a whole, the exploration efforts focused on large-size potential areas only, and small-size occurrences were neglected.

2. BACKGROUND AND OBJECTIVES OF THE GEOPOWER AFRICA PROJECT

In Africa, many rural communities, especially those in arid environments, lack access to power and water resources, either due to low levels of economic development with incomes of less than 1$/day or simply that the power is not there due to the lack of grid. People travel long distances to look for water. Lack of electricity for heating and lighting promotes cutting down of trees, resulting in environmental degradation. Consequently, lack of power inhibits socio-economic activities which would generate income for quality of life improvement. A combination of power and water access provided through applications of geothermal fluids on each site can improve this situation. Development of these hydrothermal out-cropping sites for small-sized, local geothermal projects can improve the standard of living for the rural poor; bring equity among the citizens and contribute to environment conservation. The GeoPower Africa project outcome in terms of development impacts is aimed at benefiting these poor rural communities within the EAR.

Estimates suggest that over 20,000 MWe from geothermal resources can be tapped by countries in the Eastern Africa region. The GeoPower Africa research project is focusing on potential geothermal energy use in the East African Rift Valley from any potential – even small-size - sites located in Ethiopia, Tanzania and Kenya (Figure 1). The scope of the project is to identify remote sites within the East African rift system for local geothermal energy development that will provide power for small scale socio-economic activities in these off-grid zones. The project has two aims. The first is to establish data base and map the small geothermal sites and the second is to identify new forms of geothermal direct use along the EAR in Ethiopia, Kenya, and Tanzania. These innovative sites are small size units that have the potential to combine power and heat applications from medium to low enthalpy resources (70-150^{0}C).

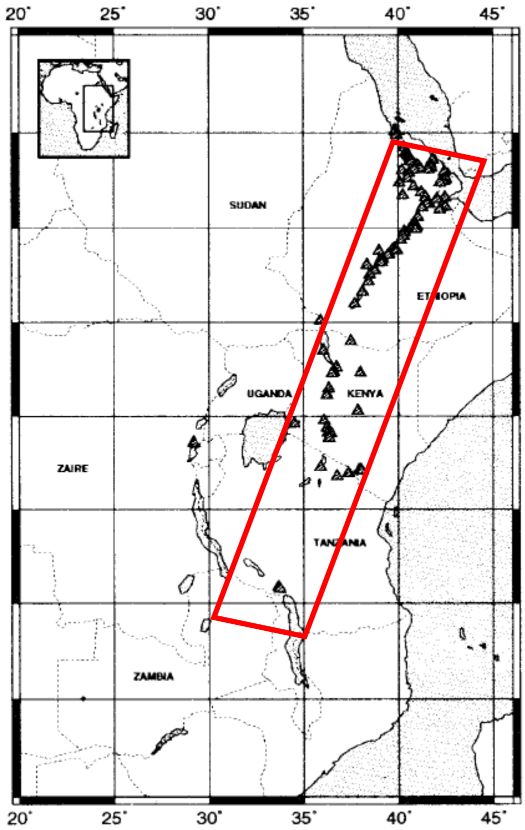

Figure 1: The area under study in the GeoPower Africa project

Conception of the GeoPower Africa project resulted from a challenging issue. Whereas a successful large-sized geothermal energy development for electric production, feeding the national and Eastern-Africa interconnected grid, is presently being developed with a well-established methodology (derived from OLADE's methodology for conventional geothermal energy development) and efficient support systems (such as ARGeo programme under UNEP of GRMF facility under African Union, the same does not apply for small-sized, local geothermal projects. Many rural communities in far-flung remote areas lack access to power, needs that could be answered by geothermal solutions.

This is a paradox that this project aims to address, as geothermal resource with appropriate characteristics is present in the project target sites and at the same time, the need for local development in these remote areas (far from the grid) is real. In these remote areas, the demand is frequently for energy and water, with both issues being inter-related as the arid climate necessitates reliance on groundwater, whereas the lack of electric power implies the need for energy to pump the water up from the wells. The project required an inter-disciplinary approach that our team was able to assemble, including geology, volcanology, hydrogeology, fluid geochemistry, shallow crustal geophysics, power engineering (notably ORC units) applied in cascade use of energy (green-housing, food drying, thermal bathing, green tourism) for social advancement.

A systematic socio-economic approach was included in order to address the needs of local populations and maximize their benefits from geothermal development. Our project's social dimension employs a gender-based approach, especially in regards to social roles of the different genders within the target local communities. Just as an example, the project's emphasis on a gender perspective, in this project, was informed by the fact that for communities found around the geothermal sites, the role of collecting water and fetching firewood is, like in practically all African communities, primarily a women's (and by extension, girls') role. Yet, despite the fact that geothermal can be used to provide water and energy, women in some of these communities where geothermal potential is found spend up to 5 hours per day searching for water and firewood, as was also confirmed by the project's field work validation (Figure 2). On the other hand, livestock rearing is an example of a role that is primarily men's (and by extension boys) within these communities as in the larger African context and beyond. Geothermal can facilitate water provision and growing of pastures (grass) for animals, thus save men and boys the long distances they are forced to walk in search of the same, especially during dry seasons, as well as death of livestock during drought.

Figure 2: Example of a site to be equipped as a consequence of GeoPower Africa project; a geothermal occurrence is used by local poor population (women and kids) for water production, by condensation of natural steam. Picture taken at Alutu, Ethiopia.

Many examples of uses of geothermal energy at local level exist, notably in rural and eventually remote areas around the world, especially in Europe and USA. A few cases also exist in Africa, notably in Kenya. But there is a lack of shared knowledge of these applications. Most of this information is site-specific, but the experience accumulated is such that it merits information and experience-sharing for benefits to the various stakeholders in the geothermal sector within Eastern Africa. Specific data also need to be collected in Eastern Africa, notably Kenya, Tanzania and Ethiopia, concerning the potential site characteristics as well as areas with potential for eco-tourism, agricultural development, pastoralism, fishing and other economic activities.

At the end, the GeoPower Africa project will have demonstrated:1) that suitable geothermal sites exist in the EAR, 2) that several of these sites are suitable for development, 3) that production and use of geothermal fluids can lead to technical and economic applications for development at a later stage, 4) the conditions necessary for success of such developments by drawing conclusions from a few representative demonstration sites , 5) that similar initiatives can succeed and be replicated on a large scale along the EAR system, thus enabling necessary local skills development and cost reduction of these systems. Hence the main outcome of this research effort is selection of a few sites where feasibility studies of demonstration projects can be conducted for the most appropriate and applicable technology using the available local geothermal resource. The type of technology to be recommended will be determined by the resource characteristics, current socio-economic activities of the local population, their needs and technology affordability.

3. ACTIVITIES ACCOMPLISHED SO FAR

The project activities are two-pronged. In the first phase: conduct a desktop data compilation of geothermal sites and validation by field visits. During the second phase, share best-practices on methodologies to implement for the case of the EAR and educate stakeholders through technology transfer programs.

3.1. Data Compilation

Many reports, academic research publications and technical or professional papers exist as published or unpublished literature on previous works on the EA Rift system. Many are of academic nature and provide useful background scientific data, but a relatively good number of professional reports focus on exploration for geothermal energy. These efforts have involved individual researchers, students, organisations (such as UNDP) geothermal companies and governments (Crabtree and Chesworth, 1992; Siebert, 1984; Teklemariam, 2006; Omenda, 2012; Teklemariam, and Beyene, K., 2005; Dunkley *et al*., 1993; Ofwona *et al*., 2006; Sturchio *et al*., 1993; Okoth and Riaroh, 1994; Wood and Guth, 2008; Kebede, 2014; UNDP, 1973; Hochstein *et al*., 2000; McNitt, 1982). These reports, describing geological, geophysical, geochemical and hydrogeological aspects of various regions along the rift, are found either in government departments and libraries, geothermal companies or universities. A good number of them contain measured data in form of tables. Sets of technical data (geology, geophysics, geochemistry, temperatures, fluid discharge characteristics) pertaining to geothermal manifestations (hot springs and fumaroles) have been compiled from these reports and data bases were established. The main focus of these earlier studies was to determine the geology and geothermal activity of the volcanoes within the rift while geothermal companies focused on exploring for large-size geothermal sites with an objective of developing the resource for electricity generation to meet the current energy demands in these countries. A good number of these reports and papers were used by the GeoPower Africa project in Kenya and formed the basis for the initial data compilation of geothermal resources along the EAR system. Important to note is that – in Kenya as well as Ethiopia and Tanzania - socio-economic data of these sites was however either very scanty or totally missing, thus a methodology and an inventory of the same had to be created from scratch by the project.

3.2. Field Validation

Systematic field visits for validation have been made in each country under study (Ethiopia, Kenya and Tanzania). Investigations on the physical and chemical characteristics of rocks hosting identified geothermal sites were carried out in which information that had earlier been compiled in the inventory was confirmed and new data/information, where available, was added. At each geothermal site visited, information on geological environment, availability of water and energy resources, existence and possible use of geothermal resources and socio-economic activities of the local population was noted. Geothermal surface manifestations around many of the sites take the form of hot springs, hot grounds, steaming grounds and fumaroles. The main areas of active fumarolic activity and with the highest recorded temperature of above 90^0C were found on or close to faults.

4. FINDINGS AND DISCUSSION

During the project's field visits it was reported that many local people frequent geothermal sites. They for example use the hot springs to bath, particularly in the evening hours. The hot springs are also considered good for curing skin rashes and stomach problems. In addition, other people come from further away areas to also enjoy the warm waters and use it for the same medicinal reasons. Communities that keep livestock (cows, goats, and sheep) also use the geothermal waters for medicinal reasons to treat animal diseases like foot and mouth disease. Some of the local communities also link the hot springs with spirituality: while some consider the sites sacred, others use its waters for spiritual rites. In some instances, the local communities have preserved the area around the hot

springs as tourist sites which they plan to make use of for income generation. There were also cases where community members put the hot waters to practical use such as boiling of maize and eggs by herders who take animals to graze.
A good number of sites with high temperatures and good fluid rates are harnessed by the local population to condense the steam and tap water for their domestic use. This is particularly developed in the most remote and dry areas, as in the Afar Desert and other parts of the Ethiopian and Kenya Rift. High inferred sub surface temperatures using various geothermometry calculations were possible good justifications for selecting such sites for more detailed work and eventually recommending them for drilling and using the steam or hot water for either electricity generation or direct uses.
For example, some sites characterized by hot and boiling springs, discharging at temperatures of about 90^0C, and close to fishing waters, if harnessed, would help the local community in the provision of enough heat to process or preserve the fish harvested from the nearby lakes and thus economically empower the people around these sites. Shallow wells could also be considered to tap into the deeper subsurface where the inferred temperatures are above 150^0C from geothermometry calculations. Such temperatures are enough for power generation using binary systems. The power produced can be used for lighting homes, for light industries, freezing, drying and for tourism promotion. In some geothermal sites, some low level tourist facilities exist and availability of power and process heat from the geothermal resource would help add value to the products by creating hot spas which would promote tourism thereby creating more income to the local people. All these give indications of the existing potential for small scale direct applications of geothermal fluids that can be harnessed to serve socio-economic needs of local communities.

In many of the sites visited, the discharge temperatures measured the same as the previously recorded temperatures by earlier workers with some slight variations in pH. This variation could possibly be resulting from the status of the measuring instrument (e.g., calibration discrepancies). Occasionally, differences in temperature could also be observed. The slight difference in the temperature recording could be attributed to the way in which temperatures of the fluids were measured, e.g., how much time was allowed for water to flow from the depth of the borehole if a manual pump was used. A steady flow would have allowed the temperature to stabilize and most probably the temperature recordings would have been closer to those recorded earlier. Another explanation for the discrepancy in the measured temperatures may be attributed to the rains experienced during the later measurements that could cool the hot steam.

Conclusions from geochemical analyses of water and steam samples from hot springs, fumaroles and boreholes carried out during earlier efforts estimated the temperatures of the deep reservoir(s). Findings from the studies suggested existence of fracture-controlled geothermal systems in the majority of the areas investigated. The heat sources for the geothermal system(s) are perceived to be either magmatic, (i.e., shallow dyke swarms and intrusive bodies that are conducting heat to shallow depths) or magmatic (that is heat transfer along permeable faulted zones, by hydrothermal convection). The structural set-up in most parts of the rift is marked by extensive faulting – frequently double-faulting in areas affected by transverse structures - resulting in enhanced permeability thus allowing for convection, recharge and storage of the geothermal fluids.

5. CONCLUSIONS

Currently, in Kenya and Ethiopia, the primary use of geothermal energy is for the production of electricity, mainly serving the national electricity grid. However, although not all geothermal waters are warm enough to be used to directly generate electricity from steam, they are and can be valuable, nevertheless, because they all contain heat energy. Resources of low to moderate temperatures (50^0-150^0C) can be used for a wide variety of applications in the artisanal, residential, commercial, tourist and industrial sectors. The direct uses include swimming, bathing, balneology, agriculture, and aquiculture. For example, a few farmers have, for decades, used geothermal heat to dry pyrethrum flowers and condense steam for drinking at Eburru, near Naivasha, Kenya, as well as in Afar and in the Main Ethiopian Rift, while the Oserian Development Company (also in Naivasha, Kenya) is using geothermal energy to heat greenhouses for growing flowers for export, and eventually, to control the $C0_2$ content in the air. A tourist hotel at Lake Bogoria is utilizing spring water at 38^0C to heat a swimming pool. Several hotels in Addis Ababa use geothermal water for sanitary hot water spass and swimming pools. Direct uses are only a tiny fraction of the total geothermal energy resource available in Kenya and Ethiopia as well as in many other countries in Eastern Africa. In recent years, this small figure of direct uses has been increasing, albeit slowly, in various parts along the rift. However, the rate of increase is insignificant, largely due to lack of information on availability of the resource and its benefits to potential users, particularly local communities. To help address the challenge associated with lack of information at local community level, the project's field visits were structured such that local community engagement was a key pillar. As a result, a methodological approach has now been established which can be applied to other sites. Other factors that have been attributed to this scenario associated with slow uptake of small scale direct application for geothermal fluids include technological constraints, commercial financing and eventually the low price of competing energy sources.

The GeoPower Africa project has demonstrated, having carried out systematic mapping and inventory of the natural occurrences that similar initiatives can succeed and be replicated on a large scale along the EAR system and that there are numerous suitable sites that have the required conditions for immediate development. The socio-economic conditions of the areas visited and feedback on needs of the local communities surrounding these sites indicate a lack of adequate modern energy and clean water supplies; a situation that can be, at least partially, be addressed by geothermal exploitation.

5. RECOMMENDATIONS FOR FURTHER WORK

In order to be seriously considered as an alternative in any project, an energy source must be easily characterised in terms of availability, applicability and cost. Historically, this has been a hurdle for geothermal energy, whose cost varies with depth and character of resource. To address this problem, a detailed survey needs to be conducted which will enable potential users to quickly evaluate the type of geothermal resource, the best technology available for answering the needs and the capital cost for developing and utilising it. So far, the GeoPower Africa project has compiled the much-needed information from various sources indicating which areas to give priority to, and the potential kind of development the concerned community may expect.

However, more hydrogeological and geochemical work needs to be carried out with specific focus on sampling and analyzing in detail more sites including the current ones with a view to characterize the geothermal discharges in this area and align them to possible economic uses. Areas with suitable reservoir temperatures will be identified for detailed exploration, including adapted shallow geophysical surveys. Recommendations will then be made, for possible drilling activities to access the deeper hotter fluids for use, either in electricity generation or direct heat applications. The potential uses will be dictated by the needs of the local population who in the case of Eastern Africa, and in this case, Kenya in particular, tend to predominantly be pastoralists. From the engagements that the project has had with local communities along the geothermal sites so far, some of the activities to be recommended would include fish farming and processing, food drying, abattoirs and hides and skin processing, honey processing, eco-tourism and hospitality industry.

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