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Kapishya Geothermal Resource Re-assessment

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ABSTRACT

This paper presents uncertainties surrounding the findings, conclusions and recommendations of the Geothermal Resource Assessment at Kapishya by Iceland GeoSurvey (ÍSOR) and Kenya Electricity Generating Company Ltd (KenGen). These studies by the two institutions were done with the view of rehabilitating, expanding and commissioning of the 200 kW power plant, which was installed in the 1980s. Kapishya hot springs located near Nsumbu on the Lake Tanganyika rift structure consists of four large springs and numerous smaller springs with a maximum temperature around 85 °C. The total discharge recorded in May 1971 was approximately 25 L/s (Legg, 1974).

In the 1980s, the Italian Government funded a prefeasibility study on geothermal power production in Zambia, which culminated in the installation of a pilot 200 kW binary power station at Kapishya (Dominico and Liguori, 1986). The plant was not fully commissioned due to lack of transmission lines to the load centres, and has remained non-operational. In 2004, ZESCO engaged the Kenya Electricity Generating Company Ltd (KenGen) to carry out an assessment of the Kapishya geothermal project with the view of rehabilitating, commissioning and investigating the possibility of expanding the plant capacity. The studies established that Kapishya is a low-enthalpy, fault-controlled geothermal resource with estimated reservoir temperatures of about 124 ^{o}C, based on geothermometry (KenGen, 2007). The study recommends drilling of five deep wells to confirm the extent and depth of the reservoir, and the use of pumps to supply hot water to the heat exchangers, as temperatures are too low to allow for sufficient self-flow to the plant. The reservoir simulation studies estimated that the resource area measures about 1 km^2 and is capable of generating more than 2 MWe (KenGen, 2007).

ISOR conducted a geothermal reconnaissance study at Kapishya in 2014, which was co-financed by the Icelandic International Development Agency (ICEIDA) and the Nordic Development Fund (NDF). The scope was to evaluate the feasibility of Kapishya, specifically to determine whether drilling of deep exploration well(s) is warranted, and to make a proposal of the location, depth, orientation and overall design of such an exploration well (ÍSOR 2014).The study established that Kapishya is a low-temperature, fault-controlled system with limited permeability due to the old age of the rock. The maximum temperature recorded from four sampled wells reveal a near constant temperature of 85.5°C at different depths. The origins of the water were established to be precipitation that fell on the plateau west of the power plant. Chemical geothermometry indicated subsurface temperatures in the range of 95 to 115 °C (ÍSOR 2014). The study concluded that the probability of successful utilization of Kapishya geothermal resource for power production is small. However, a recommendation was made for drilling of a vertical 300 m deep exploration well to reach conclusive findings. Furthermore, the study recommended drilling to be targeted towards the NW-SE fault and the SSW-NNE Tanganyika Rift fault (ÍSOR 2014).

Based on the uncertainties surrounding the conclusion on the geothermal resource assessment at Kapishya with respect to the recommendations by ÍSOR and KenGen, ZESCO recommends further assessment of the resource in order to conclude on the viability of the resource for power generation.

1. INTRODUCTION

The Kapishya hot springs are located 8 km north of Nsumbu, where a major fault of the Lake Tanganyika trough cuts impervious porphyritic igneous rocks. The hot springs consist of four large springs and numerous smaller springs, with the maximum temperature of 85 °C recorded in the largest spring. Although the spring waters are relatively dilute, rocks in the vicinity are covered with encrustations, mainly of calcium carbonate with some sodium and potassium sulphate and chloride. The total discharge in May, 1971 was on the order of 25 L/s. Some of the springs give off large amounts of gas with a slight sulphurous smell, and the area is moderately radioactive, with the level of gamma radiation being approximately double that of porphyry outcrops 100 m to the west (Legg, 1974).

In the 1980's, the Italian Government funded a prefeasibility study on geothermal power production in Zambia. The exploration studies carried out included: geological mapping, photogeology, geochemistry of the thermal waters and rocks, soil radon surveys, and electric geophysical methods. This project led to the drilling of 14 exploration and production wells (range of depth: 2 m to 120 m) and subsequently culminated in the installation of a 200 kW binary power station at Kapishya (Dominico and Liguori, 1986). The turbo generators installed were envisaged to operate at a temperature of 95 °C based on the operation principle of the organic Rankine cycle (ORC). However, the plant was not fully commissioned due to the lack of transmission lines to the load centres, and has remained non-operational.

In 2004, ZESCO requested the Kenya Electricity Generating Company Ltd (KenGen) to carry out an assessment of the Kapishya geothermal project, with the view of rehabilitating, commissioning and investigating the possibility of expanding the plant capacity. Geoscientific surveys were therefore carried out between October and November of 2006 at the Kapishya geothermal fields. The work carried out included: geological investigations, radon and carbon dioxide (CO_2) gas measurements in soil air, sampling of hot and cold springs and borehole water, and geophysical investigations that involved the use of magnetotelluric (MT) and transient electromagnetic (TEM) methods (KenGen 2007).

In 2014 a geothermal reconnaissance study was conducted at Kapishya by ÍSOR following a meeting held in Zambia in 2013 involving the World Bank, Icelandic International Development Agency (ICEIDA), ÍSOR, Department of Energy, Geological Survey of Zambia and ZESCO. The studies were co-financed by ICEIDA and the Nordic Development Fund (NDF) to evaluate the feasibility of geothermal development at Kapishya, specifically to determine whether drilling of deep exploration well(s) is warranted and to make a clear proposal as to the location, depth, orientation and overall design of such an exploration well or wells.

The work carried out consisted of: temperature logging, ground magnetic measurements, and geochemical studies. Geochemical analysis included sampling, chemical characterization, geothermometry, and analysis of stable isotopes.

2. LITERATURE REVIEW

2.1 Study 1 – KenGen

2.1.1 Methods and Findings

According to the KenGen report of 2007, the Kapishya geothermal field is a low temperature resource with estimated reservoir temperatures of about 124 °C. Conceptual modelling indicates that the reservoir is fault controlled and can be tapped by drilling wells up to 500 m depth. The report recommends the use of pumps to supply hot water to the heat exchangers, as temperatures are too low to allow for sufficient self-flow to the plant. It is estimated from reservoir simulation studies that the resource area measures about 0.5 to 1 km^2 and is capable of generating more than 2 MWe. The report further recommends drilling of five deep wells to confirm the extent and depth of the reservoir and to produce adequate hot water to the power plant.

2.1.2 Geothermal Conceptual Model

Kapishya hot springs discharge from a fault line at the foot of a major rift fault escarpment at maximum temperature of about 88.1 °C. Studies revealed that the rock types consist of metamorphic rocks of various ages from 450 Ma and older, and Precambrian metavolcanics and intrusives that date to over 2000 Ma. There is no evidence of a young magmatic body in the vicinity of the prospect, except for the dolerites dikes encountered during drilling, which could be post rift faulting in age (<12-7 Ma).

An analysis of subsurface resistivity distribution indicates presence of a near surface conductive body (200 m depth) NNW of the plant. This body probably corresponds to the reservoir for the hot springs in the area. The same area has relatively lower resistivity at depth, as imaged by magnetotelluric surveys (MT). The resistivity values of 300-250 Ωm at 2,000-3,000 m depth suggest the presence of a structurally-controlled anomalous body in the area. High values suggest that the geothermal system is restricted to a small zone along the main fault system, and that the heat source is at low temperatures. Combined MT and TEM interpretation suggests that the resource area probably measures about 1 km^2.

Geochemical evidence based on soil gas surveys and fluid chemistry indicates that the resource could be of low temperatures and of limited size. Slightly elevated radon and CO_2 values near the plant may suggest the existence of a geothermal system at depth just to the north of the plant, with possible reservoir temperatures of 124 °C. The geothermal system around the pilot plant could be the source of the Kapishya hot springs, as it is also imaged by resistivity surveys. High Rn values to the west of the plant on the high grounds could be due to other sources or processes as it is unlikely to be associated with a geothermal system. MT resistivity distribution of the corresponding area in the west shows a resistive body from near surface to deeper than 3,000 m below surface.

2.1.3 Conclusion of Study 1

According to the KenGen report, the Kapishya field is a low temperature, fault controlled geothermal resource that is recharged deeply from the western high grounds; to some extent along one end of the main fault and also from the neighbouring Lake Tanganyika via lateral flow. The latter recharge path, however, is considered minimal and could affect only the near surface fluids. The fault plane model for the Geothermal System implies deep fluid circulation without the need for a centralized heat source.

The probable heat source for the system includes a high geothermal gradient caused by thin crust due to rift setting, shallow dike intrusions, and deep circulation along structures. The main reservoir would be the rift fault along which wells are drilled and hot springs occur. The upflow of fluids would be a combination of buoyant forces and high hydraulic gradient from the assumed recharge areas in the west. Mixing by adjacent lake water within the top 100 m would produce hybrid waters observed at Kapishya. The chemistry of the hot springs and well discharges indicates that they tap into the same reservoir.

The study established that the geothermal resource area at Kapishya is confined to the major NE trending rift fault zone within the vicinity of the pilot power plant. This was confirmed by the resistivity anomaly at 500 m depth based on the combined MT and TEM data (Figure 1). A potential area of approximately 1 km^2 is believed to be achievable considering the 300-500 m resistivity anomaly confined to the fault zone that indicates the presence of a geothermal system,

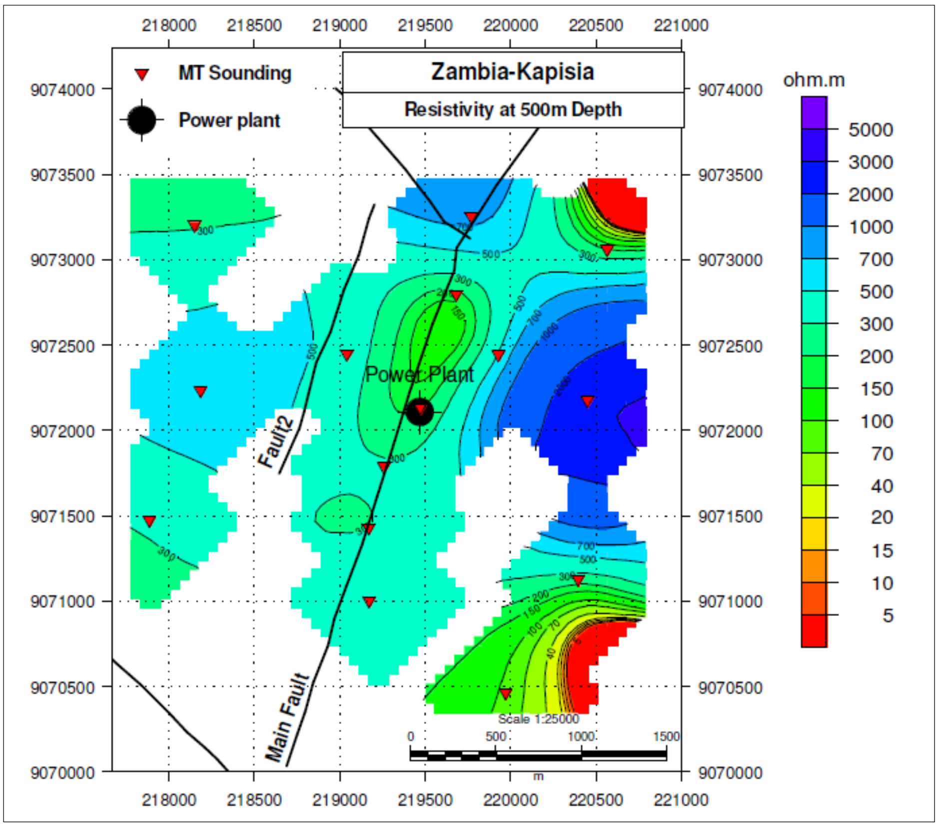

Figure 1: MT resistivity distribution at a depth of 500 m (KenGen 2007).

The 2-D MT resistivity modelling indicates that the resource depth is about 250 – 500 m. The models show that the high potential area extends northward of Kapishya power plant along the fault zone.

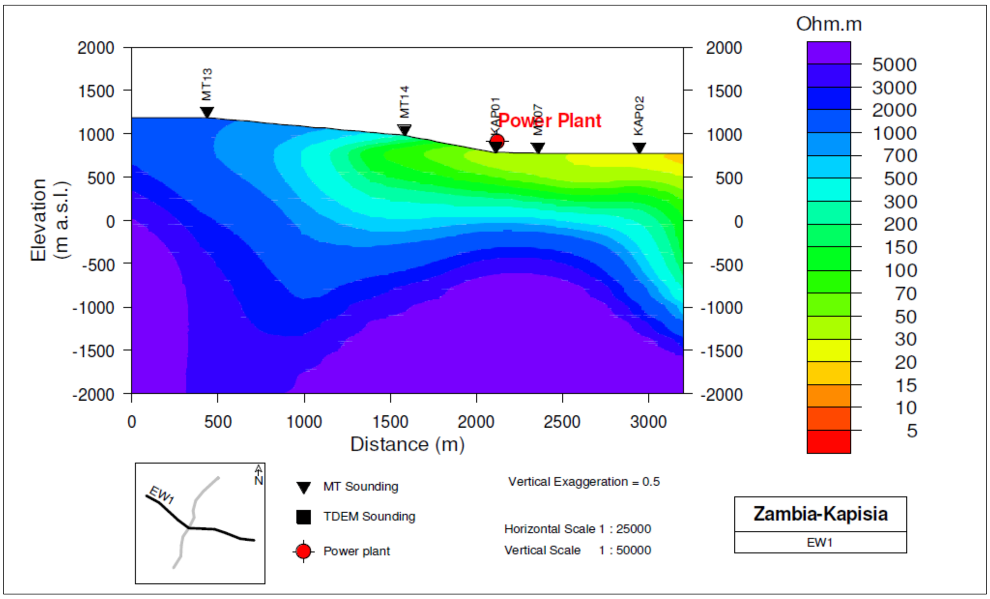

Figure 2: NW-SE MT cross-section based on a 2-D interpretation (KenGen 2007).

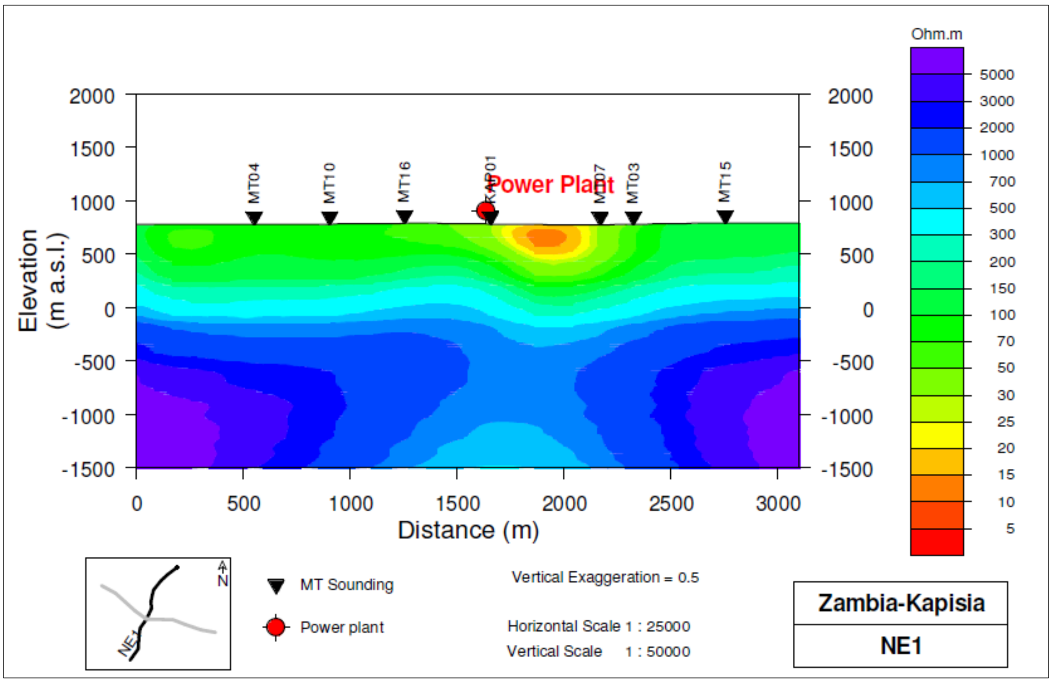

Figure 3: NE-SW MT cross-section based on a 2-D interpretation (KenGen 2007).

The study indicated that there is a high chance (> 60%) of getting more than 2 MWe at Kapishya using the binary technology. The estimates were based on volumetric stored heat model (Monte Carlo simulation) which assumed a reservoir temperature range of 120-130 °C, a resource area of 0.5 - 1 km^2, reservoir thickness of 100 – 500 m, porosity of 3-6%, and heat exchanger outlet temperature of 70 °C.

2.1.4 Study 1 Recommendations

The report recommends drilling of large wells to maximum depths of 500 m and the top cool zones be cased off to prevent cold water incursion into the bores. It further recommends that wells be designed to target fault zones at depth for increased permeability and high temperature fluid flow.

2.2 STUDY 2 ICELANDIC GEOSURVEY

2.2.1 Methods and Findings

The reconnaissance study conducted by ÍSOR confirmed that Kapishya is a low temperature fault controlled geothermal system. A near constant temperature of 85.5 ^{0}C was recorded from the temperature logs of the wells at different depths ranging from 8 to 73 m.

The ground magnetic measurements indicate the presence of a NW-SE trending dyke/fault intersecting the NNE-SSW trending main rift fault west of the Kapishya hot spring area. It is believed that the intersection of these two structures is the reason for the up-flow of the hot water in this location. The chemical geothermometers applied to the samples collected at site yielded temperatures ranging between 95 and 115 °C.

The main conclusion of this study is that the Kapishya geothermal system is a low-temperature system with 95 to 115 °C reservoir temperature, characterized by deep convection on faults. Productivity of the system might be limited. The lower end of the estimated temperature range is not likely to allow electricity production at competitive cost.

A geothermal resource temperature of 115 °C might allow production of electricity with binary technology at a cost comparable to power produced by diesel powered thermal plants. However, the study recommends drilling of a vertical exploration well a short distance west of the Kapishya Power Plant to a depth of at least 300 m.

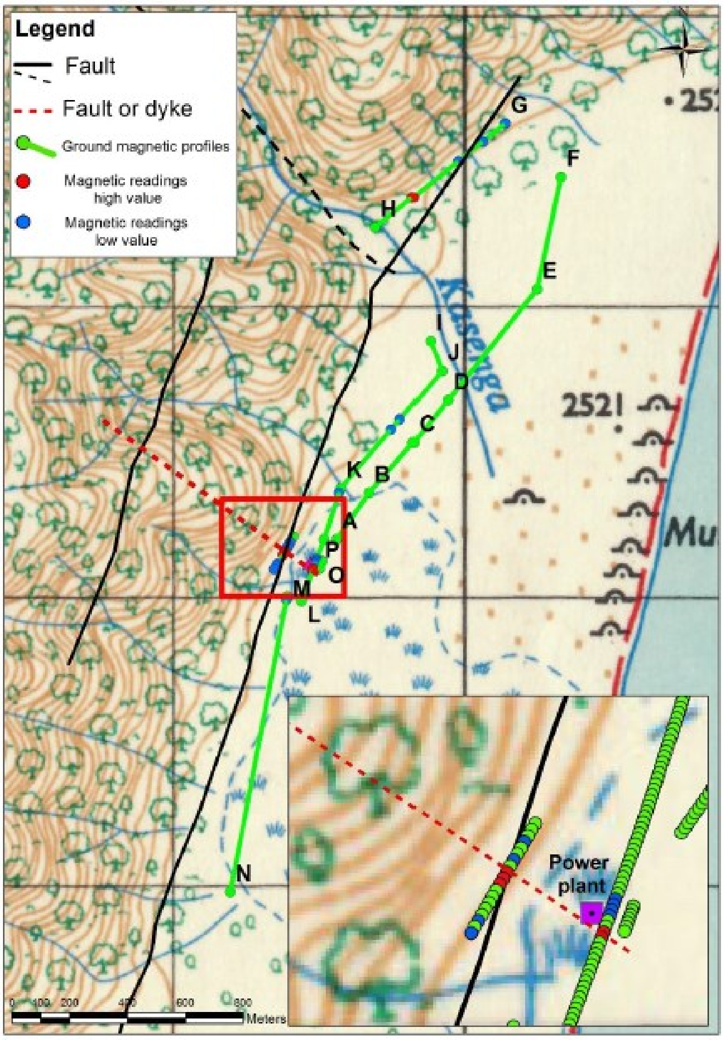

Figure 4: Magnetic field profiles in Kapishya Hot Springs area (ISOR, 2014).

2.2.2 Geothermal Conceptual Model

The results obtained by the study support the conclusion that Kapishya Geothermal System is a fracture controlled low temperature system, characterized by a reservoir temperature of about 95 to 110 °C. The study assumes that the Kapishya thermal waters are heated by relatively deep convective circulation on either the NW-SE trending fault/dyke or more likely the main NNE-SSW trending fault. The intersection between these two fault directions creates a pathway for the up-flow, as confirmed by a lateral outflow as indicated by the slight temperature reversals. Based on the MT data, an elongated low resistivity anomaly along the main (NNE-SSW) fault at 500 m depth.

The study concludes that temperature in the Kapishya geothermal system is not likely to be significantly higher than what was observed in the wells based on homogeneous chemical composition of water discharging from wells. This was supported by low Magnesium (Mg) concentrations in water samples from the wells. The fluid chemistry was found to be relatively mild in relation to corrosion and scaling.

2.2.3 Conclusion of Study 2

The study concluded that deep drilling is not likely to reveal hotter fluids in the Kapishya geothermal system. The maximum temperature to be expected is of the order of 95 to 115 °C. The overall conclusion of the study is that the probability of successful utilization of the Kapishya geothermal resource for power production is small.

2.2.4 Recommendations of Study 2

The study recommends for deep exploration drilling to be targeted towards the intersection of the SSW-NNE Tanganyika Rift fault and the NW-SE fault/dyke west of the power plant.

3. TECHNICAL EVALUATION

This section presents the similarities in the methodologies, findings and uncertainties with respect to the conclusions from the two studies.

3.1 Comparison of the Studies

Table 1: Comparison of the studies, findings and recommendations by KenGen and ISOR.

Item	Study 1 - KenGen (November 2006)	Study 2 - ISOR (November 2013)
Geology	▪ Low temperature fault controlled geothermal system	▪ Low temperature fault controlled geothermal system
Geophysics	▪ Combined MT and TEM data established that the resource area is confined to the NE trending rift fault zone near Kapishya power plant, as confirmed by resistivity anomaly at 500 m depth ▪ Resourced area estimated to be in the range of 0.5-1.0 km^2	▪ Ground Magnetic measurements indicated the presence of a NW-SE trending dyke/fault intersecting the NNE-SSW trending main rift fault west of Kapishya hot spring. ▪ Extent of resource area was not stated.
Temperature Logging in Wells	▪ Maximum temperature recorded from sampled wells: 88.1 °C	▪ Maximum temperature recorded from sampled wells: 85.5 °C
Geochemistry	▪ Reservoir temperature range based the chemical geothermometer: 104 to 124 °C ▪ Maximum flow rate recorded from sampled wells: 10 L/s ▪ Total Discharge recorded from four wells: 25 L/s	▪ Reservoir Temperature range based on chemical geothermometer 95 to 115 °C ▪ Maximum flow rate recorded from sampled wells: 4 L/s ▪ Total Discharge recorded from nine wells: 19 L/s.
Recommendations	▪ Drilling of large wells to 500 m depth and casing off the top part to prevent incursion of cold water. ▪ Wells to target fault zones at depth for increased permeability and high temperature fluid flow.	▪ Drilling of deep exploration well to at least 300 m depth and cased to about 50 m depth. ▪ The well to target the NNE-SSW rift fault or NW-SE fault.

3.2 Uncertainties

The analysis carried out by ISOR and KenGen to estimate the reservoir temperatures at Kapishya did not state the errors associated with the chemical geothermometry. The total errors propagated by geothermometry could potentially downgrade the resource at Kapishya with respect to a key parameter (reservoir temperature).

Santoyo and Verma (1997) demonstrated the theory of error propagation and outlier detection in geothermometry. The table below summarizes the errors associated with chemical geothermometry for different temperature ranges, as highlighted by the statistical study.

Table 2: Errors propagated by chemical geothermometers (Santoyo and Verma, 1997)

Geothermometer	Temperature Range (°C)	Propagated Error	
		Original Equations	New Equations
Na/K	80 – 350	24 – 43 %	19 – 34 %
Na/Li (for Cl < 10,650 ppm)	50 – 320	15 – 39 %	13 – 34 %
Na/Li (for Cl ≥ 10,650 ppm)	50 – 320	10 – 44 %	26 – 106 %
SiO_2 (for SiO_2 < 295 ppm)	20 – 210	3 – 12 %	1 – 9 %

On the other hand, the study by KenGen did not conclusively establish whether or not there is a relationship between the water from the wells sampled and that of Lake Tanganyika (1.5 km away) in relation to the mixing model applied. It was stated that it is not easy to establish a clear relationship with the current information because most of the chemical components analyzed are the reactive ones whose concentrations are determined by the degree or extent of the water-rock interaction and prevailing temperature conditions.

Despite suggesting that the geothermal resource at Kapishya had limited potential for power generation, both the ISOR and KenGen studies recommend drilling exploration wells to target the main geological structures in the area. In addition, the study conducted by KenGen indicated that there is a high chance (> 60%) of getting more than 2 MWe at Kapishya using the binary technology.

4. CONCLUSION AND RECOMMENDATIONS

Based on the uncertainties regarding the conclusions drawn by ÍSOR and KenGen, ZESCO recommends further assessment of the geothermal resource at Kapishya. This would provide a basis to conclude on the viability of Kapishya with respect to power generation. Further investigations should include drilling shallow wells to depth between 300 and 500 m as recommended by the two institutions. Drilling exploration wells would provide detailed information about the reservoir fluid chemistry, structural data, lithological data, deep temperature gradient data and fluid flow rate data. Such an assessment would therefore increase the level of certainty as opposed to the analysis done based on data obtained from shallow wells at a maximum depth of 73 m.

The geothermal resource offers sustainable climate change resilience, a renewable energy solution that would support the power generation mix in the country, and improve access to electricity. Zambia's strategic move in energy security is to diversify from over-reliance on hydropower to alternative energy sources.

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