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PRELIMINARY ENVIRONMENTAL IMPACT ASSESSMENT FOR THE DEVELOPMENT OF BURANGA GEOTHERMAL PROSPECT, UGANDA

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ABSTRACT

Geothermal investigations have been carried out in Buranga geothermal prospect in Uganda. Various analytical methods including geological, geochemical, hydrological and geophysical have been used to determine the subsurface temperatures, geological structures and flow characteristics of the surface and ground waters in this systems. The results of these studies will be used to site deep exploration wells and then install a geothermal power plant. In this study, the current status of Buranga environment, environmental effects of drilling and operation, and mitigation measures to be considered were predicted and analysed. The environmental regulations of Uganda were used as a guideline. The results indicate that the Buranga prospect should be subjected to a more stringent environmental impact assessment study and that its development has potential cumulative impacts. The adverse environmental impacts of drilling are expected to be minimal, temporary and mitigable to the level of insignificance. The physical impacts on the geology and the landscape relate to construction activities and the abstraction of water from the reservoir. Given the chemical concentration of the geothermal fluids, the risk of contaminating the groundwater by waste water disposal is considered low. Air emissions during operation are expected to cause no significant contamination of the air. All the impacts are predictable and can be mitigated with careful management of the resource and implementation of appropriate environmental protection measures and standards with the cooperation of all stakeholders. A detailed Environmental Impact Assessment based on the evaluation of additional data is recommended as a first step of the feasibility study to provide a better understanding of the potential impacts and mitigating measures that will be continuously upgraded during development.

1. INTRODUCTION

Surveys have been carried out on Uganda geothermal systems since 1993. The studies have focused on surface exploration of three major geothermal areas: Katwe-Kikorongo (Katwe), Buranga and Kibiro, all located in the Albertine graben. Earlier surveys focused on geology, geochemistry, hydrology and geophysics with the aim of elucidating subsurface temperatures and the existence of a geothermal system. Here the focus is on the Buranga geothermal prospect.

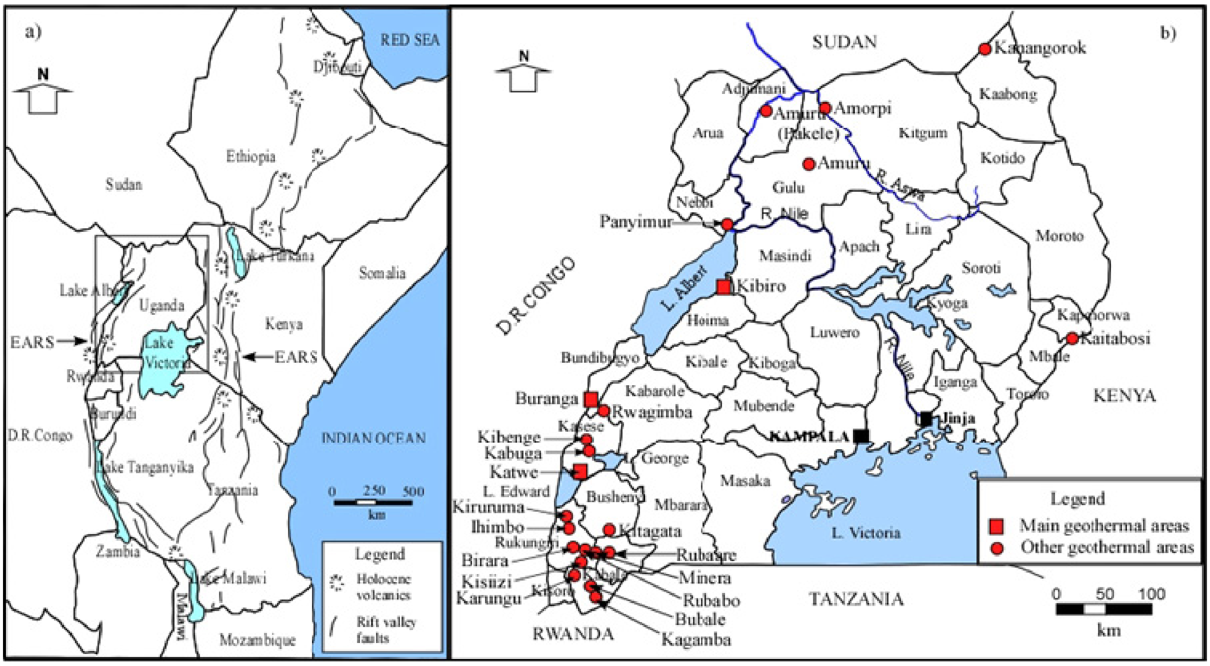

FIGURE 1: a) East African Rift System (EARS), b) Location of geothermal prospects in Uganda

The Buranga geothermal field is located in the Albertine graben that forms a part of the western branch of the East African Rift System that runs along the joint border of Uganda and the Democratic Republic of Congo (Figure 1). On Sempaya map sheet 56/1, the Buranga geothermal field is located in Kasitu subcounty in Bwamba county of Bundibugyo district. It is 50 km from Fort Portal on Bundibugyo road. Bundibugyo District lies in Western Uganda and covers 2338 km². It is bordered by the district of Kibale in the northeast, Kabarole in the east and southeast and to the west by the Democratic Republic of Congo (DRC). To the north, it shares its boundary with Lake Albert (Figure 2).

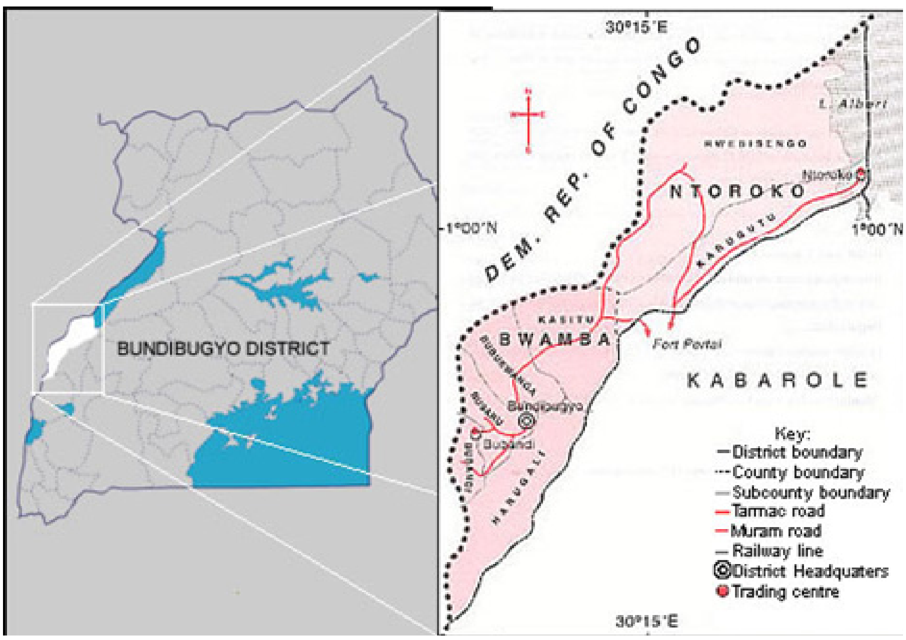

FIGURE 2: Bundibugyo District administrative units (Uganda Communication Commission, 2003)

Based on the studies, the status of geothermal exploration in Buranga field shows good potential for harnessing the geothermal resources. Hot springs and fumaroles are widespread in this area with Mubunga, Nyasinbi and Kagoro being the main springs (Figure 3). The temperature measurements in Buranga indicate that the prospect is suitable for electricity production and direct use in industry and agriculture. Results of the preliminary geophysical surveys indicate the existence of geothermal anomalies to the south of the prospect.

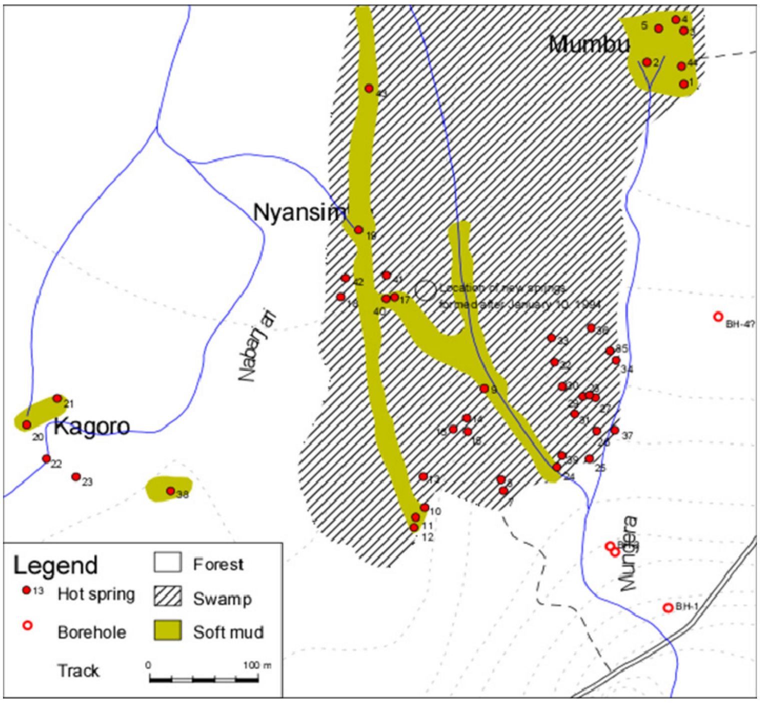

FIGURE 3: Buranga geothermal prospect (Gíslason and Ármannsson, 2008).

Generally, power generation in Uganda is dominated by hydropower, mainly generated by a single source on the river Nile (380 MW). About 17 MW are supplied by a few small hydropower plants. About 1% of the population provides itself with electricity by using generators, car batteries and solar photovoltaic systems. Electricity demand is growing by 10% per annum; the low electrification rates (8%) constrain the economic and social development (Bahati, 2007a). Uganda's potential for geothermal power generation is estimated at about 450 MW (McNitt, 1982 in Bahati, 2007a). The most promising geothermal areas are Katwe, Kibiro and Buranga (Figure 1b).

With a greater global awareness of environmental issues, the efficient use of natural resources is becoming increasingly desirable. One of the ways to achieve this goal is by imposing environmental regulations. In this study, the preliminary Environmental Impact Assessment for the development of Buranga geothermal prospect, in accordance to the National Environment Statute (statute no. 4 of 1995) of Uganda, has been carried out. This paper outlines the expected activities in the development of Buranga geothermal prospect, analyses the current status of the environment in the prospect and discusses the possible environmental impacts and recommended mitigating measures during drilling and operation of the geothermal prospect. The environmental requirements and processes of Uganda, which are the basis of this analysis, are also discussed.

2. GEOTHERMAL EXPLORATION IN BURANGA

2.1 Geology

The Buranga hot springs emerge at the surface through 'Epi-Kaiso' beds and 'Peneplain gravels' (of upper to middle Tertiary age), sediments which consist of boulder beds and unsorted scree overlying sands and clays which have been described as Kaiso-Kigezi beds. South of Sempaya and close to the Buranga hot springs, a fault line (striking between 20 and 45° and dipping 60-65° westwards) is exposed (Johnson and McConnell, 1951). The presence of mylonite along the fault zone suggests movement along a very old fracture zone of compression. Traced further north, this fault system displays both a change of direction and a reduction in magnitude. Step faulting is also present as per topographic features (Harris et al., 1956).

The northern part of the Rwenzori massifs is made up of Precambrain rocks. Johnson and McConnell (1951) described these rocks as consisting of a migmatite series of biotites. Semiliki valley consists of younger rocks of Tertiary to Holocene; Pallister (in Harris et al., 1956) described these rocks as fine-to medium-grained, poorly consolidated sands and clays in parts coated with calcareous material. Exploration for oil around Buranga showed a Tertiary succession of sands, clays and boulder beds with occasional tuffs (PEPD, 1991 -2000). Geophysical surveys confirmed the presence of these rocks down to a depth of 1,524 m. The boreholes showed that the Tertiary succession was terminated in the fault zone by breccia cemented by calc-tuffs followed by mylonite (Harris et al., 1956). The clays are of various colours and the sands are fine-to-medium-grained, varying in colour between white, brown, grey and green. The most common binding material is clay, although this may be patchily replaced by calcium carbonate, giving rise to calcareous sandstones and grits. Pebble beds are of rare occurrence. There are no fossils apart from plant fragments.

2.2 Geophysics

The earliest reported geophysical investigations in Buranga area were gravity measurements performed by Bullard (1936) using swinging pendulums. In 1973, two Schlumberger soundings were made at Buranga (Maasha, 1974). The soundings were located between Bwamba escarpment and Mubunga springs and they showed that the resistivity in the sediments decreases towards the west, from the escarpment to the springs.

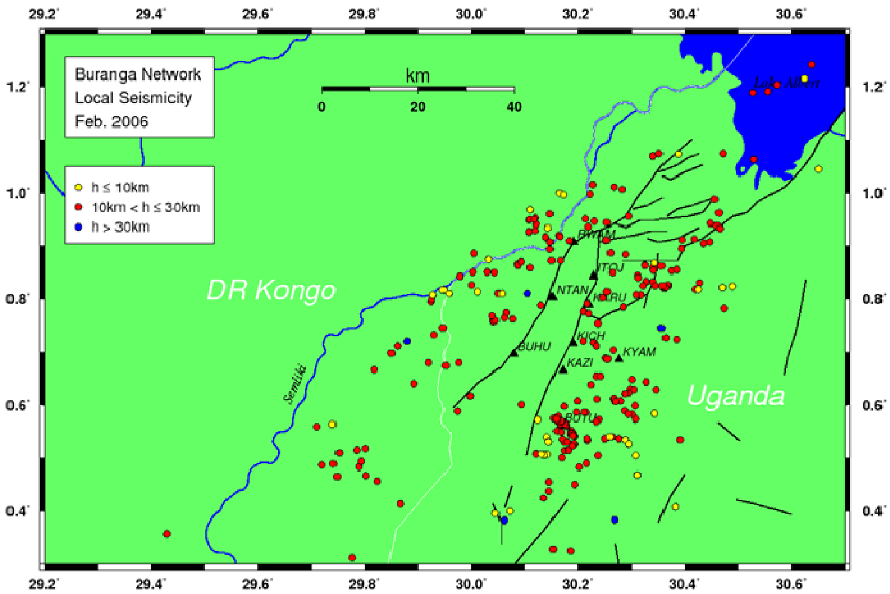

FIGURE 4: The P-wave velocity anomaly in Buranga (Bahati, 2007a)

The known high seismicity (about 500 local earthquakes per month) suggested that Buranga provides excellent requirements for applied seismology. The micro earthquake activity around Rwenzori was studied in order to delineate an assumed magnetic intrusion. A total of 4185 earthquakes were localised in the period January to August 2006. The majority of the localised events exhibit a focal depth between 10 and 30 km; the deepest events occur at a depth of about 55 km. The strongest P-wave velocity anomaly at 10 km depth was located directly south of Buranga hot springs. The centre of the anomaly is situated below the surface trace of the Bwamba fault (Figure 4). If the dip angle of Bwamba fault, at about 60°W, continues also at depth it can be assumed that the centre of the anomaly is situated within the Precambrian basement (BGR-MEMD, 2007).

2.3 Geochemistry and hydrology

The three main springs, Mumbuga, Nyasimbe and Kagoro (Figure 3), are said to have fluid rising through rock sediments and volcanic rocks. The movements take place intermittently and reactively through the fissures to the surface. The thermal waters in Buranga are brackish. Ármannsson (1993 and 1994) reported results of chemical analyses of waters from seven hot springs in Buranga and from 1999 to 2006, IAEA experts and Ugandan professionals sampled several hot springs, cold springs, dug wells, rivers and lakes as well as surface outcroppings, as shown in Figure 5 (Bahati, 2007b).

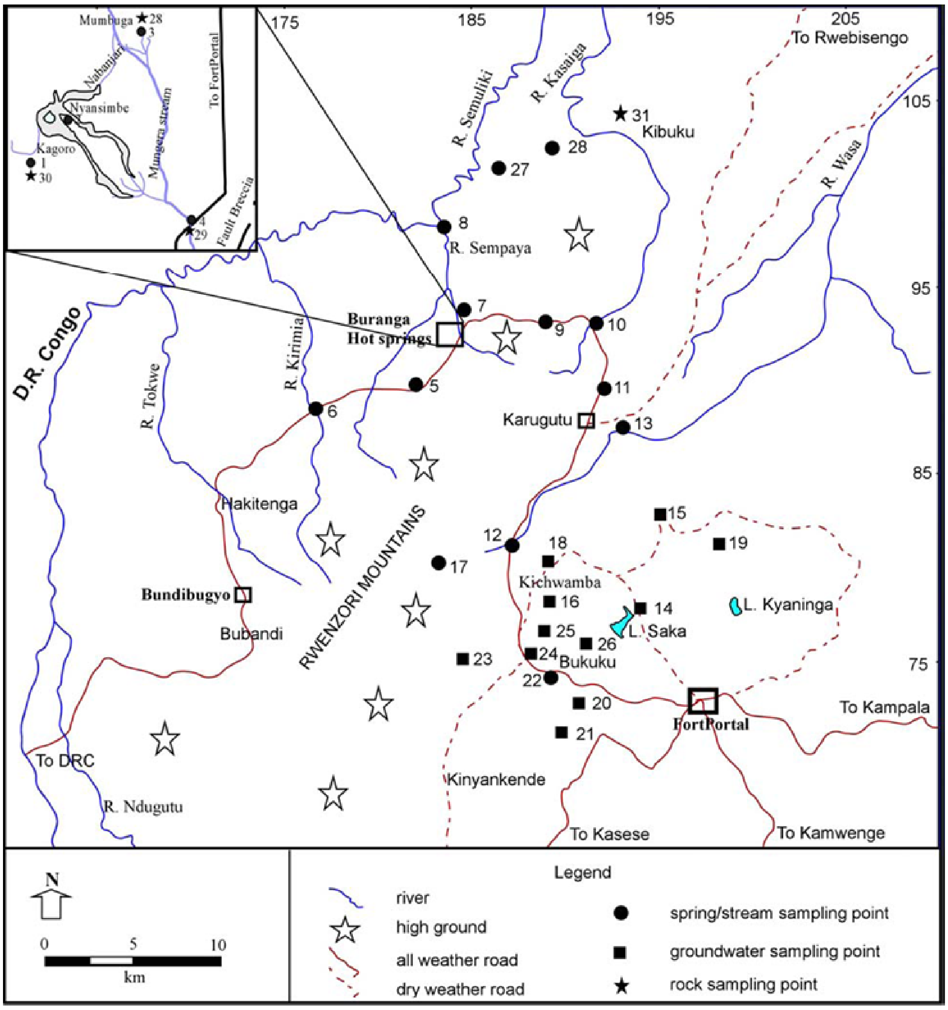

FIGURE 5: Geothermal, surface and ground water and rock sampling points in Buranga (Bahati, 2007b)

The fluids have neutral pH (7-8) and salinity 14,000-15,000 mg/kg TDS. The CO_2 and SiO_2 contents are also fairly constant, about 2600 mg/kg and 65-90 mg/kg, respectively. Carbon isotopic composition of CO_2 ($\delta^{13}C$) indicates a mantle source of gases released at Buranga. This has also been confirmed by helium isotopes, indicating a contribution of >30% mantle helium. A helium isotopic ratio ($^3He/^4He$) in gaseous discharges from hot springs above 30% (R/Ra=2.8) suggests a magmatic source of solutes (BGR-MEMD, 2007). Subsurface temperature is 120-150ºC, from solute geothermometry; isotope geothermometry gives 200ºC. Strontium isotopes indicate that the water interacts with granites/gneisses. There are no signs of oxygen shift from the LMWL for hot spring waters, an indication of reasonable permeability in the area (Figure 6). The groundwater and river

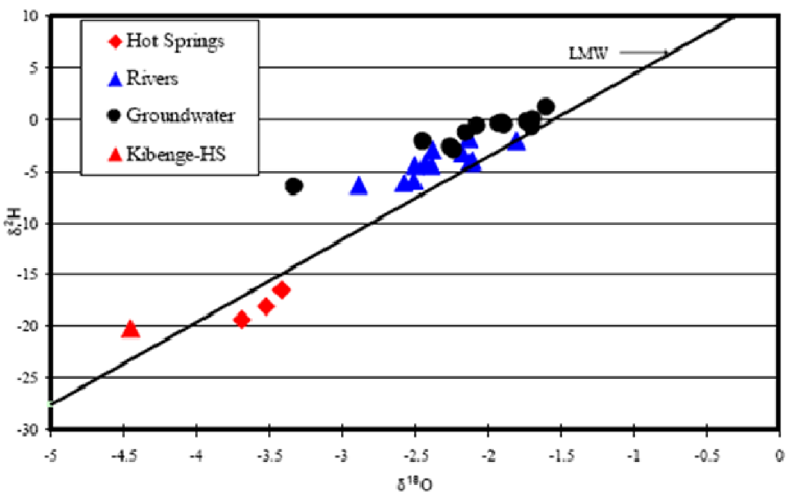

FIGURE 6: Buranga stable isotopic composition of hot and cold water samples

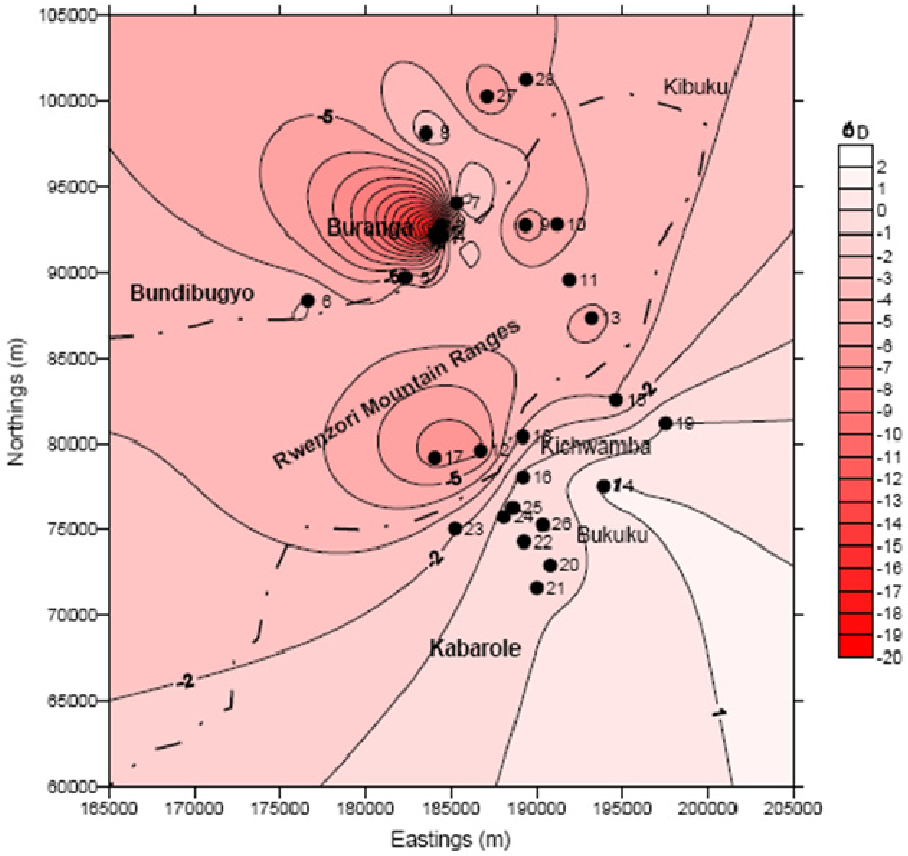

FIGURE 7: Deuterium concentration in Buranga waters (Bahati, 2007a)

waters are more enriched in δD than the hot spring waters by about 5%, an indication that this cold water cannot be a source of recharge for the thermal waters in this area (Bahati, 2007b).

A plot of deuterium in water (Figure 7) shows no relationship between the hot springs at Buranga and potential recharge from the river waters in the neighbourhood and the groundwater across the Rwenzori Mountains ranges in Kabarole district. All cold waters plot in the region of higher deuterium values, compared to the Buranga thermal waters, suggesting that these cold waters cannot be the source of the hot spring waters in this area. The source of heat, therefore, is localized around Buranga thermal area but the source of recharge is from high ground in the Rwenzori Mountains.

Four boreholes drilled in the early fifties (Figure 3) recorded highest temperatures of 58-66°C at depths up to 180-350 m. The fault zone was hit at 172-177 m at 58°C in one of the boreholes (Stadtler. 2007). H_2S was measured in a sample from a spring in the Kagoro spring area and signs of sulphur depositions, believed to be from minerals or rock with possible magmatic contributions, were found at the spring.

3. ENVIRONMENTAL IMPACT ASSESSMENT

The National Environment Statute (1995) defined the environment as a combination of elements whose complex inter-relationships make up the settings, the surroundings and the conditions of life of the individual and of society, as they are or as they are felt. It involves the physical, biological, social, economic, cultural, historical and political factors that surround human beings, including natural and built environments, human health and welfare**.**

The most important aspect of environmental regulations is carrying out an Environmental Assessment (EA), or an Environmental Impact Assessment (EIA) and the requirement for an environmental analysis report called Environmental Impact Statement (EIS) or Environmental Impact Report (EIR), which is applied to any developmental project.

EIA is a systematic examination conducted to determine whether or not a project will have an adverse impact on the environment (The National Environment Statute, 1995). It is a tool for comparing the benefits of development with an unchanged environment, an integral part of the general planning process in developing countries (Morris and Therivels, 1995). The purpose of carrying out an EIA for a project is to promote co-operation of stakeholders and the public, make known to the public any environmental impacts of a project, propose mitigations for reducing impacts, and give the public the opportunity to comment without compromising the project.

In Uganda, the environmental assessment for the proposed project is conducted with stringent adherence to the National Environment Statute, 1995 (Sections 20-24) and by EIA Regulations, 1998 (statutory instrument no. 13 of 1998). The National Environment Statute (statute no. 4 of 1995) identifies those activities that require an EIA due to the potential of detrimental impacts on the environment. Every developer of a project listed under the "Third Schedule of the National Environment Statute" must carry out an EIA. Buranga Geothermal prospect is one such activity.

The National Environment Management Authority (NEMA) is the principal agency for the management of the environment. It coordinates, monitors and supervises all activities concerning the environment. The NEMA acts through lead agencies to implement the National Environment Statute. A lead agency is any ministry, department, parastatal agency, local government system, or officer to whom the Authority delegates its functions under Subsection 2 of Section 7 of the statute.

The basic components of the EIA process consist of three interconnected phases: screening, environmental impact study, and decision making. The basic components of the EIA process, including outputs and inputs, are illustrated in Figure 8. Briefly, the three main phases include:

Phase I: Screening
During initial screening, an evaluation of likely environmental and social impacts of a proposed project is carried out. Screening is a process to determine whether a proposed project has or does not have significant impacts and assists in determining whether a proposed project requires an EIA or not.

Phase II: Environmental impact study
An environmental impact study is divided into two steps namely scoping, and conducting an environmental impact study and preparation of EIS. Scoping is done to determine the key boundaries, issues and impacts (e.g. time scale, geography, budget, project alternatives, affected environment, and significant impacts). It includes the selection of interdisciplinary expertise needed for the EIA and the development of Terms of Reference for the impact assessment. Conducting an environmental impact study involves the undertaking of specialist studies to predict and identify the likely environmental impacts of a proposed project, taking into account inter-related consequences of the project proposal and socio-economic impacts. The study ends with the identification of mitigating measures that include: not proceeding with the project, finding alternative designs or sites to avoid impacts, incorporating safeguards into the design of the project, or providing compensation for adverse impacts.

Phase III: Decision making
Decision making: either on the basis of a finding that a project is exempt, appropriate mitigating measures incorporated for identification of environmental impacts, or the preparation of an EIS, a decision is made to approve or disapprove the environmental aspects of a proposed project. The Authority will issue a *Certificate of Approval* of the EIA. After approval, the lead agency decision makers and licensing authorities will then take appropriate action to approve or disapprove the project based on all its merits and a *Record of Decision* shall be prepared.

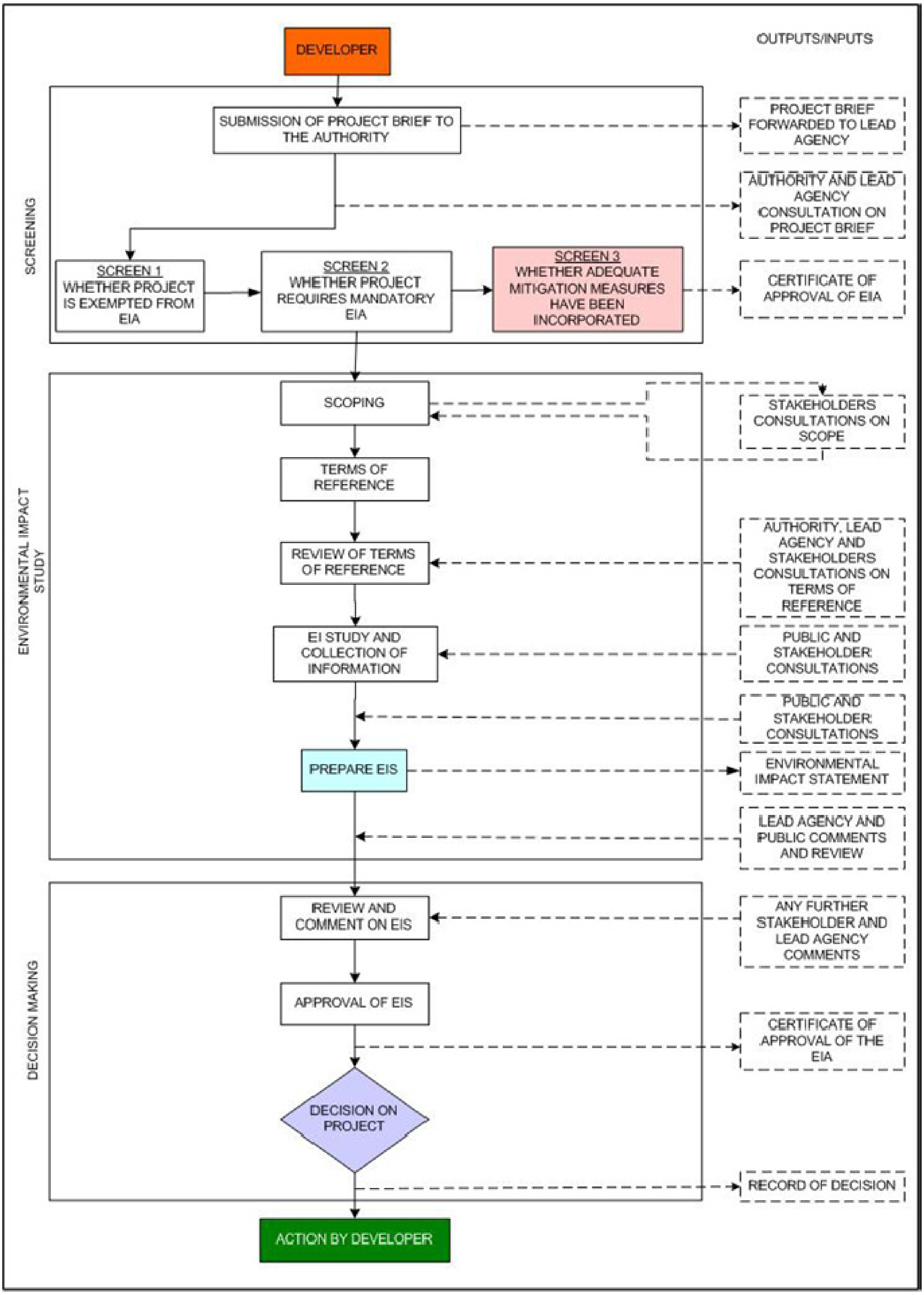

FIGURE 8: Environmental Impact process flow (NEMA, 1997)

4. DESCRIPTION OF THE EXISTING ENVIRONMENT

The information presented in this section provides an overview of the present status of the environment affected by the proposed project. Detailed components of the environment affected should be more closely looked at in the detailed EIA, as recommended at the end of this report. A description of the existing environment includes:

- Conservation status;
- Environmental geology;
- Water and air quality;
- Land use and soil conditions;
- Climate;
- Flora and fauna;
- Socio economic conditions.

4.1 Conservation status

Buranga field falls in the Semiliki National park which is an area of national importance for nature and landscape conservation and natural heritage preservation with ecologically viable units. This park has been under the protection and management of the Uganda Wildlife Authority (UWA) since 1993. The Uganda Wildlife Statute 1996 permits viewing and scientific research as well as harvesting of approved resources in the gazetted area, and prohibits the hunting of wildlife and or the disturbance of vegetation (UWA, 2000).

4.2 Environmental geology

The area of interest is generally located in a terrain that is difficult to access: the eastern part is situated at the steep dipping escarpment of the Ruwenzori massifs (Bwamba fault), the western part of the survey area is covered by dense tropical rain forest with creeks and swamps, and in the northern part, the terrain changes to a plain covered by grass (Figure 3). The area generally occupies a flat with a gently undulating landform ranging from 670-760 m above sea level and going up 200 m towards the Rwenzori Mountains.

Buranga prospect is localized by the major Rift Valley faults. There is no evidence of volcanism in the area but it is highly tectonically active. It has the most impressive surface geothermal manifestations (hot springs) with wide area coverage (120,000 m^2) in the whole of the western branch of the East African Rift System. Hydrothermal activity, both active and extinct, can be observed in Buranga geothermal field. The three main hot spring areas: Mumbuga, Nyansimbe and Kagoro (Figure 3) are located within a distance of 700 m from each other along a strike N30°E, approximately parallel to the Bwamba fault scarp about 0.5 km to the east (Pallister, 1952).

FIGURE 9: Buranga prospect: the swampy area

Nyansimbe spring is located in a swampy area (Figure 9) and can be accessed mainly during the dry season. It has built a carbonate cone 1 m above the swamp level and can be described as a pool with a diameter of 30 m and more than 5 m deep (Figure 10b). A temperature of 86°C was measured in the pool, flowing at 15 l/s (Gíslason et al., 1994). In the swamp east of Nyansimbe, a number of warm and hot springs exists.

Farthest to the north is Mumbuga, which has a great number of hot springs in an area 60 m × 40 m. The largest spring has built a cone with terraces of travertine, 1.5 m above the surroundings. Water rises under pressure from a pool at the centre of the mud up to 50 cm above the pool surface in a vigorous flow (Figure 10a). All the main springs have deposited carbonates and there is vigorous release of gases accompanying the water discharge. Water temperature is close to boiling. The water drains off the Mumbuga area in many small streams which join up in the Buranga River. The total flow of the main streams can be estimated to be 6.5 l/s (Gíslason et al., 1994).

The Kagoro springs are farthest to the south and are located in a small clearing of a rain forest that stretches from north to south for 50 m, about 15 m wide. The area is characterised by travertine cones with the largest about 1.5 m above the ground. Water flows from its top and at its base is the only sign of sulphur deposits in Buranga geothermal field. Temperatures range from 60 to 91°C.

Generally, Buranga's 37 hot springs have an overall flow rate of 30 l/s and temperatures up to 98.4°C (Ochmann et al., 2007).

FIGURE 10: a) Mubunga hot spring; b) Nyansimbe pool close to boiling

4.3 Water and air quality

Open waters, swamps and rivers cover 570 km^2 of the total area of the district. The survey area is stretched along the meandering River Semiliki, and streams Mungera and Nabanjari descend from the Rwenzori mountains and flow into Semiliki Valley swamp, forming Buranga River which is a tributary of River Semiliki (Figure 3). The state of the atmosphere within Bundibogyo district is good and very fresh, being located in the countryside with no industrial development and very low traffic movement. The district has virtually no air polluting industries to speak of.

4.4 Soil condition and land use

The district covers an area of 2,338 km^2 of the total area of Uganda (241,000 km^2). Of this area, open water, swamps and rivers cover 570 km^2, while 1,243 km^2 are covered by mountains, forests, national parks (Semiliki and Mt. Rwenzori) and forest reserves. A total of 145 km^2 is covered by game reserves and 380 km^2 are used for agriculture. The soils found in the district are: organic, ferrosal, podsols/eutrophic, and hydromorphic (Chenery, 1960). Crops cultivated are mainly cassava, maize and cocoa. Fishing along the Semiliki River and from Lake Albert is a common practice. Livestock and crop farming is still under traditional practice in the district and marketing is still substandard due to a number of factors including poor roads, which hinder mobility. Cattle, goats, sheep and chickens are the major animals kept.

4.5 Climate

Climate in Bundibugyo District is influenced by the Rwenzori Mountains. It is generally humid and characterized by excess moisture (more precipitation than evaporation). The area experiences a bi-modal rainfall pattern. The first rains occur during March-May and the second from August-December. Annual rainfall ranges from less than 800-1600 mm and is greatly influenced by altitude. Rainfall distributions in the district enable agriculture (crop growing) to take place throughout the year. There is a wide temperature variation influenced by altitude, temperature that fluctuates from very high at the plains to below zero degrees high in the mountains.

4.6 Flora and fauna

Buranga prospect is part of a wildlife reserve (Semiliki National Park) which also protects an eastern extension of the vast Ituri forest and forms part of a forest continuum that stretches across the Democratic Republic of Congo to the Zaire River. The western part of the field is mostly inhabited by moist semi-deciduous rain forest, mostly ironwood- dominant (Cyanometra alexandri) with patches of swamp forest, and the aquatic habitat is represented by forest streams and oxbow lakes with adjacent swamps (Figure 3). A total of 305 species of trees have been recorded, of which 125 species are restricted to this park alone. Being a relatively stable forest "refugium" during the climatic upheavals of the Pleistocene, this is one of the richest areas for forest birds and mammals in Africa, as indicated in Table 1. A large number of predominantly Central African species reaches the eastern limit of their distribution here and cannot be found anywhere else in East Africa (*www.safari-Uganda.com).*

TABLE 1: Examples of Fauna species found in Semiliki National park
(Great Lakes Safaris, Ltd., 2008)

Fauna type	Species examples	Total number of species
Birds	Congo serpent eagle, Long-tailed hawk, Nkulengu rail, Black-wattled hornbill, Lyre-tailed honeyguide, Spot-breasted ibis, Hartlaubs's duck, Chestnut-flanked gooshawk, Red-thighed sparrowhawk, Long-tailed hawk, Forest francolin, Nkulengu rail, Western bronze-napped pigeon, Black-collared lovebird, Yellow-throated cuckoo, Red-chested owlet, Bates' nightjar, Chocolate-backed, White-bellied and African dwarf kingfishers, White-crested, black Dwarf, Red-billed dwarf, Piping hornbill, Red-rumped tinkerbird, Spotted and Zenker's Honeyguides, African piculet, GabonwWoodpecker, Red-sided broadbill, White-throated blue swallow, Green-tailed bristlebill, Sassi's olive, Xavier's, Swamp, Simple and Eastern bearded greenbuls, Yellow-throated nicator, Capuchin babbler, Northern bearded scrub robin, Forest and Grey ground thrushes, Lemon-bellied crombec, Brown-crowned eremomela, Blue-headed crested flycatcher, Ituri batis, Red-billed helmet-shrike, Red-eyed puff-back, Black-winged starling, Maxwell's black weaver, Blue-billed, Crested and Red-bellied malimbes, Pale-fronted and Chestnut-breasted negro finches, Grant's bluebill.	400
Mammals	Grey-cheeked mangabey, Vervet, Red-tailed and Mona, gentle (blue) monkeys, Olive baboon, Guereza colobus, De Brazza's monkeys (rare), Chimpanzees, Pottos, Galagos, Elephant, Bush pig, Water chevrotain, Buffalo, Sitatunga, White-bellied duiker or Dwarf antelope, Beecroft’s anomalure or Zenker's flying mouse, Squirrels such as Fire-footed rope or Red-legged sun squirrel, Little collard fruit bat and Target rat.	53
Butterflies		30
Forest Swallowtails		46

4.7 Socio-economic conditions

The district has a population of 174,800 people of which 87,700 are males and 87,100 are females. Of the total population, 32,831 are under five years of age. Uganda has a population of 25 million people. The district population density is 58 persons per km^2 (Population census, 2002). The local population includes four ethnic groups: the Pari Bamba and Bakonjo found in the valley and mountain slopes, respectively, who are agriculturalists that grow cash crops such as coffee and cocoa and subsistence food crops that include bananas, rice and potatoes. North of the park, the rift valley plains are occupied by Butuku pastoralists. The smallest group in Semiliki valley is a community of Batwa (Pygmies); traditionally, these were forest dwelling hunter gatherers originating from the Ituri. Their life is now changing due to interaction with other local communities and the impact of tourism, and the Batwa have migrated to the forest edge at Ntandi. They now support themselves by small scale cultivation and contributions from tourists.

5. CHARACTERISTICS OF THE PROPOSED PROJECT

Buranga geothermal prospect has been considered a high-temperature field by the pre-feasibility phase. The source of heat could be magmatic and magmatic intrusions have been mapped in the vicinity of the geothermal prospect. The area is tectonic and subsurface temperatures of 200°C have been given by isotopic geothermometry (Stadtler, 2007). This temperature is suitable for conventional power generation. The main activities expected to be involved during the development of Buranga geothermal prospect are described below in two phases, the drilling phase and the operational phase.

5.1 Drilling

The proposed geothermal development involves the drilling of 3-5 geothermal exploration wells in the Buranga geothermal prospects and, if results are positive, more production wells will be drilled. This will be followed by delineation and characterisation of the full extent of the reservoir in the early stages and installation and operation of a power plant in the later stages.

5.1.1 Road construction

Accessibility to Buranga prospect is rather difficult because the survey area is located in rain forest and swamps under the steep hills of Rwenzori Mountains (Figure 3). Access roads to the drill sites will be constructed for movement of survey equipment and accessories. The amount of land that is disturbed by road construction during geothermal development can be quite large, estimated at about 12 hectares for road construction alone when drilling 15 wells, depending on the topography (Brown, 1995).

5.1.2 Transportation

Drilling will involve transportation of the rig and all its accessories to the drill site. The rotary drill rig is transported on set trailers pulled by a truck. About 130 tons of casings, 140 tons of cement with an additional 25 tons of drilling mud and 30 tons of diesel oil and some lubrication oil will also be transported to the drill site. Transportation takes two to four days depending on the number of trucks and the distance to each drill site. Two to three days are also needed to remove the rig after drilling is completed (Bahati, 2005).

5.1.3 Drilling activity

Initially 4-5 deep wells will be drilled and additional evaluation and developmental drilling will be conducted to support a 30 MWe power plant in the prospect. The wells will be drilled to a depth of approximately 1500-2000 m. Drilling will take place on a rectangular flat area, the drill pad, on the ground. This area is required to accommodate the drill rig and its accessories including drill pipes. One drill pad generally occupies about 0.4 ha. and this area is cleared of vegetation and compacted to form a flat, hard surface. During drilling, the cuttings from the drill head are flushed out with water when water is used as a drilling fluid. Drilling with other fluids like drilling mud will need detergents to assist in the collection of cuttings. The detergent used must be capable of withstanding high temperature and, in cases of eruptions, heavy substances like barium sulphate are usually added. The returning water or fluid is channelled to sumps where it cools before being recycled or disposed of. Accidental discharge of geothermal fluids to surface drainage could occur due to blowouts during drilling, leaking pipes or wellheads, and overflow from well sumps. Petroleum products from lubricants and fuels plus cement spills may be produced. Air pollution may stem from non-condensable gas emissions and exhaust smoke from generators and compressors. In vapour-dominated reservoirs where air-only drilling is used, large compressors are required, thus generating noise.

5.1.4 Drilling fluids

Water will be required for drilling. A typical shallow well requires 1000 m^3/day, some or all of which may be lost to the formation. A deeper well may require up to 3500 m^3 for 24 hours of drilling. Completion testing and injection testing can use up to 10,000 m^3/day of water (Brown, 1995). If this water is discharged, care must be taken to have it disposed of in a well designed for this purpose, as the quality of the water can be affected by suspended solids and chemical content changes.

Drilling mud will be used for smooth drilling of the first few hundred metres that are used for the installation of the surface casing; it also prevents loss of circulation to the groundwater aquifers within the groundwater table. A drilling mud like bentonite is mostly used when well clearing is inadequate or when well stability is a problem. After use, the drilling mud becomes a solid alkaline waste that contains many other chemicals, shown in Table 2 (Ármannsson, 1997). Drilling mud is lost to the circulation in the well or ends up in the drilling sumps as solid disposable waste.

TABLE 2: Chemical composition of bentonite and perlite (% mass)

Material	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	Loss on ignition	Water solubility	Acid solubility
Bentonite	64.1	20.0	3.66	0.16	1.52	2.38	2.18	0.49	6.26	-	-
Perlite	73.0	12.5	0.7	0.1	1.0	0.5	4.5	4.8	1.3	0.1	0.5

5.1.5 Casing and cementing

During drilling the use of casings and slotted liners, which are fixed in the well bore at different depths as required, will be needed. There are three main types of casings, namely: the conductor casing, the surface casing and the slotted liner. The conductor casing is the largest diameter casing and is required only where the surface soils are so loose that the washing and eroding action of the drilling mud would create a large cavity at the surface. The surface casing is of a smaller diameter and serves as an anchor for well control equipment, e.g. the blow-out preventers, which protects fresh water zones and isolates lost circulation intervals. The amount of surface casing required, therefore, depends on the depth of the fresh water table with a minimum of 60 m and a maximum of 400 m and is cemented all the way to the surface. If the fresh water table is below the surface casing, then control authority requires that the fresh water be protected by setting either intermediate or production casing and cementing with enough cement to completely fill the casing well bore annulus from the shoe to the surface (Corsi, 1995). The intermediate or anchor casing prevents the breakthrough of steam up through the surface during drilling, protecting the rig and crew. The production casing closes off cold aquifers and provides a conduit for the fluid up the well. The slotted liner is not cemented and prevents the well wall from collapsing into the well during operation and is also a conduit for the inflow of geothermal water into the well. The cementing of a casing in a well is carried out for a number of reasons. Where a conductor casing is required, it must be cemented in order to prevent the drilling fluid from circulating outside the casing which may lead to surface erosion. The surface casing must be cemented in order to seal off and protect freshwater formations. Cement also effectively protects the casing from corrosive environments, notably corrosive fluids that may be present in the surface formations.

5.1.6 Demobilisation

After drilling is completed, the rig is removed and drill pads are restored to their original status, as much as possible. During demobilisation, a slotted liner is put in the well, the rig is transported away and flow equipment is erected, i.e. pipes, additional vents, and atmospheric separators (silencers). An aerated shelter is usually fixed to protect the wellhead. Once the structures are removed, the sites can be rehabilitated to achieve comparable status with the neighbouring area.

5.1.7 Warm up, flow initiation and flow

After demobilisation, the wells will be tested and closed in order to warm up and build up pressure.
This is common with wells that can self-discharge. Drilling soap is normally added for compression while some wells have to be airlifted to initiate flow. Testing of wells has often had a deleterious effect on local vegetation with trees and other plants being scalded by escaping steam and spray. This effect is more severe during the vertical discharge of wells, which is carried out in order to clean them.

5.2 Operation

Based on past recommendations, the plant to be installed at this stage is considered to be about 30 MWe (medium-scale plant). However, it should be remembered that final decisions on the future plant will be made after the characterisation of the full extent of the reservoir. The future utilisation of Buranga geothermal prospect will depend on the nature of the geothermal resource to be discovered. The type of power plant to be operated will be selected, based on the economic viability of the resource. A conventional condenser-type power production process for a 30 MWe power plant (Figure 11) was considered in this report to assist in identifying potential environmental impacts of developing the prospect. Also, by building up the steam supply system and the power plant in relatively small phases, it is possible to start power production early and then build further phases with added confidence as knowledge and experience of the geothermal system increase.

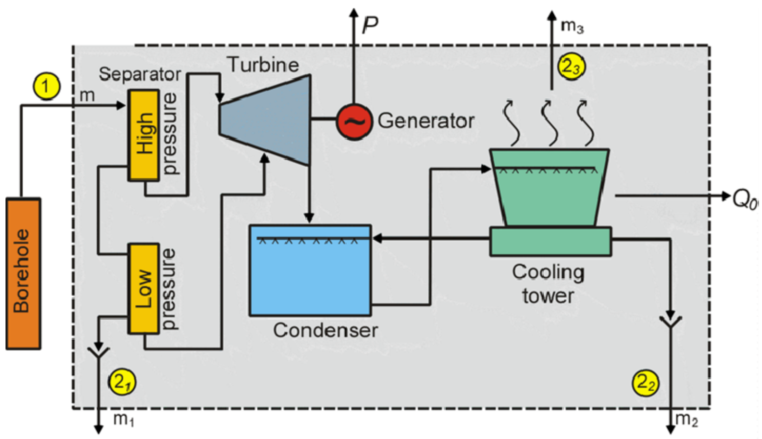

FIGURE 11: Wet steam double-flash system (Karlsson, 1982)

5.2.1 Main elements of a proposed power plant

I. Simplified process diagram for the power plant
The proposed power generation facility will consist of all on-site equipment and systems required to safely and reliably generate up to 30 MWe. The equipment installed will include a number of wells, separators, a turbine and auxiliary systems, cooling tower, electrical equipment and structures for the protection of equipment and operation. The condenser-type generation process is most commonly applied to geothermal power projects, extracting energy from high-temperature reservoirs with fluids in excess of 200ºC.

II. Wells
Wells are drilled through the geothermal reservoir and produce geothermal fluids at the surface. In wells that are generally 1500-2000 m deep, the top 800-1000 m are cased and cemented but the production zone is completed with a slotted liner to permit flow. The wells will either be drilled vertically or directionally. Directional wells increase the chances of intersecting highly productive fractures; fewer well pads are needed for directional drilling which is an environmental and economical advantage. Surface structures associated with the wells include the drill site template, wellhead equipment, wellhead shed and blow-out silencers.

III. Steam supply system
The steam supply system gathers the two-phase geothermal fluid and transports it in insulated pipes to the separation station where the steam phase is separated from the brine phase. In some cases, the brine phase is re-flashed at a lower pressure where secondary steam is separated from the remaining brine. The steam (both high-pressure and low-pressure) is carried to the power house to drive the turbine, but the brine phase is directed to the disposal system.

IV. Disposal system
A disposal system is used to dispose of both the brine from the separation station and the condensed water from the cooling towers. There are many methods for fluid disposal, namely: surface disposal to waterways or fissures and fractures; reinjection into the reservoir and shallow injection into delineated disposal zones (300-500 m deep).

V. Turbine and auxiliary systems
The generating system comprises a turbine, generator, intake valves, condenser, cooling system, and operating instruments. The effluent steam from the turbine is condensed in a condenser located downstream to the turbine. Normally, the cooling medium is condensed water that has been cooled in cooling towers but, in special cases e.g. Nesjavellir power plant, Iceland, groundwater is used instead of a cooling tower (Arnórsson, 2004). Among other auxiliary systems is the gas removal system (ejectors or pumps) that removes non-condensable gases from the condenser.

VI. Electrical equipment
The electrical equipment includes control and protection systems, a power transformer and both high and low voltage systems.

VII. Structures
The operating area for a power plant depends on its type and size but generally the land uptake for a geothermal power plant is approximately 20,000 m^2 (Brown, 1995). The key elements of geothermal power plants are the power house, cooling tower, the disposal system and the switch yard. Other structures like separators, wellheads and pipelines may be located outside the operating area. Normally the powerhouses are steel buildings, whereas service compartments are concrete structures.

5.2.2 Electricity generation process

The power harnessing cycle can be divided into two stages: (1) the collection and processing of steam from boreholes; and (2) the production of electricity (Figure 11). Steam mixed with water will be conveyed from boreholes through collection pipes to the separation station where the water is separated from the steam. The separation station is proposed to have two levels, high pressure and low pressure, in order to maximize the amount of steam collected. From the separation station, steam will be conveyed to the turbine where steam energy is converted to mechanical energy; the turbine then drives the generator that converts mechanical energy to electrical energy. The separated fluid will be sent to the disposal system and the cooled steam from the turbine will join the cooling system composed of the condenser and the cooling tower with the excess sent to the disposal system.

6. ENVIRONMENTAL IMPACTS AND POSSIBLE MITIGATING MEASURES DURING DEVELOPMENT

The environmental aspects of geothermal development are receiving increasing attention with the shift in attitude towards the world's natural resources. Not only is there greater awareness of the effects of geothermal development on the surrounding ecosystem and landscape, but there is also a growing appreciation of the need to efficiently and wisely use all the natural resources sustainably. An overview of the environment affected by the proposed project is given below. It is worth noting that understanding the nature of the geothermal resource to be developed is needed in order to predict and evaluate the environmental impacts of its development. Bundibugyo district is considered to be the environment primarily affected in the development of Buranga geothermal field.

Geothermal energy is a clean and sustainable energy source, but its development still has some impacts on the environment. The positive and negative aspects on the environment have to be considered prior to any decision about developing a geothermal field, as well as possible mitigating measures. In identifying potentially significant environmental impacts of the drilling and operating phases of the development of Buranga geothermal prospect, local knowledge, experience and expert knowledge of the project area were used. The main environmental issues are outlined in Table 3 below.

TABLE 3: Environmental issues related to the development of the Buranga prospect

Phase	Environmental issues
Drilling	Effects of surface disturbance for well pads and roads; Discharge of drilling mud, cuttings, and geothermal fluids; Noise; Emissions to the air from steam and gasses; Loss of habitat and potential disturbance of vegetation and wildlife; Potential health effects for project workers from exposure to geothermal fluids and possible hydrogen sulphide emission; Potential effects on nearby residences, recreation, or indigenous people; Water use.
Operation (production and utilization)	Surface disturbance for production and reinjection wells, pipelines, access roads, power plant facilities, transmission lines etc.; Air emission of concern is hydrogen sulphide (worker safety, public nuisance odour); Potential effects on nearby residences, recreation, or indigenous people; Physical effects of fluid withdrawal; Heat effects and discharge of chemicals; Water quality; Subsidence and induced seismicity.

The potential environmental impacts identified above are discussed below in different sections and their possible mitigating measures are also given. The environment affected may include the following:

- Geology and landscape;
- Land use;
- Fauna and flora;
- Visual and aesthetic qualities;
- Water quality and hydrology;
- Population, housing and employment;
- Transportation and traffic;
- Air quality;
- Public services and utilities;
- Energy;
- Public health and occupational safety;
- Cultural situation.

6.1 Drilling

6.1.1 Geology and landscape

Construction of access roads to the drill site for moving equipment and accessories will involve the clearing of vegetation and land for drill pads and sumps to contain drilling and produce fluids. This may cause extensive intrusion on the geology and topography of the area which is forested and along steep hills and may lead to slumping or landslides with consequent loss of vegetation cover. This may greatly accelerate soil erosion of cut slopes and fill slopes with further slumping and an increase in suspended sediments in the surrounding watershed if the soil is not well compacted.

The area has an average rainfall of approximately 800-1600 mm/year with a very brief dry season. These conditions are not favourable for road construction throughout the year. Therefore, road construction and other earthworks should only be undertaken during the dry seasons to avoid serious topographical and geological problems like landslides and soil erosion. Re-vegetation with grass and trees on the cut slopes, fill slopes and well pads should be considered to contain any possible erosion. Drill pads in steep areas can be reduced by drilling a number of deviated wells from a single drilling pad. In this way, a large volume of the reservoir can be tapped at depth, while requiring only small areas which can be situated on stable land at the surface.

Drilling is expected to have minor impacts on geology and landscape if mitigating measures are considered. It is, however, difficult to predict the effect on surface geothermal features.

6.1.2 Land use

The construction of roads and drill pads may conflict with the adopted environmental plans of the area and the goals of the communities through which the roads will pass. It may possibly convert prime agricultural land to non-agricultural use, or impair its agricultural productivity. The land use may also conflict with the local government's general plans. The road construction may take up land from private farmland and therefore there will be a need to compensate the owners.

Land uptake by drilling can be minimised by directional drilling as explained above. It also minimises the transport of drilling and construction materials and makes it possible to gather the fluids from many wells into a single pipe before it is transported to the separation plant. The local population should be contacted at a local level in order to investigate the ownership of land and gain legal consent to use it.

6.1.3 Fauna and flora

Buranga field is a wildlife reserve (Semiliki National Park) with a wide diversity of fauna and flora. Drilling will increase the rate of use of natural resources, like water, and will involve clearing of vegetation for roads and wells. It will decrease the habitat for wildlife and may interfere with the movements of some species. This may lead to changes in the diversity of species, or the number of any species of plants (including trees, shrubs, grass and aquatic plants) or land animals, birds, reptiles, fish and insects. Clearing of bushes may lead to the introduction of new plant species in the area through succession and become a barrier to normal replenishment of existing vegetation.

The bare ground around the drill pads and along the roads can be restored after drilling and well testing through succession and re-vegetation.

Drilling may affect the fauna population in the park but possibly not in a significant manner, being a temporary project. Of greater significance is the effect of clearing the drill site where natural vegetation will be completely removed. However, this can be minimised if the site cleared for well drilling is kept to a minimum as far as is practicable. Perennial plant species which are indigenous to the area should be introduced immediately. The cleared grounds for roads will remain a permanent issue and this may affect birds and insects that nest in the vegetation.

6.1.4 Visual and aesthetic qualities

Drilling may interfere with the local goals or guidelines related to visual quality and hence create visual pollution. Visual obstruction is caused by the rig's high mast, which rises several tens of metres above the surrounding environment, and its accessories. It may change the visual quality of the area and result in an obstruction of scenic views open to the public or destroy the visual quality of the area leading to a substantial, demonstrable negative aesthetic effect. Visual quality may be diminished by a loss of naturalness and the imposition of man-made structures like drill sites, drill rig, and accessories which create artificial landscape elements in the project area.

The scenery needs attention, since it is located in the National Park and serves as a recreational area. The obstruction will be temporary during drilling since it takes a short time and the natural beauty will be restored when the activity is completed and the rig is demobilised. However, the roads and the drill pads will take some time to restore.

6.1.5 Water quality and hydrology

A considerable amount of water is required for drilling, completion testing and reinjection well testing, as indicated in Section 5.1.4. These activities are a source of wastewater, which is likely to affect the quality of surface and ground waters. The wastewater from drilling can create serious gulling if discharged directly to the surface, e.g. into valleys. It can change the amount of surface water in the area and result in alteration of surface water quality including temperature, dissolved solids and turbidity. The wastewater may be contaminated with drilling fluids, which may substantially change the chemistry of the surface and ground waters. This may result in degraded water quality and contamination of the public water supply. Release of the wastewater into cooling ponds and waterways may result in groundwater contamination and cause erosion and the deposition of silica.

The source of water for drilling is expected to be the rivers and streams around the prospect. A considerable amount of water is used as drilling fluid and although most of it is lost to the formation, the return fluid will be discharged into well designed sumps and re-circulated to keep the water level in the sumps as low as possible.

The impact that this activity will have on the watershed will vary greatly depending on the well's location and depth. Due care must be taken to ensure that flooding and breaches are allowed for when designing sumps. Local meteoric aquifers need to be protected by casing out these intervals during drilling; and regular monitoring of both chemical and physical properties of these ground water aquifers will normally be a requirement.

6.1.6 Population, housing and employment

The drilling programme will create numerous temporary jobs for various activities on site and this may induce population growth and thus affect the average age of the population, since the workers will probably not be accompanied by their families. This increase in local population, due to migrant workers, may cause a strain on the available resources and may result in conflicts.

The increase in population during the drilling phase can be temporary and once the drilling operation is over, the population may return to its original state. Drilling will not affect the housing facilities in the area since the workers will be camping on site with all resources and facilities provided.

6.1.7 Transportation and traffic

Traffic will increase in the area mainly during the transportation of the rig and its accessories to the drill site. There is generally little traffic in Bundibugyo district and according to local observations, only about five cars can be seen in a day. The increased traffic may lead to an increase in dust, noise and vehicular emissions. This will have an impact on special interest groups like children, the elderly who may not have seen such heavy vehicles before, and sensitive locations, like schools and places of worship though not near the road, may be abandoned.

Heavy traffic is expected during mobilisation and demobilisation, up to 4-7 days in total when drilling a single well. During drilling, traffic is limited to service trucks that are not expected to cause significant dust and noise in the surroundings. Increased traffic activity is temporary and normality is restored after the drilling is completed.

6.1.8 Air quality

The impacts arising during drilling can affect the ambient air quality through the release of fugitive dust from heavy vehicles and site clearing. During well testing, steam and spray may have an adverse effect on vegetation with trees and grass being scalded. There may be objectionable H_2S odours. Drilling being a temporary activity, no significant long-term air quality impacts are expected. H_2S and possibly mercury in the atmospheric air may need to be monitored.

Drilling is believed to have little impact on air quality except for minor emissions of exhaust fumes from diesel engines and the generation of dust from vehicles travelling on unsealed roads. The impacts are unlikely to ever reach significant levels. Inexpensive H_2S and CO_2 sensors can also be installed.

6.1.9 Public services and utilities

The increased traffic during the drilling phase will inconvenience the residents by taking up parking space in Bundibugyo town, affecting the local parking space which is already very small, meant for no more than 10 cars. This is likely to increase the risk of theft (very common in Uganda in unprotected parking areas), and the outbreak of fires as a result of congestion and uncontrolled fuel spillages. Drilling will also create all kinds of waste including waste fluid containing chemicals like barium sulphate, mud and detergents. Other types of drilling fluids like aerated water or mud and foam sometimes used for pressure balancing can have impacts on the environment, e.g. foam can affect vegetation around the site and cause eye irritation when it covers a large area. Before being recycled or disposed of, the effluent fluid is channelled to sumps to cool. The activity will produce solid waste in excess of available landfill capacity and can cause a significant increase in the consumption of potable water, thus breaching the local standards relating to solid waste control.

Additional law enforcement and fire protection staff, and equipment to maintain acceptable service ratios will be required to check on possible thefts and fire outbreaks. Proper disposal systems need to be constructed for channelling the effluent fluid prior to recycling or disposal. This would require the construction of a septic tank, effluent retention sumps, communication systems, water supply and drainage, and a landfill for solid waste disposal.

Drilling is expected to be of less impact on public services and utilities if designated additional parkland in Bundibugyo town is provided for local parking and if the disposal of wastes is planned for and handled by concerned authorities.

6.1.10 Energy

Drilling will require a considerable amount of energy resources for powering the heavy combustion equipment and lighting. It can, therefore, significantly affect energy resources at local and regional levels. The activity will cause an increase in the use of fossil fuels by encouraging activities which result in the use of substantial amounts of fuel, water and energy. It may also affect the demand upon existing sources of energy, or require the development of new energy sources which may conflict with the existing energy standards. This problem could be solved by setting up a fuel supply station within the prospect to avoid conflict with the existing energy standards at local and regional levels.

6.1.11 Public health and occupational safety

During drilling, accidental release of hazardous substances like oil, chemicals in the drilling fluids to the water cycle and toxic gas emissions can pose public health and safety problems. The drilling process can create potential health hazards or involve the use, production, or disposal of materials which pose a hazard to people or animal or plant populations in the area. Drilling will generate noise that will affect the surroundings since the area is remote and the natural noise level is low. The residents will probably regard any additional noise as an intrusion into their otherwise quiet environment. About 110 decibels of noise is generated in vapour-dominated reservoirs where air-only drilling is used and requires large compressors (Brown, 1995). The powerful lighting needed to illuminate the work space at night could disturb the local residents and animals. The main sources of erosion during the drilling phase are the accidental leakage of fluids from sumps and the surface discharge of wastewater from a well during testing. The activity may expose people or property to water related hazards such as flooding and hot waste water.

Care must be taken to reduce the accidental release of hazardous substances and where they do occur, measures should be taken to clean up the environment. The effects of using powerful lamps to light the drilling site at night could be reduced by temporary screens and the careful placement of lamps. The noise generated by drilling operations can be quite high, i.e. ranging from 45 to 120 decibels, depending on the specific activity. Using cylindrical type silencers, the noise can be brought down to about 85 decibels during air drilling and well discharge (Brown, 1995). However, even with good designs for noise reduction, workers will be recommended to use ear protectors. The noise associated with the use of heavy machinery can be reduced by using suitable mufflers on the exhausts of the earth moving equipment.

The drilling activity is not expected to create a risk of TAC concentrations exceeding the air pollution control threshold. Lighting is temporary and will be removed after the rig is removed from the site. There is always a risk of blowouts when an unexpected permeable high-pressure zone is encountered, therefore blow out preventers should be used. Also, places expected to be harmful to public and fauna intrusion can be fenced off.

6.1.12 Cultural situation

The activity is likely to affect the social life in the area as a result of an influx of people from different areas and cultures. This may give rise to social problems such as lack of housing, an increased spread of diseases, increased pressure on social services and increased cultural misunderstandings.

The geothermal prospect is also located in a tourist destination.

Project development is usually accompanied by all sorts of social misunderstandings because of an influx of people from different cultures to a new area. It is, thus, vital to avoid conflicts with the local communities, and to involve all the stakeholders in the project activities from beginning to end. To avoid social problems like lack of housing, the spread of diseases and competition for social services, the drilling programme usually sets up a temporary arrangement with a minimum infrastructure in the vicinity of the drilling site. Such an infrastructure is always demobilised at the end of the drilling programme and the site is restored to its original status.

6.2 Operation

This phase is considered to have the greatest impact on the environment. By this phase of development, exploration has defined the type of geothermal resource and the developer has decided whether the resource is economically viable, and which type of power plant is warranted by the resource. Construction and operation of the power plant, steam gathering and injection pipelines, construction of electric transmission lines, additional production and injection wells are considered to be the activities in this phase and their impacts and mitigating measures are discussed below. A 30 MW wet steam double-flash power plant, as discussed in Section 5 above, is considered and all the environmental impacts and mitigating measures given are based on that.

6.2.1 Geology and landscape

The construction of the power plant will affect the topography and geology of the area as part of the land will be levelled off on the construction site. Geothermal production and injection operations have at times resulted in low-magnitude events known as micro earthquakes, which are likely to weaken the ground and give way to landslides during heavy rains in the area. Massive withdrawal of fluids from the reservoir may lead to subsidence (downward sinking of land) mainly due to geothermal reservoir pressure decline.

Since geothermal energy must be utilised relatively close to the resource in order to minimise heat losses, disruption to the landscape is concentrated in one area and, thus, the area affected should be kept as small as possible. The average geothermal power plant occupies only 400 m^2 to produce a gigawatt hour of electricity over 30 years (Flavin and Jenssen in Brown, 1995). Revegetation, or some other type of slope stabilisation, and appropriate drainage are priorities. Landslide hazards can be properly managed through detailed hazard mapping, groundwater assessment, and deformation monitoring, among other management techniques. Care must be taken to ensure that power plant sites are not in the path of landslides, and many power plants are sited on ridges. The spent fluid will be re-injected into the reservoir and will not form mineral deposits on the surface that may obstruct or change the course of surface water flow.

Natural surface features such as hot springs, mud pools, fumaroles and steaming grounds associated with this geothermal system may be affected. These visible signs of geothermal activity are part of the country's heritage but at the moment, it is difficult to predict the effect of geothermal development on them. Therefore the issue of natural features is coming more to the fore in geothermal development and decisions need to be made concerning the preservation of these features prior to development.

6.2.2 Land use

Land will be required for production wells, pipelines, power stations, cooling towers, electrical switchyards, and power transmission lines. This will conflict with the adopted environmental plans and goals of the local government. The possible conversion of open space into urban scale use, as a result of new roads and an influx of people into the area, may also affect general plans for the area.

The Buranga geothermal prospect is located in a national park (wild reserve) and, therefore, its development should be compatible with the Uganda Wildlife Statute 1996 in cooperation with the Uganda Wildlife Authority (UWA) which manages the area. Conflicts with other land use such as agriculture, recreation, and housing can normally be addressed at a local level by identifying the initial impact; participation of the local population is very vital.

The actual land use for geothermal energy production is relatively small and geothermal power plants can also be designed to blend into their surroundings, more so than many other types of electricity-producing facilities. Other land users can be encouraged to continue with their activities after installations around the pipelines.

6.2.3 Flora and fauna

During operation, biodiversity is affected, mainly during construction where vegetation is cleared and fauna habitats are lost leading to their displacement. Accidental discharge of geothermal fluids to surface waters and streams may occur. The hot water increases temperatures in the rivers and thus reduces the oxygen available to the living organisms in the rivers and other water bodies downstream. Massive withdrawal of fluids may raise the ground temperature through leakage of steam along faults and thus affect the land animals and plants. Operation will also increase the rate of use of water resources; this may affect water organisms and substantially diminish habitats for plants. It may introduce into the area new species of plants on the cleared area or animals which are tolerant to raised temperatures, or it may become a barrier to the normal replenishment of existing species.

The impacts on flora and fauna, caused by the massive withdrawal of fluid from the reservoir and the disposal of fluids into surface waters that would lead to changes in the ecosystem, could be avoided by reinjecting the fluid back into the geothermal system. Reinjection is the only acceptable means of fluid disposal at the moment and helps maintain reservoir pressures. It may solve the problem of the thermal ground caused by leakage of fluid in the form of steam to the surface through fractures.

Discharge of gases from the power plant may have an effect on the flora and fauna if the concentrations of these gases exceed the limits set by regulations. Therefore, there must be continuous monitoring of the quality of discharged gases. The impacts of geothermal gases have not been reported in studies in several fields in the world, and may not be a problem in Buranga field. Abatement techniques can also be employed for H_2S removal.

6.2.4 Visual and aesthetic qualities

Operation involves the installation of power plants, wells, pipelines, cooling towers, switch yards and transmission lines. The complex will affect the visual and aesthetic qualities of the area. It will interfere with the local guidelines related to the visual quality. This may have a substantial demonstrable negative aesthetic effect, may significantly change the visual quality of the region or eliminate visual resources. Some other key visual quality effects related to geothermal development are the presence of steam plumes, night lighting on the well field and power plant, and visibility of the transmission line. The effect of permanent features can be minimised by detailed site planning, facility design, materials selection, revegetation programs, and adjustment to transmission line routing. Many geothermal operators already employ these mitigating techniques in their facilities. Visual impacts can also be minimised by painting all of the piping on the plant forest green so that it blends into the surrounding landscape. Additionally, use of non-specular conductors, which reduce reflection and glare on transmission lines, can be adopted.

Geothermal power plants impose minimal visual impacts on their surroundings when compared to fossil-fuel plants. Careful use of the natural vegetation and planted trees can reduce the visual impact of power stations, pipeline corridors and drill pads by siting them behind ridges and in hidden valleys.

6.2.5 Water quality and hydrology

During operation, changes in the quantity of groundwater, either through direct additions or withdrawals, may occur. This may substantially degrade water quality, contaminate the public water supply, degrade or deplete groundwater resources, and interfere with groundwater recharge. The considerable amount of water needed for construction and in the cooling tower system may be taken from the rivers and streams around the area; this may require damming or diverting local streams, thus decreasing the amount of water available for public water supplies.

The reinjected fluid would be released to the geothermal reservoir, which is much deeper than the shallow groundwater system. However, measures need to be taken to avoid accidents when casings fail by using robust pipes and casings to stop possible leakages that may lead to mixing of the geothermal water with cold water in the shallow groundwater table. Reinjection of the spent fluids also maintains reservoir pressure, which prevents subsidence and drawdown effects that are likely to lower the groundwater table and, hence, affect thermal features like hot springs.

Impacts on the water quality of surface water or groundwater in shallow aquifers are not expected during normal production and reinjection practices. However, impacts could be experienced due to mixing of the geothermal fluid with water in the shallow groundwater aquifer through damaged well casings or accidental discharge. The local water quality could be affected if the well casing fails.

6.2.6 Population, housing and employment

On a positive note, permanent jobs for daily operation and maintenance of the plant, surface flow equipment and wells will be created by making use of local skills, thereby improving the income of the local people. However, the influx of project workers and possibly their families can have an effect on existing housing and create a demand for additional housing and other resources.

The project management will need to set up housing facilities for its staff, preferably outside the project and away from Bundibugyo town to avoid conflicts with the local community. The most common attitude of the host community is to support development as long as it is not in their back yard; the main goal of the developer is to promote cooperation with the stakeholders.

Operation of a power plant is a long term venture and its impacts on population, housing and employment may not be so simple, depending on how much more the project will be developed with time. This calls for an inventory of directly affected households, housing facilities and economic indices (prices of goods, land prices and incomes) in order to mitigate any future impacts.

6.2.7 Transportation and traffic

Operation will increase the number of vehicles in the area and on a permanent basis; this may affect the general traffic safety of the area. Additional population and the need for housing materials will alter the present patterns of circulation or movement of people and/or goods. This phase will cause an increase in traffic which is substantial in relation to the existing traffic load and may significantly impact intersection levels of services.

Transportation during operation will mainly involve workers operating the power plant and providing maintenance. It is believed to have a minimal effect on the environment since the number of vehicles will decrease after the main activities. However, the building of new roads will open up the area to tourists and researchers who will be visiting the power plant and other attractions in the National Park. These could increase traffic on the roads to a significant level. The impact on transportation and traffic may not be of great significance at an early stage but with time, as more tourists and people visit the area, there may be a future need for road maintenance programmes and construction of gazetted parking areas to accommodate the increased traffic.

6.2.8 Air quality

In high-temperature geothermal fields like Buranga, power generation from a standard steam-cycle plant causes non-condensable gases and fine solid particles to be released into the atmosphere. This may create objectionable odours and hamper visibility. The most predominant non-condensable gases in the steam are CO_2 and H_2S. While geothermal plants do not emit SO_2 directly, once H_2S is released as a gas into the atmosphere, it eventually changes into SO_2 and H_2SO_4 acid. Therefore, any SO_2 emissions associated with geothermal energy is derived from H_2S emissions. The discharge of the gases affects people, plants and animals directly, and could also affect the microclimate of the area by increasing fog, clouds or rain depending on the rainfall, topography and wind patterns, as seen in Table 4. It may alter air movement, moisture, or temperature, or result in changes in climate.

TABLE 4: Impacts of emissions associated with geothermal development (Alyssa et al., 2007)

	Nitrogen oxide (NOx)	**Sulfur dioxide (SO_2)**	**Particulate matter (PM)**	**Carbon dioxide (CO_2)**
Impacts	Lung irritation, coughing, smog formation, water quality deterioration	Wheezing, chest tightness, respiratory illness, ecosystem damage	Asthma, bronchitis, cancer, atmospheric deposition, visibility impairment	Global warming, thus increasing sea level, flood risk, glacial melting

The release of gases into the atmosphere during operation can be minimised by standard countermeasures which include reinjecting all the waste fluids, designing power stations to minimise gas discharges, and employing active monitoring systems to enable the power plants to be shut down, or reduce generation if the amount of gas discharged exceeds set levels. H_2S removal, for example, is based on a mechanism by which it is oxidised to sulphur dioxide and then to sulphuric acid. According to Sanopoulos and Karabelas (1997) the most attractive abatement methods for H_2S include: scrubbing with alkali; use of steam re-boilers; and compression and use of the reactant Biox as a catalyst to oxidise H_2S to H_2SO_4.

The visible plumes seen rising from some geothermal power plants are actually water vapour emissions (steam), not smoke. The expected gases are NO_x, CO, H_2S and hydrocarbons but their amounts could be too low to cause environmental pollution. Although chemical contamination of the environment may occur through gas, steam and bore or cooling water discharge, impacts can be minimised by careful management.

6.2.9 Public services and utilities

Operation brings to the surface a large amount of waste fluid. The fluid is disposed of in waterways, evaporation ponds or is reinjected back into the reservoir. The operation of the power plant requires a lot of potable water for the cooling towers and other apparatus in the plant. The activity will therefore generate a considerable amount of wastewater and solid waste needing disposal. Operation will significantly increase the consumption of potable water and may breach the national and local standards relating to solid waste control and disposal of wastewater.

During operation, the influx of workers and possibly their families into the area will affect public services, which will need to expand to accommodate the increased population. The existing school system will presumably need to be expanded and new schools established. Additionally, there may be a need for a new hospital and amenities for the handicapped. The developer, therefore, needs to accommodate these amenities in their developmental plans and budgets.

The project management will need to construct disposal facilities like landfills for solid waste and acquire a water supply and treatment plant for potable water to be used in the plant. Other facilities needed are: a septic tank, communication systems, and water supply and drainage lines. The national and local standards relating to solid waste control and disposal of industrial wastewater need to be studied and implemented.

6.2.10 Energy

Operation will introduce a new type of energy source, geothermal energy, for electricity and direct heat and encourage activities which result in the use of substantial amounts of water and energy. This is likely to result in significant effects on other energy sources and may conflict with the existing energy standards of the area.

Operation will introduce a new type of energy, geothermal energy, into the energy mix of the area that will conflict with the existing energy supplies. This will be a positive development since most of the population is using biomass and, to a small extent, fossil fuels as sources of energy. The geothermal energy will also boost the existing unreliable hydropower supply from the single hydropower source on the River Nile at Jinja. Additionally, the geothermal power will be used in industry and agriculture for drying and processing purposes where it will not be in competition with other sources of energy in the area and in western Uganda at large, which is known for tea growing and depends on wood for drying their products.

6.2.11 Public health and safety

Discharge of wastewater that contains toxic chemicals like lithium (Li), boron (B), arsenic (As), hydrogen sulphide (H_2S), mercury (Hg), and sometimes ammonia (NH_3) may occur during operation. Release of untreated wastewater into a waterway can result in chemical poisoning of fish, birds and animals residing near and inside the water, because some of the toxic substances move up the "food chain" causing biomagnifications. The activity may also generate some considerable noise that may conflict with the local noise standards, leading to several kinds of disturbances.

During operation care should be taken not to release waste fluid to surface waters. The fluid should be reinjected to avoid effects on biodiversity and human health. The TAC will be monitored so as not to exceed acceptable levels. Light and glare can be replaced by normal lights like those used in any other area or settlement, Most of the noise from power plant operations results from three power plant components: the cooling tower, transformer, and turbine-generator building. Once the plant has started operation, noise mufflers should be implemented to keep the noise below the 65 decibels limit around the power plant (D'Alessio and Hartley, 1978).

As operation is a long term issue, possible hazards need to be identified and limits placed on allowable levels. Health criteria for hazards such as airborne contaminants, liquid and solid contaminants, noise and heat, as well as safety criteria such as adequate isolation of dangerous areas, safety clothing for special jobs, and protocols for potentially dangerous operations, may need to be set up before the development of Buranga field.

6.2.12 Cultural situation

The opening up of the area with roads will have a positive impact on the research, tourism and recreational activities in the area. The influx of workers to the area will create employment and markets for agricultural produce and other consumables which will improve the income of the local communities. There will be a general change in lifestyle from rural to an industrial/economic setting. The new people from the different cultural backgrounds will have to integrate into the new society and abide by local government standards and legislation.

There may be great danger of cultural erosion if the process of cultural economic development is not properly managed. Therefore, identification of recommendations such as preventive, mitigating and contingency measures which may be institutional or compensatory in nature, the formation of social enhancement programs, and the development of a monitoring plan should be greatly considered.

6.3 Summary of environmental impacts and possible mitigating measures

Table 5 summarises the environmental impacts and the possible mitigating measures in Buranga prospect.

TABLE 5: Summary of environmental impacts and possible mitigating measures

Activities	Impacts	Possible mitigating measures
Drilling - construction of access roads, well pads, sumps and drilling and testing of wells.	Surface disturbance; Vegetation removal; Discharge of drilling mud, cuttings, and geothermal fluids; Noise; Land use conflict; Emissions to the air; Health effects on workers (risk of well blow outs); Competition for recreation uses; Lack of housing and utilities; Water use; Water quality; Visual quality; Population increase.	Area of natural vegetation cleared should be minimal, directional drilling; Use well designed sumps; Reduction to acceptable noise levels, use of ear muffs; Community participation; Monitoring emission levels; Occupational safety and health standards should be put in place, use of blowout preventers; Planning by concerned authorities; Use and monitoring of good casing materials; Construction of housing facilities; Re-circulation of used water.
Operation - construction of a power plant, steam gathering and injection pipelines, transmission lines, drilling of additional production and injection wells.	Surface disturbance; Loss of vegetation; Effect on fauna; Emissions of CO_2, NO_x and H_2S, (worker safety, public nuisance odour); Effects on nearby recreation uses; Population increase; Physical effects of fluid withdrawal (subsidence and induced seismicity); Noise; Heat effects and discharge of chemicals; Water quality and usage; Visual and aesthetic pollution; Increased traffic and dust.	Detailed hazard mapping, revegetation and minimising the affected area; Deep reinjection of fluids; Monitoring of gasses and H_2S removal; Detailed site planning and engineering; Painting of pipelines and buildings; Use of non-specular conductors and robust pipes and casing; Community planning and putting standards on noise levels and emissions.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Main conclusions

Geothermal energy is environmentally friendly and the least expensive option when compared to energy production from fossil fuels (such as coal, oil), natural gas, and hydropower for electricity generation. Its impacts are predictable and mostly mitigable with the most appropriate technology.

The potential environmental impacts for this geothermal system have been identified. Magnitudes (significance) were analysed and mitigating measures proposed. The results indicate that operation has more impact on the environment than drilling. This is because operation of the power plant is a long term process and its impacts accumulate with time. The likely impacts of drilling were found to be temporary and can presumably be mitigated to insignificant levels. Wells should be monitored during operation.

This study has identified impacts on flora and fauna, water quality and hydrology, air quality, utilities, visual and aesthetic qualities, and public health and safety as very critical areas in the development of Buranga geothermal prospect. Therefore, they should be considered for further assessment and detailed investigations. Implementation of mitigating measures may still not prevent some negative impacts. Impacts like subsidence, induced seismicity, and landslides can have serious and possibly disastrous consequences and thus warrant the serious attention of scientists and engineers. Operation, therefore, must utilise measures to minimise the impacts to acceptable levels. Other likely impacts on geology, landscape, land use, population, housing and employment, transportation and traffic, public services, energy, and culture, are not considered to be of critical importance since they have a high mitigation potential. However, they should also be considered further during the detailed environmental impact assessment, with specialised input being obtained where necessary.

Because EIA is a tool for environmentally sound planning, it should be a continuous process and must be integrated into all levels of policy and project planning and development. This calls for full participation of all agencies, institutions and the general public. EIA is mandatory for the proposed project; therefore, the screening stage was omitted. According to the guidelines, the environmental impact study (Phase II) is divided into two parts: scoping and detailed impact assessment (Figure 8). The study was centred on the scoping stage and laid a foundation for the detailed assessment as recommended below.

7.2 Recommendations

From the results of this study a detailed EIA should be carried out before the feasibility study, as required by the Ugandan laws on the environment. The following should be put under consideration:

- Utilisation of geothermal energy for electricity is always accompanied by excess heat that is dissipated to the environment, mainly as spent fluids and vapour. Such heat could be used as direct heat in agricultural processing and in industry and therefore increase the efficiency of the generation process. The possibility of direct utilisation of geothermal energy and the recovery of minerals from brine needs to be investigated and their environmental impacts assessed in the detailed EIA.

- Detailed EIA should address the general characteristics of the existing fauna and flora, their populations and habitats, i.e. lakes, rivers, forests and bushes. The possible effects of the proposed development on the different species, primary and secondary impacts, temporary and long-term, unavoidable impacts and risks, synergism, and possible irreversible changes should be clearly investigated.

- Based on this study, there is further need to investigate the quality of water and the general hydrology of the area before any development kicks off. This will involve addressing the aspects related to groundwater and surface water contamination as well as water resource availability. Therefore, characteristics of the water resources at risk (rivers, lakes, streams, aquifers and aquifer recharge areas), topography and ecological characteristics, seasonal and annual flows, rainfall and runoff should all be considered. Detailed evaluation of all sources of effluents from the drilling rig and power plant, their impacts on the environment affected and possible mitigating measures should be provided.

- In relation to public health and safety, there is need for the evaluation of infrastructure requirements necessary to meet the demands of an increased labour force. These should include housing, clinics and hospitals, domestic waste management, water usage and demand and transportation. This will help reduce potential increases in conflicts and will help in the identification of both direct and indirect benefits which will be derived from the proposed development. There should be a plan for safety and risk management which should include training and education, publishing protocols and perhaps construction. All the above should be monitored to ensure that developmental protocols are being followed (Brown, 1995).

- The study should address all issues related to the disposal and treatment of waste and wastewater from the drilling rig and power plants. The study should specifically consider different types of sewage disposal systems, their layout and facilities, i.e. reinjection wells, sewage treatment plant, septic tank, landfills and other systems that are relevant to the development. The consistency of the proposed disposal mechanism with national, regional or local planning instruments, and the relationship with neighbouring residential and tourist areas should be looked at in detail. The type and quantity of waste to be disposed of (geothermal spent fluids, domestic), possible impacts of the disposal systems on groundwater and surface water, as well as proposals for the monitoring of the systems should be identified (Bahati, 2005).

NOMENCLATURE

BGR	Federal Institute for Geosciences and Natural Resources, Germany;
DRC	Democratic Republic of Congo;
EARS	East African Rift System;
EIA	Environmental Impact Assessment;
EIS	Environmental Impact Statement;
FRSP	First Road Sector Project;
IAEA	International Atomic Energy Agency;
MEMD	Ministry of Energy and Mineral Development;
NEMA	National Environment Management Authority;
TAC	Toxic air contaminant;
UNDP	United Nations Development Programme;
UWA	Uganda Wildlife Authority.

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