

Research Article

Analysis of Reservoir and Steam Flow Data in Olkaria Domes Geothermal Field, Kenya

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Abstract

This study evaluates reservoir performance and steam production in the Olkaria Domes Geothermal Field, Kenya, over the period 2019-2023, with a focus on key wells supplying Olkaria IV, Olkaria V, and wellhead power plants. Monitoring data from wells such as OW-914, OW-916, and OW-921 show stable wellhead pressures ranging from 6.5 to 9.8 bar, and discharge enthalpies between 1400 and 2650 kJ/kg, consistent with production from a high-temperature liquid-dominated reservoir. Reinjection rates remained above 48%, helping maintain reservoir pressure. However, evidence of cooling and dilution was observed in wells like OW-923 and OW-926, where enthalpy values dropped by up to 250 kJ/kg, and silica concentrations declined from 470 ppm to 410 ppm, suggesting the encroachment of colder reinjection fluids. Using discharge test data and pressure logging, mass flow rates, pressure trends, and thermodynamic conditions were analyzed. The findings underscore the necessity for continuous reservoir monitoring and the need to optimize reinjection design to avoid long-term pressure drawdown and thermal degradation. These insights are vital for sustaining steam supply and ensuring the long-term viability of geothermal energy production in the Olkaria Domes field.

Keywords

Sustainability, Pressure Drawdown, Reservoir, Thermodynamic Changes

1. Introduction

1.1. The Greater Olkaria Geothermal Area (GOGA)

Kenya is widely recognized for its rich geothermal resources, most of which are found in the Rift Valley, home to Africa's busiest steam field. Because the country straddles the East African Rift, it has settled into a spot that puts it near the world's premier geothermal hotspots [1] Today, Kenya ranks as the sixth-largest producer of geothermal electricity globally, with an installed capacity of 988.7 MW [2] Olkaria Park is part

of that total, even though it is currently undergoing refurbishment and upgrade for improved performance.

The Olkaria geothermal field is situated in the western part of the Olkaria Volcanic Complex, within Nakuru County, specifically in Naivasha sub-county. It is characterized by a web of faults, volcanic domes, distinct surface features, and hotspots exhibiting high heat flow. Spanning 204 square kilometres, the field is primarily operated by the government-owned Kenya Electricity Generating Company (KenGen), in conjunction with Independent Power Producers

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or Power IV Inc. and Oserian Development Company.

Over the years, the site has been steadily expanded, with more than 360 wells now in place. This growth means that more steam is extracted and more energy is fed into the national grid. Due to its size and quality, Olkaria is often regarded as the premier geothermal resource in the East African Rift System and a cornerstone of Kenya's renewable energy sector. It is mainly characterized by high-temperature geothermal systems, with a two-phase geothermal fluid that plays a crucial role in Kenya's renewable energy development. Continuous monitoring of steam production and reser-

voir status has been essential in this field for as long as power generation optimization and long-term viability of the field are concerned. The field, which is the newest geothermal field in the greater Olkaria area under development, supports two main power plants (i.e., Olkaria IV & V power stations) plus four wellhead stations (i.e., OW-905, OW-914, OW-915, and OW-919 wellhead generating stations). The field boasts a total of 95 wells, comprising 74 production wells, six pressure monitoring wells, and 15 reinjection wells that support the generation within the field.

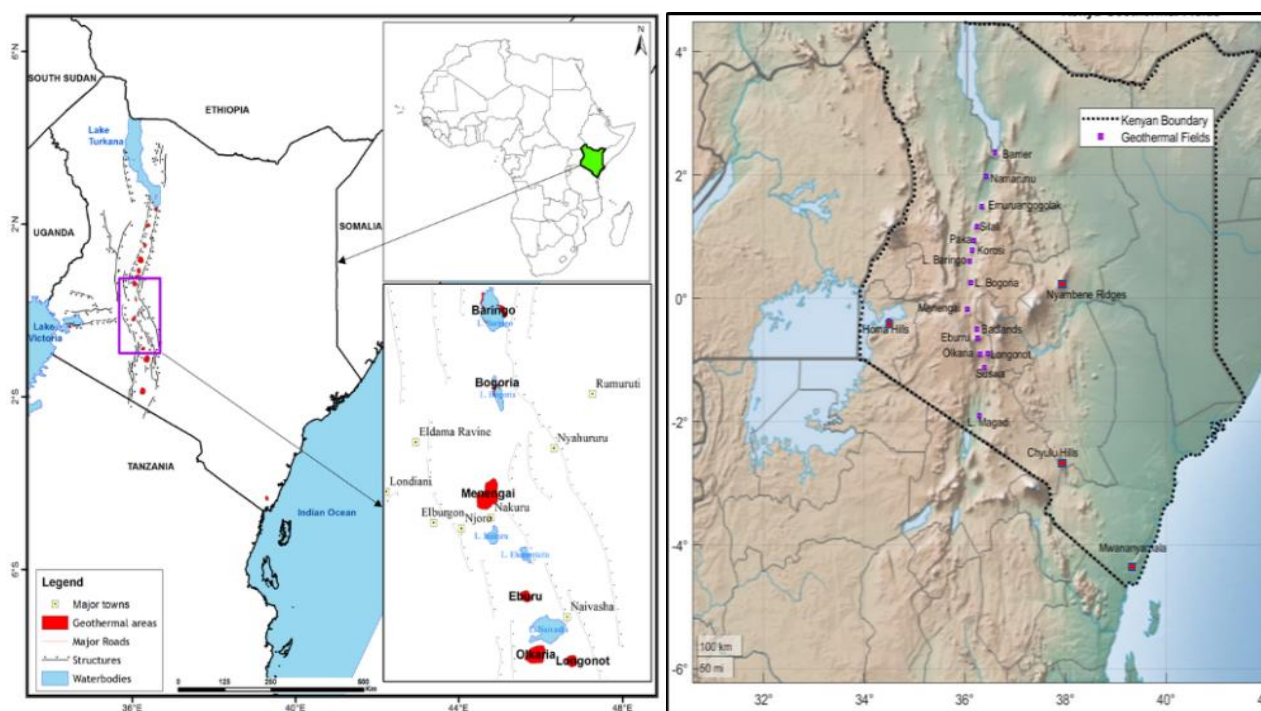


Figure 1. Greater Olkaria Geothermal Area [3].

Geothermal power generation taps into the heat stored beneath Earth's crust by pulling up geothermal fluids, which carry the heat needed to spin turbine generators. Those fluids usually consist of steam, hot water, and dissolved gases. Once the mixture reaches the surface, steam is separated and directed to the turbines, while the cooler brine-water is pumped back underground to maintain steady pressure. After passing through the turbines, the steam condenses into water and is also reinjected. This process of reinjection is vital because it helps recharge the resource and slows down the rate at which the reservoir is drained.

In Kenya, geothermal energy currently accounts for over 50% of the country's electricity generation (Figure 2), with central installations such as Olkaria, Eburru, and Menengai fields leading the way [4]. This is attributed to a 21.84% increase in geothermal energy power generation.

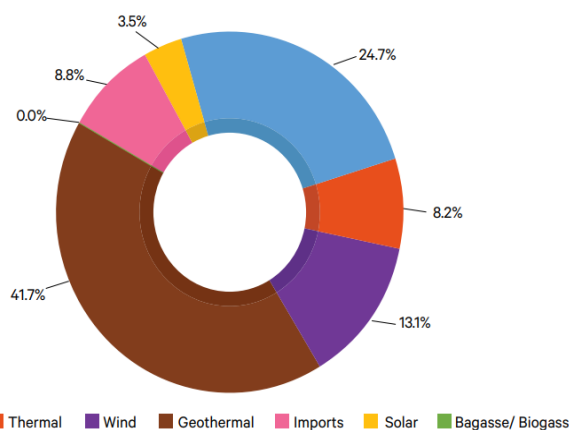


Figure 2. Energy generation mix in Kenya [5].

The Greater Olkaria Geothermal Area (GOGA) is subdivided into seven main segments for the ease of its development (Figure 3). The development has occurred in phases

since 1963 when the first exploratory well (OW-X1) was drilled.

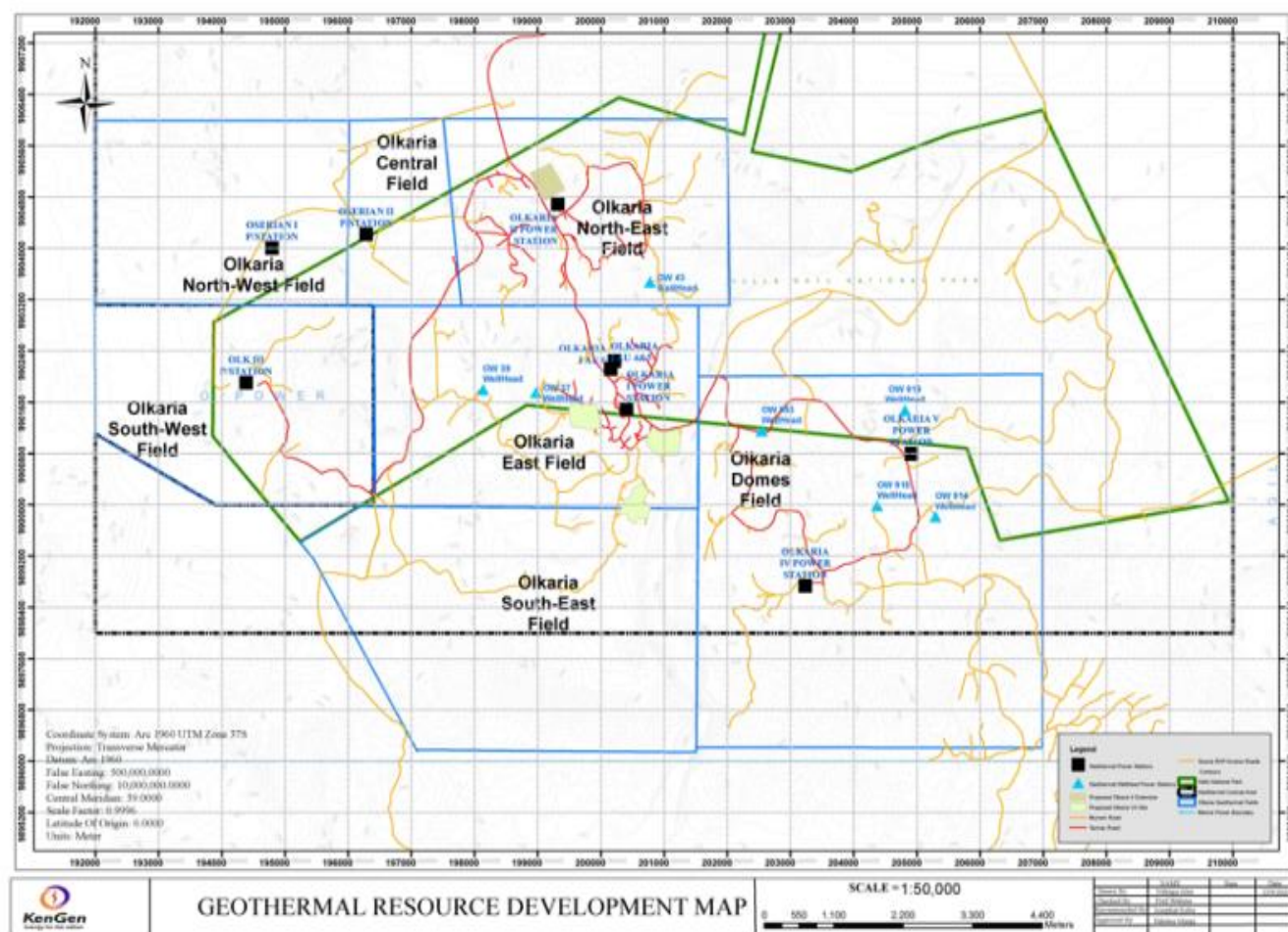


Figure 3. The 7 segments of the Greater Olkaria Geothermal Area field map and the Olkaria Domes field[6].

In Olkaria, KenGen owns five geothermal power stations, whereas Orpower 4 Inc. and Oserian Development also operate in the area. Co Ltd owns one power plant (150MWe) and two Wellhead stations (5MWe) respectively. Thus, KenGen Plc operates the Olkaria I, Olkaria II, Olkaria IV, Olkaria V, and Olkaria VI power plants. In addition to the Power Stations, KenGen Plc owns fifteen wellheadgenerating plants. To date, Olkaria's field total geothermal power generation capacity stands at 931.7 MW (Figure 4), including Olkaria I, which is currently 45 MW and is undergoing refurbishment.

This research focuses on real-time, well-specific monitoring data to diagnose subtle but critical changes in reservoir behavior. This approach moves beyond broad conceptual models to deliver operationally relevant insights that can directly inform reinjection design, well targeting, and long-term reservoir sustainability. By bridging the gap between reservoir physics and production operations, the study contributes to enhanced geothermal resource management in



Figure 4. Current Olkaria 's total power generation capacity[7].

Olkaria and similar East African fields.

1.2. The Olkaria Domes Field

The Olkaria Domes field, which is part of the Greater Olkaria Geothermal Area (GOGA), currently supports a total of 367.8 MWe of electric power generation, as illustrated in Figure 5 below, respectively.

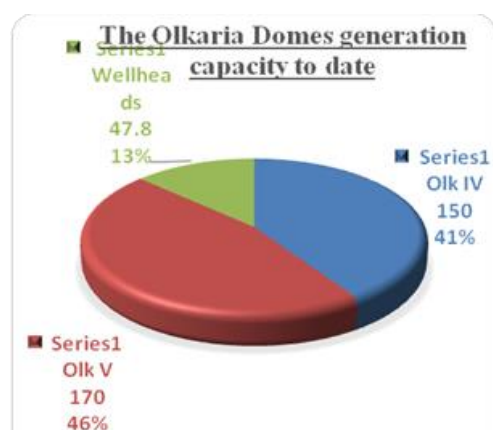


Figure 5. The Olkaria Domes total power generation capacity to date [7].

The Olkaria Domes steam field system is designed with centralized separator stations, where two-phase flow from multiple wells is fed to a single separator station for separation. Thereafter, the combined steam flow first from a single separator station joins with steam from other separator stations before it is admitted to the power plant for electric power generation. On the other hand, brine separated from various separator stations is pooled into a standard flow, which is then distributed to several hot reinjection wells. Two cold injection wells share the condensate flow from the power plant after it is generated.

The steam status report covers the monitoring period from January 2019 to December 2023. During the 5-year monitoring period, all the wells were in production interchangeably. This report thus presents the status of flow outputs from each well and individual healthy head pressure of wells connected to Olkaria IV and V power plants for the above-mentioned monitoring periods.

2. Literature Review

2.1. Geology of the Greater Olkaria Geothermal Area (GOGA).

The Olkaria geothermal area is geologically composed of Proterozoic Basement Rocks, pre-Mau volcanics, Plateau Trachytes, Olkaria Basalts, and Upper Olkaria Volcanics [8].

Four (4) fault systems characterize the field and are associated with fluid movement in the Olkaria geothermal area (Figure 6). These include ENE-WSW, NW-SE, N-S, and E-W structures, all of which are defined as normal faults based on the correlation of lithology and alteration mineralogy zones. These structures include the Ololbutot fault, Olkaria fault, Olkaria fracture, Gorge farm fault, Ring fault structure, and Ol Njorowa Gorge. The Ololbutot fault, which runs from Northwest to Southeast, is also believed to be the one capable of providing a cold recharge to the larger part of the Olkaria system directly from Lake Naivasha as the primary source. The most prominent and recent active faults in volcanic history are the Ololbutot fault, the Olkaria fracture, and the NNE- to NE-striking faults. The Ololbutot lava flow, which emanates from the Ololbutot fault, is the youngest, indicating that it is the latest active fault in the area. The Ol Njorowa Gorge is a structurally controlled feature that has been modified by erosion. The Gorge trends in a nearly north-northeast direction, and it is controlled by the north-northeast and northwest striking faults. This structure is a characteristic geological feature in the area, which may influence fluid flow. The volcanoes are arranged along the ring structure (Figure 7). In the Olkaria Domes field, the area is dominated by Rhyolite, Basalts, and Trachyte, which are uniformly distributed throughout the area, with the ring structure situated in the far eastern part.

Some of the main volcanic features still evident in the region include the Ol'Njorowa Gorge, Olkaria Fault, Ololbutot, and the Gorge Farm Fault, among others. The Olkaria Domes field also boasts several eruptive features that are yet to undergo extinction, with the main one being the Olkaria hill. It is also perceived that an NW-SE fault passes through the Ololbutot lava flow, acting as a hydrogeological barrier that separates the fields closer to it, forming a conduit to sustain constant pressure boundaries. This might lead to a general confirmation of the assumption that some geological features act as barriers, feeders, and recharge avenues to the main reservoir of its geothermal system.

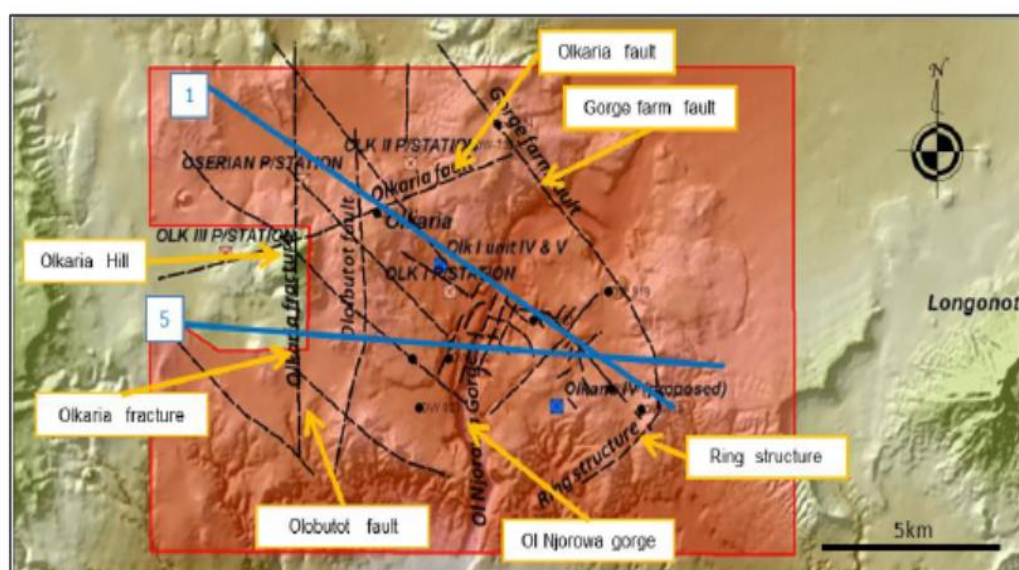


Figure 6. The geological structural map of the greater Olkaria geothermal field [7].

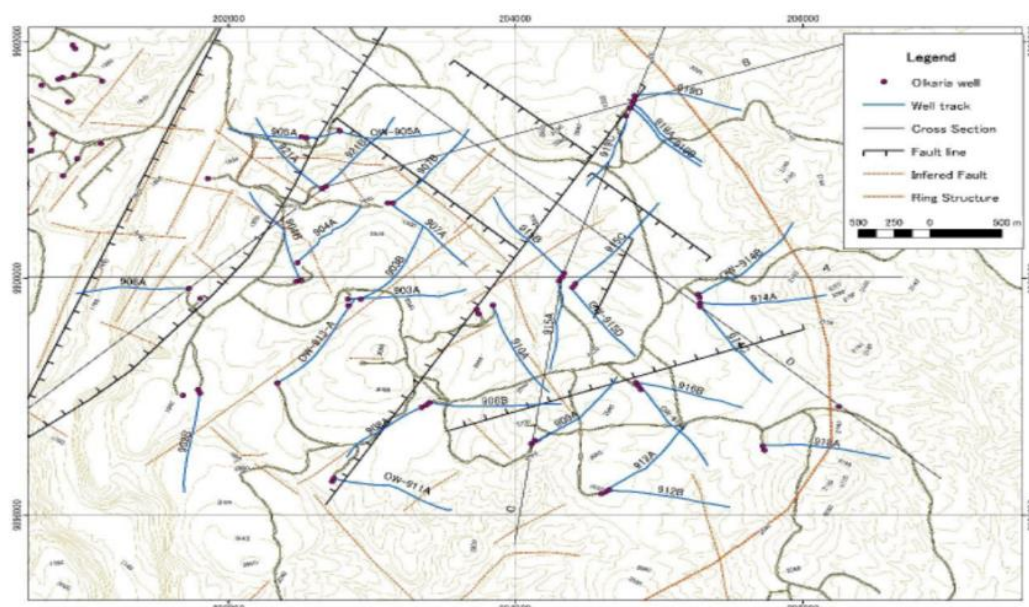


Figure 7. Geological structural map of Olkaria Domes field [7].

Apart from the faults and fractures, several geothermal manifestations remain evident throughout the entire Olkaria geothermal field. Among the most common features in the Domes area are the steamy hot grounds, few traces of fumaroles, and some geothermal grasses, among others. All these features are prevalent at the Domes field, apart from fumaroles, which are not very common, possibly due to the huge ash cover from the Longonot eruption, as well as other human activities in the area. The hot grounds are aligned along the complex geothermal structures beneath the Earth's surface, which are intersected during intensive deep drilling activity. This therefore confirms the permeability status as well as proof of good production exhibited by wells drilled targeting

these areas.

Similarly, the wells have also shown relatively high productivity and injectivity indices for the production and re-injection wells, respectively. Examples of such wells include OW-923B, OW-924A, and OW-921A, which are directional-drilled wells targeting these permeable zones. Currently, OW-921A serves as the largest producer, with approximately 30MWe of discharge testing capacity in the entire GOGA. On the contrary, several wells also exhibited low permeability and thus encountered low production within the same field. Examples of such low producers are: OW-927A, OW-926, and OW-922, among others.

2.2. Overview of Olkaria Domes Geophysical Data

The Olkaria geothermal field has undergone significant geophysical studies since the region was recognized to have a resource beneath its surface. To ensure the accuracy of the geophysical findings, various methods were employed to investigate the geophysical nature and characteristics of the Domes field. Some of these methods used included, but are not limited to, resistivity methods, magnetics and electromagnetic methods, gravity methods, among others. The most common and significant resistivity methods used in the area include the Magneto Telluric and the Transient Electro Magnetic.

Among the documented studies was the joint one-dimensional inversion of MT and TEM [9]. The findings of this study revealed that the Domes field is characterized by a relatively high resistivity surface layer greater than 100 Ωm which is associated with the presence of unaltered rocks, a second conductive layer of about 10 Ωm associated with the clay alteration of the cap rock and a deeper zone of high re-

sistivity demarcating the geothermal reservoir. The study also correlated resistivity structure, alteration mineralogy, and reservoir temperature from a few wells in the Domes field, which were found to be in fair agreement.

Recent resistivity data in the Domes field revealed that there exists low resistivity at a depth around the ring structure. This is presumed to be due to hydrothermal activity associated with magma emplacement and partial melting. The resistivity models in the Domes field also revealed three layers varying with increasing depth. The dimensionality analysis revealed a near-subsurface zone composed mainly of 1D and 2D structures, while 3D structures dominate the deeper part of the reservoir. A relatively high resistive zone beneath the caprock implies the presence of permeable pathways associated with upwelling magmatic fluid circulation [10]. Similarly, magneto-telluric investigations and micro seismicity hypocentre locations have indicated the storage of at least three separate magmatic intrusions at ~depths of approximately 5.5-8 km below Olkaria [10]. Figures 8-10 illustrate a cross-section showing the locations of the wells and cross-sections across the Olkaria Domes geothermal field.

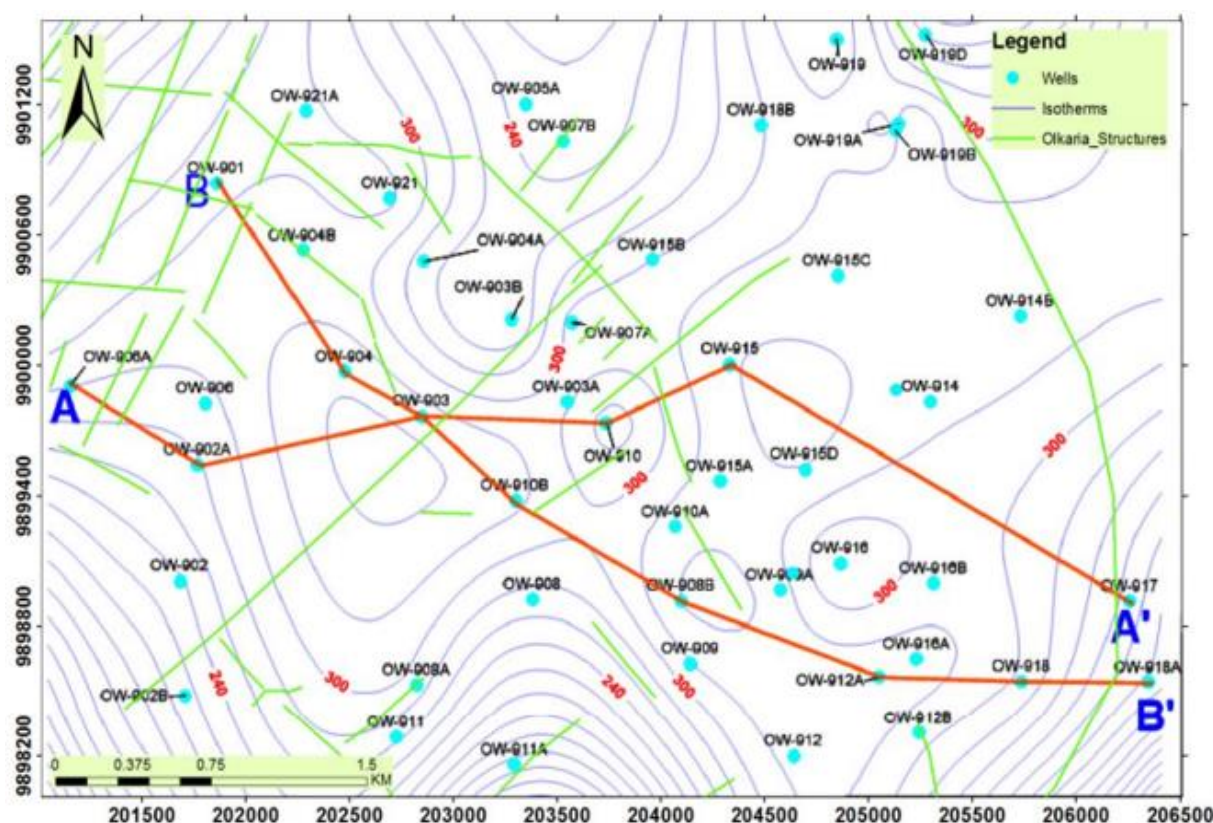


Figure 8. A map illustrating well locations and cross sections across the Olkaria Domes geothermal field.

Temperature cross section AA

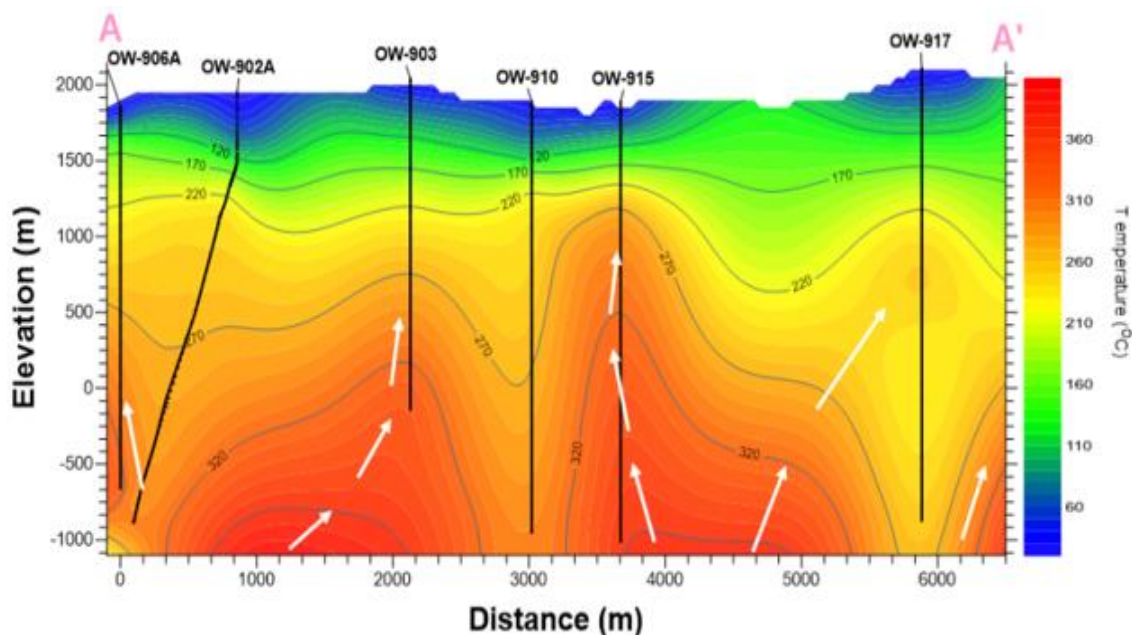


Figure 9. Amap showing temperature model cross section A-A'.

Temperature cross section B-B'

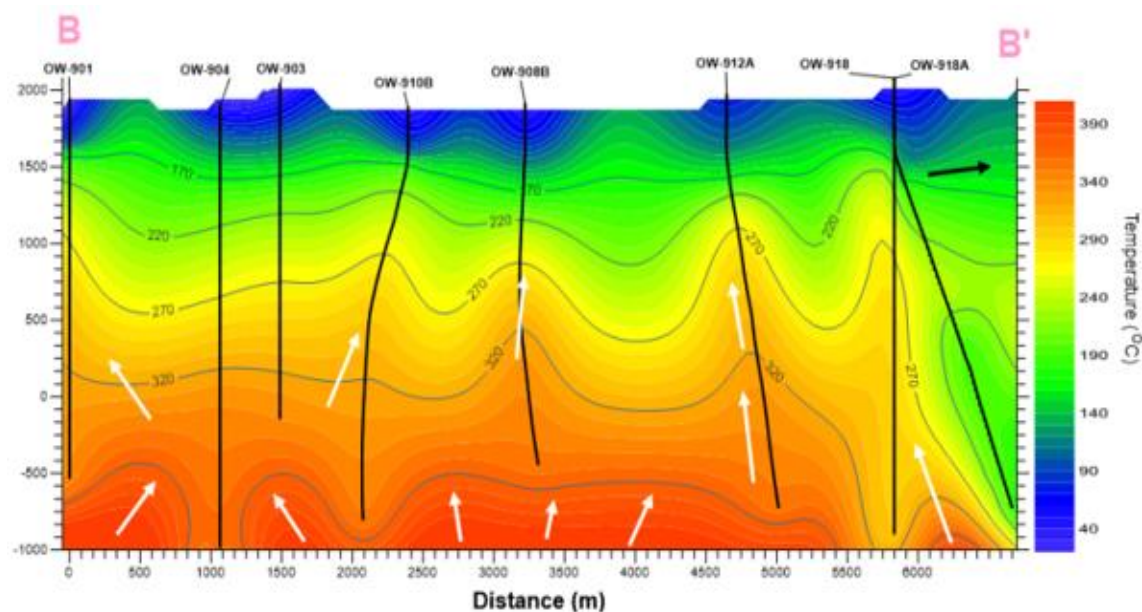


Figure 10. Amap showing the temperature model cross section B-B'.

2.3. Overview of Olkaria Domes Geochemistry Data

Previous studies in the area have proved that the geothermal reservoir fluids in the Olkaria Domes are bicarbonate in nature and correspond to peripheral waters [10]. Solute and gas geothermometry indicate high temperatures in the range of 250 °C- 350 °C. Fluids extracted from Olkaria Domes wells

contain low calcium concentrations and high pH. Calcite scaling can be expected to be minimal in these wells; however, the fluid must be separated above 100 °C to prevent silica scaling (Karingithi, 2000). Studies conducted by [10] show that wells in the Olkaria Domes field discharge a mixture of chloride and bicarbonate end members, as illustrated in Figure 11.

The chemical content of fluids from the Domes sector

supported the possibility of a hot up flow in the southeast part of Domes, as well as the contention that the resources there extend further to the east and southeast. The existence of these up-flow zones was supported by Cl - concentration and Na/ K temperature estimates as well as resistivity data. Bicarbonate waters are found in areas to the northeast and southwest of the Olkaria Domes field. This could be due to the contribution of recharge fluids through the NE-SW faulting and the interpreted buried caldera, which forms a concentric series of rhyolitic ash domes in the east, frequently referred to as the ring structure. Well OW-901 fluids exhibited relatively lower molecular gas ratios of $\text{CO}_2/\text{H}_2\text{S}$, CO_2/H_2 compared to wells OW-902 and OW-903. The lowest gas ratios of $\text{CO}_2/\text{H}_2\text{S}$ and CO_2/H_2 , and the highest ratios of H_2/CH_4 , often indicate fluids that are close to the up flow or have the most direct route to the surface. These ratios are also indicative of proximity to an underlying hot water source [11].

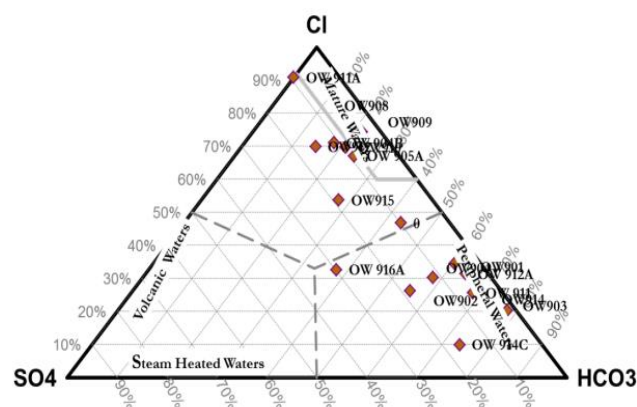


Figure 11. A map illustrating the geothermal waters composition in the Olkaria Domes field [10].

3. Methodology

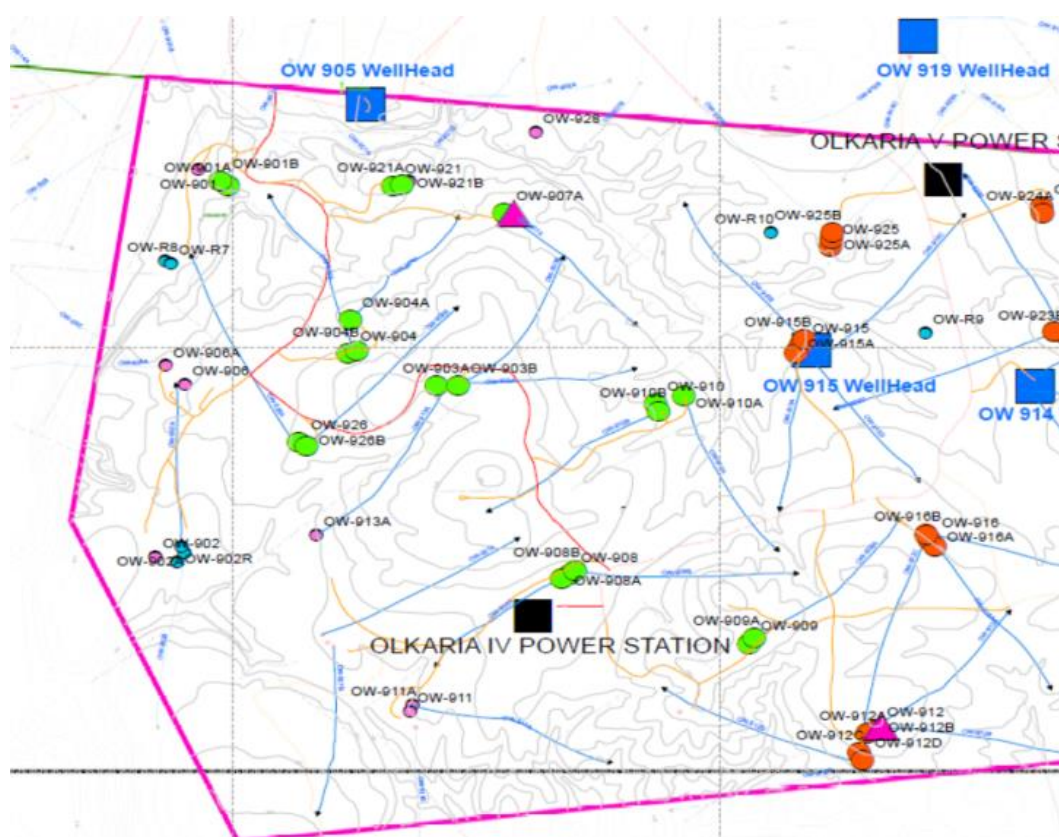


Figure 12. A map showing location of existing wells & power plants at the Olkaria Domes geothermal field.

3.1. The Study Area

The research was conducted in the Olkaria Domes Geothermal field in Kenya (Figure 12), spanning for 5 years from 2019 to 2023. The effects of both cold and hot reinjection

have been assessed since the Olkaria IV power plant was commissioned in 2014. The reinjection performance was correlated with reservoir pressure monitored vis-à-vis the enthalpy trends obtained from sampled wells within the Olkaria Domes geothermal field.

3.2. Production & Pressure Monitoring Data Collection Methods

Production & Pressure Monitoring Data was collected with the aim of evaluating variations in steam production across different wells, identify signs of cooling or dilution within the reservoir, analyze the impact of cold fluid incursion on geothermal performance and Provide recommendations for optimized reservoir management strategies

The data included flow tests (discharge testing), Pressure monitored data from the three pressure monitoring wells i.e. OW-907B, OW-912B and OW-917.

The data used were previously collected from secondary sources, including both pressure-monitored wells and discharge measured values, as well as production and steam flow data from Olkaria IV and the power plants, and the 4 Well-head generating stations situated within the Olkaria Domes geothermal field. Key geothermal production parameters were measured and analyzed, including; a) Wellhead Pressure (WHP), b) Steam and brine flow rates and c) Fluid enthalpy of the production wells. Data from discharge measurements were used to quantify the output (steam and brine flow rates) of production wells. During raw data processing and analysis, the wells production data were averaged annually and plotted against monitoring years to assess performance trends over time. Similarly, the pressure decline trends were analyzed to identify signs of reservoir cooling, dilution, or pressure drawdown within the Olkaria Domes geothermal field.

Thereafter, analysis of the data set was done (using Grapher software & excel) in order to establish reservoir response to production in relation to current steam being extracted from the Olkaria Domes reservoir in order to support the existing power plants. The effects of both hot and cold fluid reinjections were assessed using data since 2014, when the Olkaria IV (150 MWe) power plant was commissioned. The established re-injection performance was correlated with trends in reservoir pressure and enthalpy before final conclusion was derived.

3.2.1. Wells Flow Test Data

The flow rates (brine and steam) data for the wells used in this study are secondary data obtained from the power stations upon separation, just before steam is admitted to the power plant for power generation, between 2019 and 2023, during the field monitoring periods. Pressure monitoring data was obtained from the historical monitoring period between 2019 and 2024. To date, there is ongoing mass extraction from the Domes field. Thus, it is considered prudent for KenGen to optimize the resource sustainably to ensure sustainability is achieved in the long run.

3.2.2. Steam Status in the Olkaria Domes Geothermal Field

Advanced surface exploration was conducted in the early

1990s, which led to the drilling of 3 appraisal wells within the Olkaria Domes Field (ODF). The wells were drilled by the hired rigs from the Great Wall Drilling Company (GWDC). All three exploratory wells confirmed the presence of a sound geothermal system within the region, as they successfully initiated self-discharge during their opening for production testing purposes. Later, in 2010, a contract to drill 80 production wells capable of producing 280MWe was awarded to the GWDC. The 280MWe project was part of Olkaria IAU (140MWe), located in the Olkaria East field, and Olkaria IV (150MWe), located in the Olkaria Domes field. In 2019, Olkaria V's 170MWe (each unit producing 85MWe) was commissioned, thus adding additional power to the national grid. Both Olkaria IV and Olkaria V power plants are situated in the Olkaria Domes production field.

Production from wells connected to Olkaria Domes started in July 2014 when the first unit of the Olkaria IV power plant was commissioned. The wells were gradually added to the steam supply system, with the last being commissioned in 2016. Initially, the wells operated at low separator pressures (6-8 bar g). However, as of mid-2015, the pressure let-down system was commissioned, and the separator pressures were raised from 10-15 bar g to mitigate potential silica scaling. Currently, a total of 20 production wells are connected to the Olkaria IV power plant, continuing to supply steam for electric power generation.

Olkaria IV is designed with a condensate reinjection system that uses two wells, 902A and 902B. These two wells are alternated to each other and are therefore required to have the capacity to reinject 100% of the pumped condensate individually. However, in late 2022, brine re-injection into the two wells was stopped due to suspected corrosion, which is presumed to have affected the well casings, making them unsuitable for re-injection purposes.

Olkaria V power plant is the fifth power plant constructed by KenGen within the Greater Olkaria Geothermal Area (Figure 14). It is located within the Olkaria Domes Field, like its counterpart, the Olkaria IV power plant. The plant's construction began in late 2018 and was completed by November 2019. Its commissioning was executed in November 2019, thereby adding 172 MWe (2 units, each generating a total of 86 MWe) to the national grid. Currently, a total of 18 production wells are connected to the Olkaria V power plant. With the coming up of the Olkaria V power plant, some wells that were initially connected to separator SD3 of the Olkaria IV power plant were rerouted and replaced by wells OW-926, OW-901A, and OW-901B, separating in OW-921B separator and wells OW-926A and OW-926B separating at OW-926 separator. To maximize steam usage, an interconnection is in place that allows the production wells to supply both power plants (Olkaria IV and V) according to their respective steam requirements.

3.2.3. Olkaria Domes Wellhead Generating Stations

Wellhead stations refer to smaller geothermal plants, pri-

marily located near geothermal wells, directly at the well pads. The technology involves tapping steam from already drilled and tested wells, but it is currently waiting to be connected to the main power plants. They are designed to capture and convert geothermal steam directly from the wells into electricity, optimizing well potential and generating revenue early. KenGen therefore embarked on the execution of a wellhead plant as part of a research and development program, culminating in the successful implementation of two 5.5 MW and 2.4 MW plants in 2012 within the Olkaria and Eburru fields, respectively.

The first WHG plant in Olkaria was installed in the Olkaria East Field in 2011. The plant is generating a total of 5.0MWe. Following the successful realization of the two wellhead generators (one in Eburru in 2011 and another in Olkaria in 2012), KenGen recognized the need to construct additional units of this type. Between 2014 and 2015, KenGen commissioned four additional wellhead generating stations (i.e., OWs 905, 914, 915, and 919) at the Olkaria Domes field. By June 2017, a total of 16 wellhead generators were in operation within the greater Olkaria geothermal field.

Currently, 15 wells are connected to the re-injection system in the entire Olkaria Domes geothermal field, as illustrated in Table 2 below. The project was also designed to incorporate an online brine reinjection system, utilizing wells OW-901, OW-902, OW-906, OW-906A, OW-911, OW-911A, and OW-913A. This reinjection network consists of two streams, namely OWs-901/906/906A serving separator stations SD1 and SD4, and OWs-902/911/911A/913A serving separator

stations SD2 and SD3. The two streams are distinct but interconnected, offering redundancy. Figure 13 illustrates the initial injection capacity distribution for Olkaria IV's brine reinjection wells.

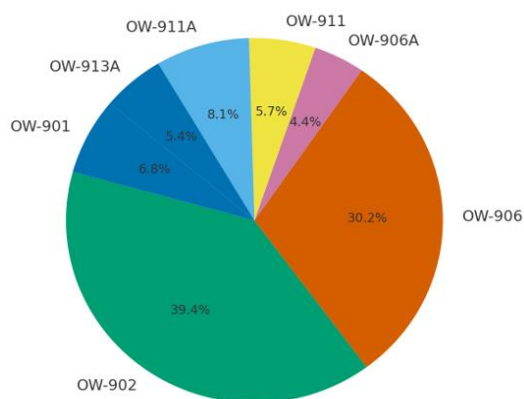


Figure 13. The initial injection capacity distribution for Olkaria IV brine reinjection wells.

3.2.4. Olkaria Domes Condensate Re-injection Summary

The Olkaria IV is designed with a condensate reinjection system that uses two wells, 902A and 902B. These two wells are alternatives to each other and are therefore required to be able to reinject 100% of the pumped condensate individually.

Table 1. General data on Olkaria IV's condensate reinjection wells.

Well	Elevation (m.a.s.l)	Drilled depth	Casing shoe	Initial injection	Estimate total flow
OW-902A	1954	2990	846	641	360
OW-902B	1954	3000	851	N/A	as OW-902A

3.2.5. Olkaria Domes Flow Monitoring, Mass & Enthalpy and Pressure Monitoring

Since the commissioning of the TFT equipment in 2017, individual well monitoring has been made possible, with all wells in production monitored at least twice annually. The average steam flow rates from separator stations SD2 and SD3 were also determined at least once in the monitoring period to help in checking the quality of the data obtained from the individual wells. Flow from SD1 separator was not determined due to inaccessibility during the monitoring periods under study.

The wells have demonstrated varied performance over the past four years. Wells OW-908, OW-910A, and OW-921

have had nearly constant steam flow since 2018. However, a significant increase in steam of over 10% is noted in wells OW-903B, OW-908B, OW-909A, and OW-910 in 2021, whereas wells OW-903A, OW-909B, and OW-921A showed significant steam decline. The steam in well OW-908A had dropped to 26t/hr from 40t/hr in 2020 but improved to 36t/hr in 2021. Most wells have experienced a significant decrease in brine content, with well OW-908A showing the most substantial decrease. This may be attributed to the effects of reinjection, which require further investigation. A few wells maintained the brine volumes or had a slight increase. These included wells OW-910A, OW-921, OW-909A, and OW-921A, which experienced a brine increase of approximately 13%. The enthalpy recorded seemed to have increased slightly, though ranging between 1200 and 2700kJ/kg, with

the west of the field around well OW-904B, OW-903B, and the central parts of the Domes, around well OW-908A, recording lower values. Wells OW-909s, OW-910s and

OW-912A recorded the highest enthalpies (Figures 14-17 below).

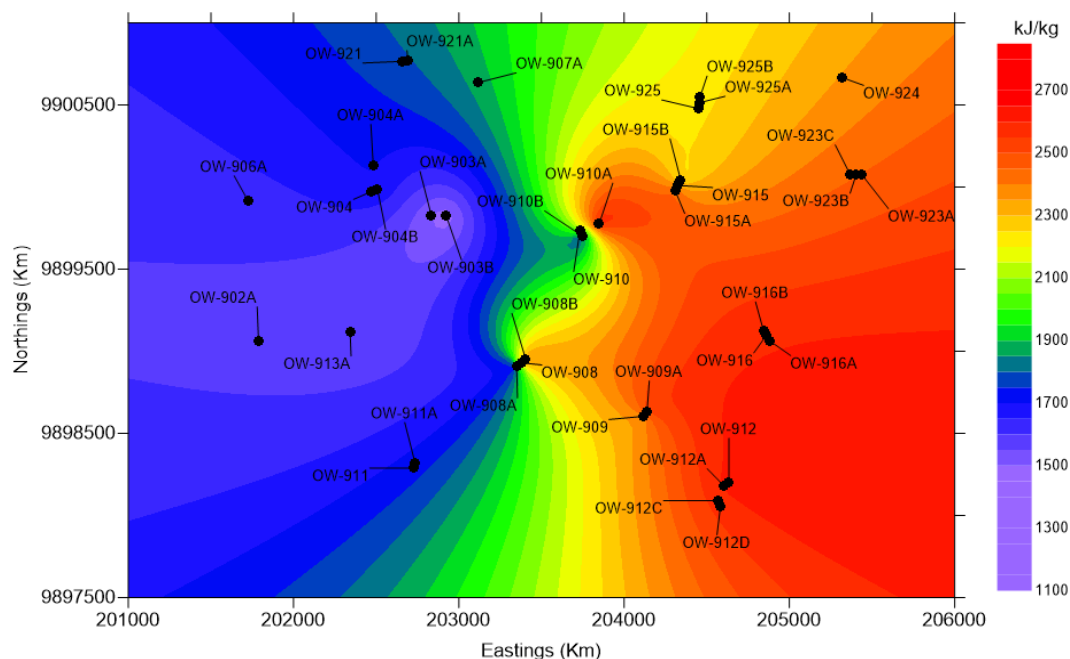


Figure 14. Olkaria Domes field 2019/2020 enthalpy distribution.

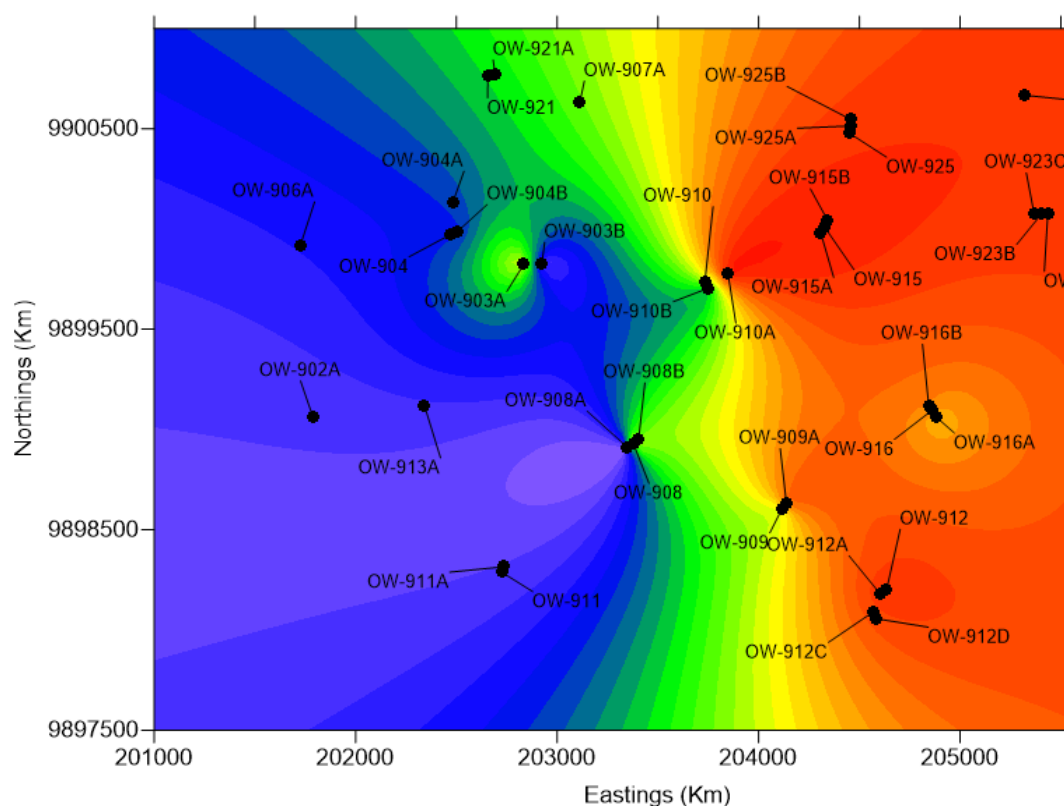


Figure 15. Olkaria Domes field 2020/2021 enthalpy distribution.

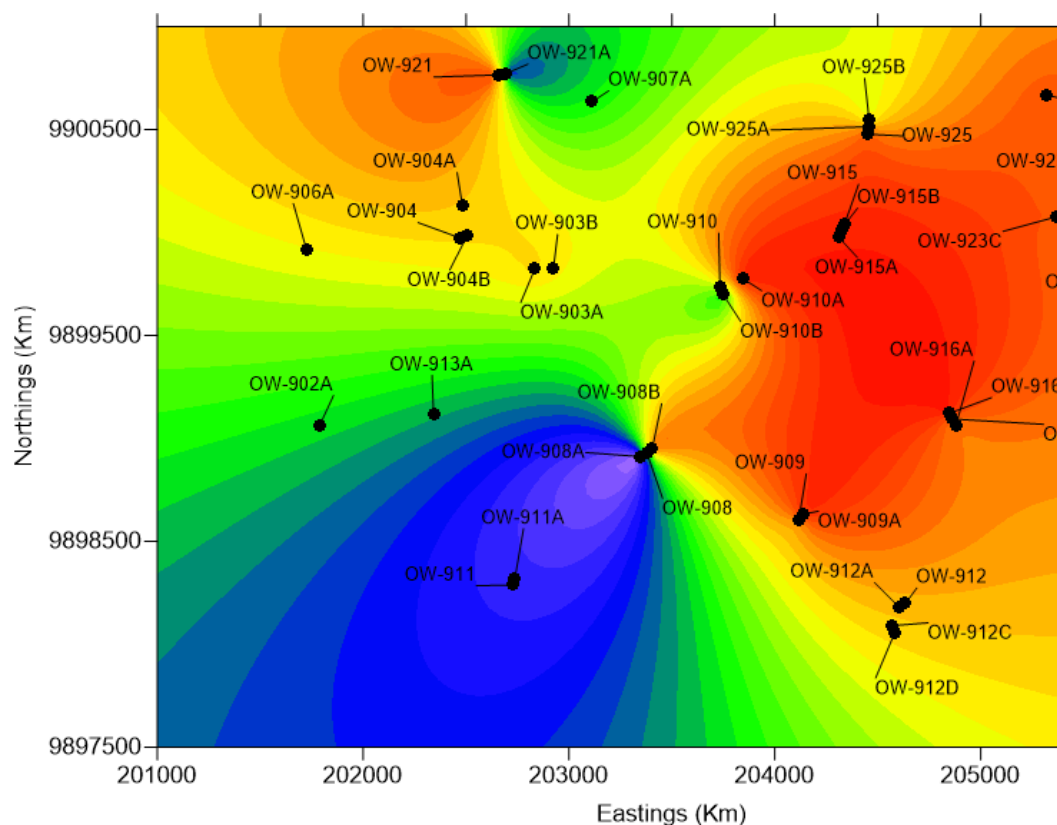


Figure 16. Olkaria Domes field 2021/2022 enthalpy distribution.

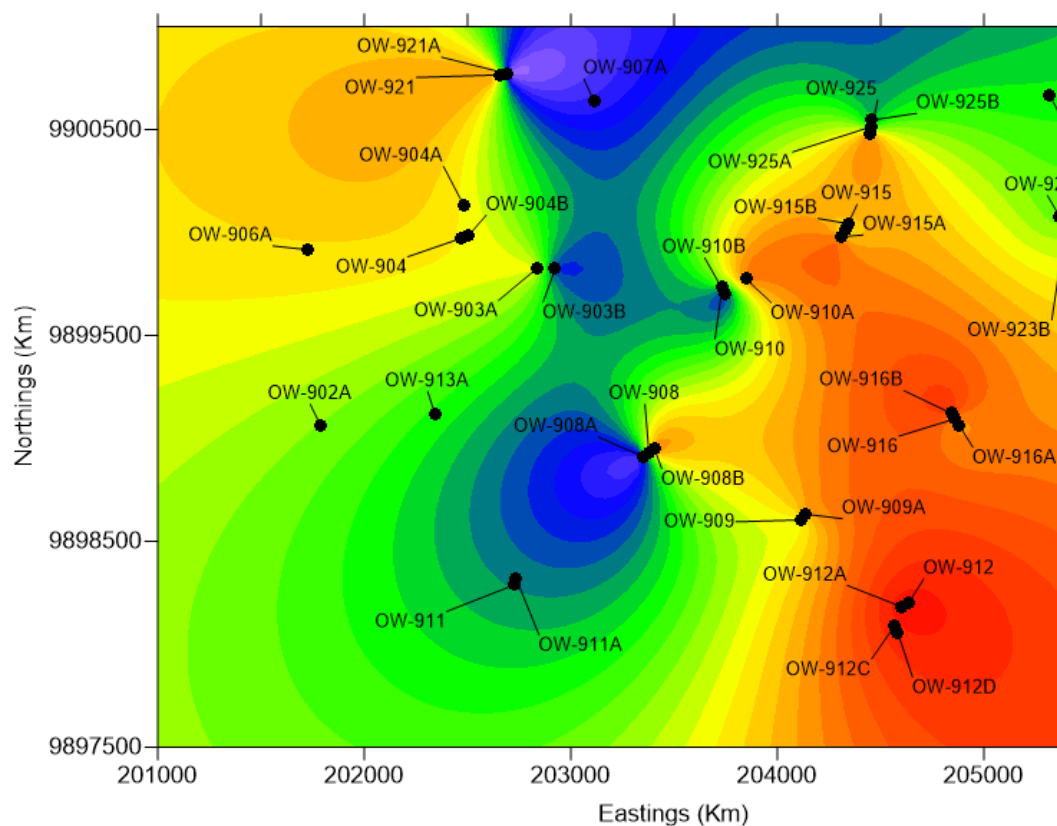


Figure 17. Olkaria Domes field 2022/2023 enthalpy distribution.

3.2.6. Downhole Pressure Monitoring for the 3 Observation Wells

Three wells (OW-917, OW-912B and OW-907B) were allocated as observation wells for this part of the field. Pressure monitoring is very critical in characterizing the geothermal reservoir response in Domes area to current production/ injection and develop future resource management strategies. With the recent commissioning of Olkaria V (2019)

power plant, and based on sustainability considerations, the importance of reservoir pressure monitoring cannot be overstated. Capillary tubing was installed in these observation wells to monitor pressure changes in the deep liquid reservoir continuously. Figure 18 below shows the location of pressure monitoring wells in the Olkaria Domes field (highlighted in green shade).

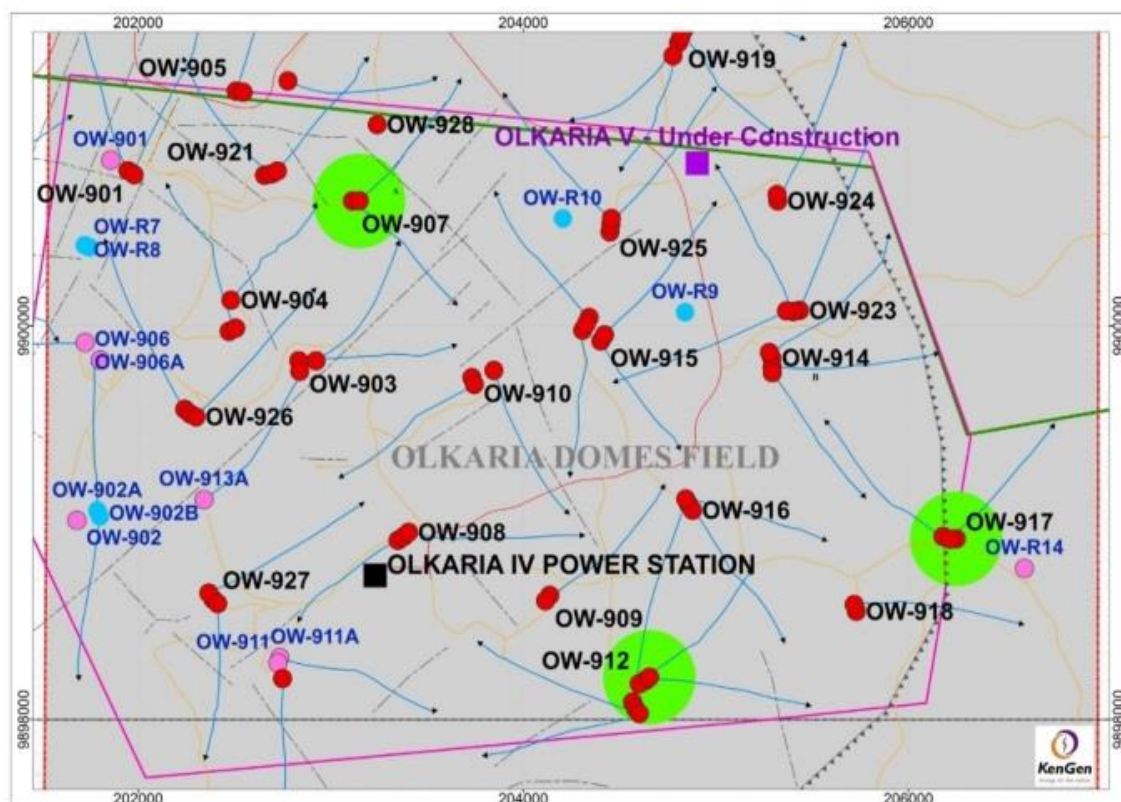


Figure 18. A map showing existing observation, production, and re-injection wells in the Olkaria Domes geothermal field.

4. Results & Discussions

4.1. Results

The deep reservoir pressure in well OW-912B declined from 132 bars to 117 bars between 2011 and 2015, which was an average decline of 3.75 bars per year. This was after the commissioning of the Olkaria IV power plant. The pressure recorded in 2018 was approximately 120 bars, which is slightly higher than the 2015 reading, indicating that the res-

ervoir pressure has now stabilized (Figure 19). In this monitoring period, a pressure increase is noted in OW-917. This is associated with effects of cold re-injection in the pad. Tracer measurement is thus required to check the fluid movement in the field in response to re-injected fluid to avert breakthroughs. OW-907B is located near OW-928, a new reinjection well that takes brine from wells supplying the Olkaria V power plant. Pressure increase in OW-907B is also believed to be from re-injection at OW-928.

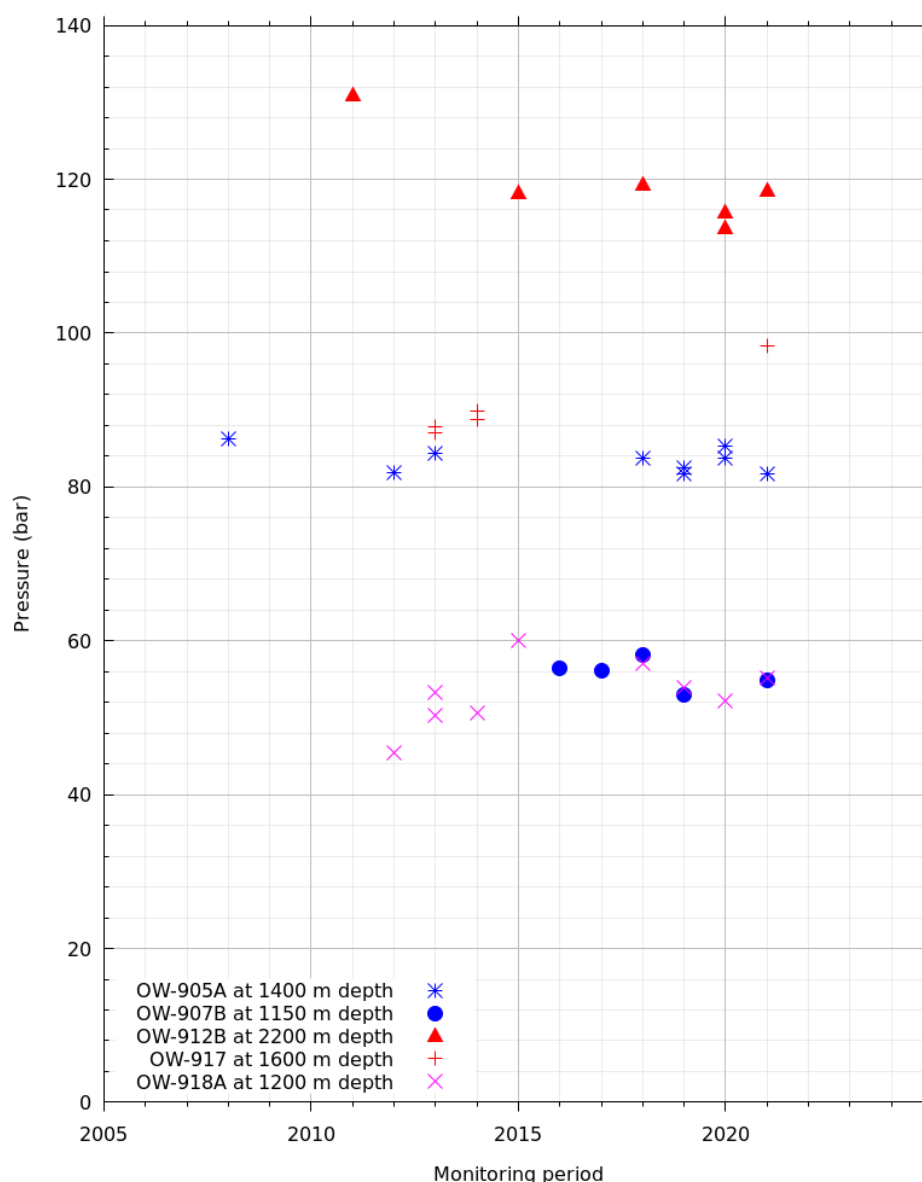


Figure 19. Observed pressure drawdown in the Olkaria Domes field.

Brine from Olkaria IV and all Olkaria V wells are connected with an online re-injection system in the Olkaria Domes production field. Brine and condensate from wells serving the four Wellhead plants in the Domes field are disposed of into sumps, from which they are then pumped into shallow reinjection wells within the field. Table 2 below shows the estimated brine and condensate output from the two big power plants as well as the wellhead generating stations in the Olkaria Domes field.

Figures 20 and 21 below illustrates the average steam production rates for the four years i.e., from 2019/2020, 2020/2021, 2021/2022, and 2022/2023 monitoring periods.

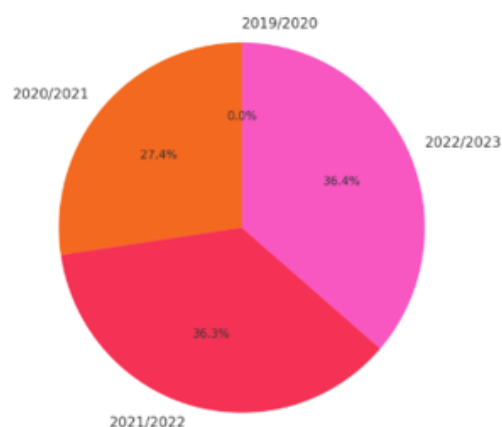


Figure 20. Steam production by well (in t/hr) across the four monitoring periods.

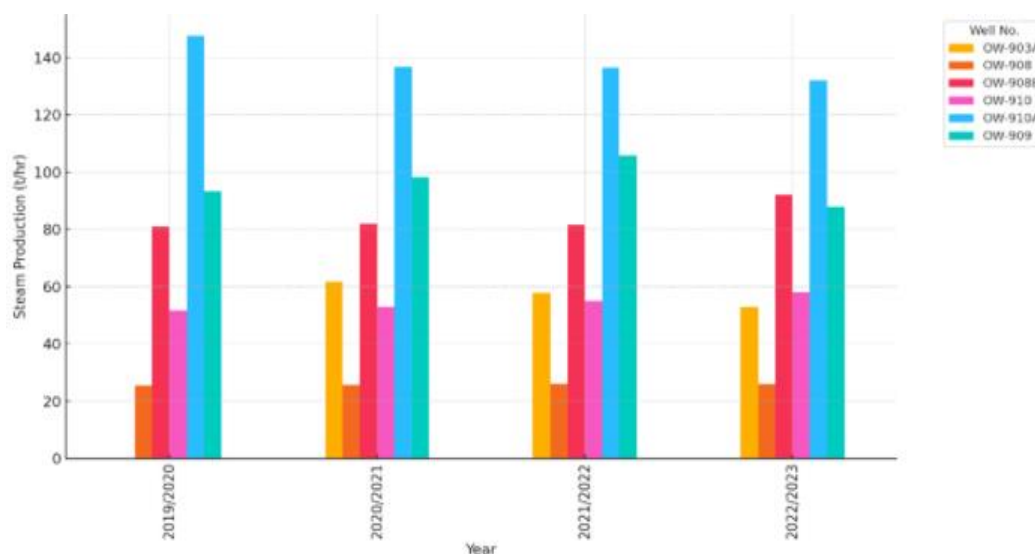


Figure 21. Steam production by well (in t/hr) across the four monitoring periods.

Table 2. Estimated Olkaria Domes brine and condensate output.

No.	Power plant	Brine in t/hr	Condensate in t/hr
1	Olkaria IV	800	360
2	Olkaria V	840	380
3	Wellheads	490	100
	Average	710	280

4.2. Discussion

The highest steam production rate was recorded during the initial monitoring period. However, a lack of enough data hindered a good comparison of the results obtained. On the contrary, there was a noticeable increase in steam production from the 2020/2021 to the 2021/2022 monitoring periods, indicating improved well/field performance.

The year 2020/2021 had the lowest steam production rate over the five-year monitoring period. However, the production rates for 2021/2022 and 2022/2023 were higher, with 2022/2023 being the highest among all during the relevant monitoring periods. There was also a general upward trend in steam production rate over the 5-year monitoring period, excluding the production rate for the initial monitoring period, i.e., the year 2019/2020.

Well, OW-910 constantly shows the highest steam output among all the other wells. This is attributed to its good permeability, having been drilled targeting the existence of fractures. Wells OW-908 & OW-909 also maintain strong production with some fluctuations. Well, OW-903A exhibits a gradual decline over the five-year monitoring period, while

wells OW-910 and OW-908 display relatively stable outputs during the study periods.

5. Conclusion and Recommendations

5.1. Conclusion

The following conclusions can be deduced for the steam status update within the monitoring period 2019-2023:

The WHP of all the wells has remained relatively constant in the recent monitoring periods. The wells had varied steam performance, with wells OW-908, OW-910A and OW-921 showing some stability, wells OW-903B and OW-909A showing a significant increase, whereas wells OW-909 and OW-921A showed some decline. Most Olkaria Domes wells had a significant decrease in their brine, with OW-908A showing the most considerable decrease. The average enthalpy for the entire Olkaria Domes field has remained within the range of 1,200 to 2,700 kJ/kg for the past four years. Pressure in monitoring wells is noted to have increased. This is attributed to the existing re-injection (both hot and cold re-injection) exercise in the vicinity.

5.2. Recommendations

- 1) Develop a detailed numerical model of the Olkaria Domes geothermal field. The model should be refined, recalibrated, and upgraded, and a time-dependent simulation should be performed to enhance model accuracy and viability.
- 2) Use of reservoir tracer flow testing (TFT) & interference test data to evaluate the impact of re-injection and siting of more usable re-injection wells at the Olkaria Domes field.
- 3) Conduct a fresh optimization study of the GOGA to enhance efficiency, sustainability, and economic viability of geothermal energy production while incorporating updated reservoir data, technological advancements, and day-to-day operational insights.
- 4) Utilization of Green Loop® technology to make use of previously unproductive and low-pressure wells in the Olkaria Domes Field.
- 5) Drilling of deeper wells and additional reservoirs to boost geothermal capacity, as well as balancing systems, reservoir pressure, thus enhancing resource sustainability within the Domes Field.

Abbreviations

GOGA	Greater Olkaria Geothermal Area
GWDC	Great Wall Drilling Company
KenGen	Kenya Electricity Generating Company
OW	Olkaria Well
TFT	Tracer Flow Testing

Conflicts of Interest

The authors declare no conflicts of interest.

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