Potential of Cascaded Use of Geothermal Energy to Uplift Fish Production in Kenyan Aquaculture

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ABSTRACT

Kenya's population in 2020 was 52m and projected to be 70m by 2033 thus raising demand for food by a factor of 10-15%. Currently, the Kenyan food basket relies on poultry and fish for white meat. The poultry is derived from small-scale farmers while the fish are obtained from Lake Victoria, Lake Naivasha, Lake Turkana and the Indian Ocean. Unfortunately, the lakes mentioned have longstanding challenges of overfishing and their fish production, 100,000MT/yr on average, has been declining over time. Lack of advanced fishing vessels in the Indian Ocean limits Kenyan ability to scrape up significant marine fish. In 2019, Kenyan aquaculture produced about 20,000MT of fish from artificial ponds at a backdrop of a countrywide annual demand of 700,000MT. Besides, the Kenyan fish industry faces additional challenges of limited cold-handling facilities for chilling the fish from the source to the markets since most fish production areas are off the grid. The traditional alternatives for cold storage systems in Kenya are fish-smoking and sun-drying which dehydrate the fish to lengthen the shelf life, compromising on taste and sanitation. This paper looks into the various ways injection of geothermal energy into aquaculture in Kenya could improve production. The paper also compares the competitiveness of geothermal energy to solar energy for suitability to powering aquaculture. As the direct utilization of geothermal energy is localized near the resource or in locations with significant geothermal gradients, the paper seeks to rank the best locations for energy boosted aquaculture in Kenya and those regions that are best suited for other renewable energy sources; solar, wind and biomass.

1. Introduction

Kenya is a majorly semi-arid country with a few rivers that originate from the forested mountainous regions bordering each side of the East African Rift (EAR). Some of the rivers flow into a series of lakes located on the floor of the East African Rift (EAR) while the others flow eastward into the Indian ocean and westward into Lake Victoria as shown in Figure 1. The main wild-catch fisheries in Kenya are Lakes Victoria, Turkana and Naivasha. Despite Kenya's 6% share of Lake Victoria, the lake is the principal freshwater wild-catch fishery providing the largest quantity of fish traded in the Kenyan markets. Some of the common species obtained from Lake Victoria are Tilapia, Nile Perch, African Catfish, Dagaa (Omena or Siver Cyprinid) among others(Outa et al., 2020).

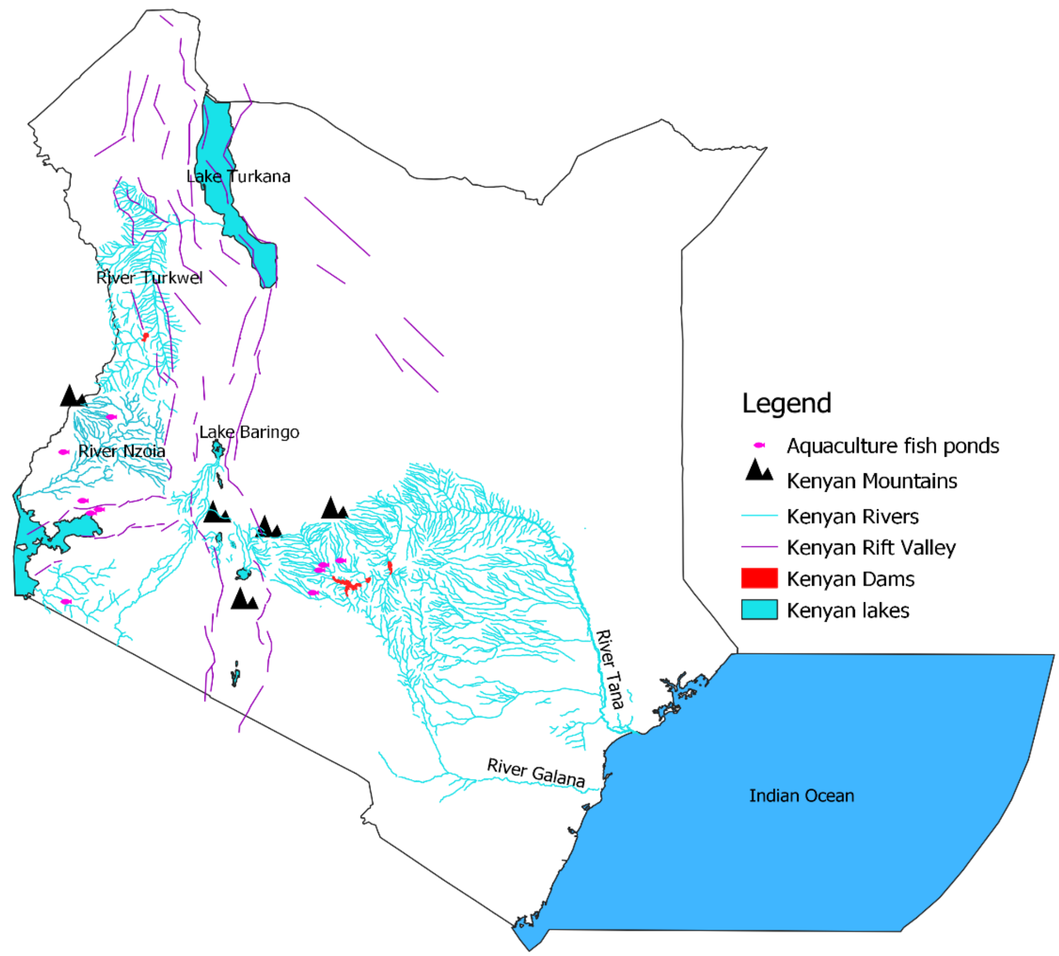

Figure 1: Main Kenyan fisheries

On the Kenyan side, Lake Victoria's fishing industry employs over 100,000 artisanal fishermen and many more associated traders of fish along the supply chain. The fishing industry is generally based on an informal platform where fishermen using wooden boats propelled by wooden oars or sails use nets to catch fish from the lake, mostly in the wee hours of the morning. After a day's catch, the fishermen sell their fish to the small-scale traders/processors (mostly women) by the landing site who coalesce the catch to bigger quantities for wholesalers(Kariuki, 2011).

Unfortunately, the wild capture of fish from Lake Victoria is experiencing a myriad of challenges resulting in a rapid decline of the quantity of fishery in recent years. Among the major environmental challenges facing East African lakes, pollution from plastics, residues of chemical fertilizers and pesticides, a proliferation of water hyacinth, overfishing, siltation as well as prolonged droughts hinder sustainable utilization of their biodiversity. The deteriorating status of Kenyan lakes is equitable to future loss of livelihoods and more dependency on the importation of fish. Figures 2 (a) and (b) show that there is a general trend of the quantity of wild catch obtained from Lake Victoria over the last 10 years prompting for diversification to aquaculture and other a more sustainable water management approach to fish culture.

(a)

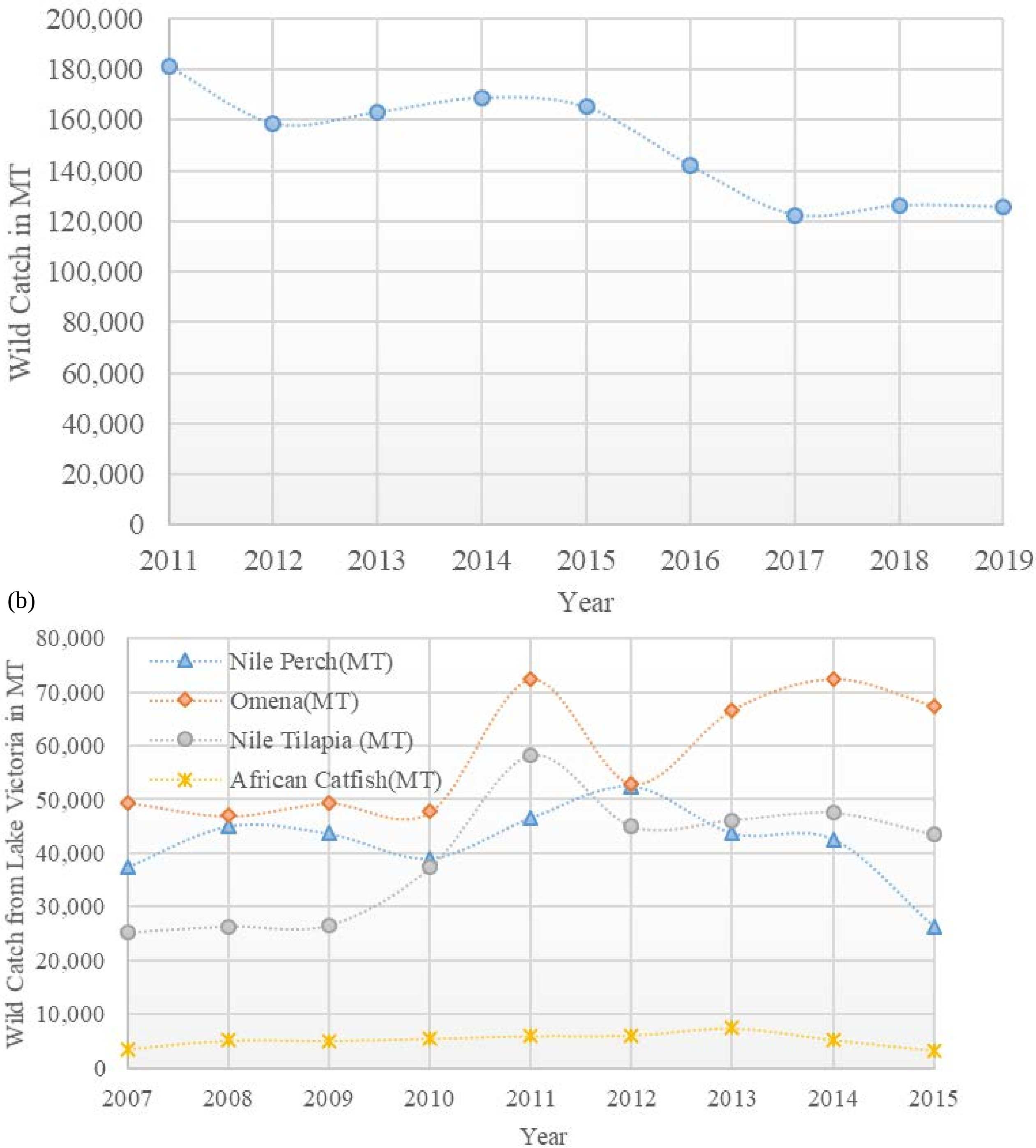

Figure 2: Wild fish capture from Lake Victoria on the Kenyan side

Developing aquaculture provides a suitable chance to relieve pressure on available wild fish stocks in most natural water bodies(Walakira et al., 2012). The Kenyan aquaculture industry has thrived encouragingly well in the last decade by improving production from 4895MT in 2009 to a peak of 24096MT in 2014, Figure 3. This accelerated growth was in response to a $16 million Economic Stimulus Program in Aquaculture initiated by the Kenyan government in 2009 aimed at increasing the country's fish ponds from then 7,500 to 48,000. At the same time, the hatcheries increased from 21 to 152 to meet the demand for fingerlings. However, laxity in implementation of the program saw production fall to 12,356MT in 2017 though the industry has weathered the storm and in an upward trend again since 2017. The industry has also overcome resistance to farmed fishes and the markets are now ready for both wild and cultured fish. The two most cultivated fish species are Nile Tilapia and African Catfish.

Figure 3: Unique flowers cultivated at Oserian Development Company

1.2 Aquaculture practices in Kenya

Kenyan aquaculture is semi-intensive mainly composed of earthen ponds with or without PVC paper lining. A few farms use concrete, plastic, or collapsible tanks while others use cages anchored in natural water bodies such as lakes and rivers to keep fish from escaping. The majority of fishponds in Kenya are earthen types due to their low capital requirement and little maintenance. Despite their popularity in Kenya, earthen ponds are difficult to clean and regulate water temperatures and suffer from loss of water due to downward percolation. They also allow African Catfish to burrow in the mud during harvesting and if they are unprotected by nets, the small animals or birds that prey on fish contribute to reduced fish production.

To limit downward water loss and discourage weeds from growing within the pond, PVC lining is applied along the floor and sidewalls of the pond. The fingering hatcheries use recirculating systems on concrete or plastic ponds. The fish species mostly farmed are Tilapia (69.9%), followed by African Catfish (21%), Common carp (8%) and Trout (1%)(Manyala, 2011). Tilapia is the most preferred culture species due to faster growth, disease resistance and ability to withstand low dissolved oxygen levels (KMFRI 2020).

The African lungfish are particularly advantageous to farm since their ability to breathe air makes them resilient to drought and stressful water quality conditions. In addition, their nature of feeding on mollusks, small fishes, crustaceans and plant materials make them easy and affordable to feed on locally available food materials (Walakira et al., 2012). Their behavior of aestivating in the mud burrows allows the species to survive pond cleaning thus cutting down on fingering re-introduction. Unfortunately, the quantity of African lungfish farmed in Kenya currently is very small though most African lungfish are hunted/fished from their natural habits in rivers, tributaries, marshes, and swamps(KEMFRI, 2017). The number of African lungfish traded in Kenya is marginal compared to the quantity traded in Uganda where this species of fish has found a market niche(Walakira et al., 2012).

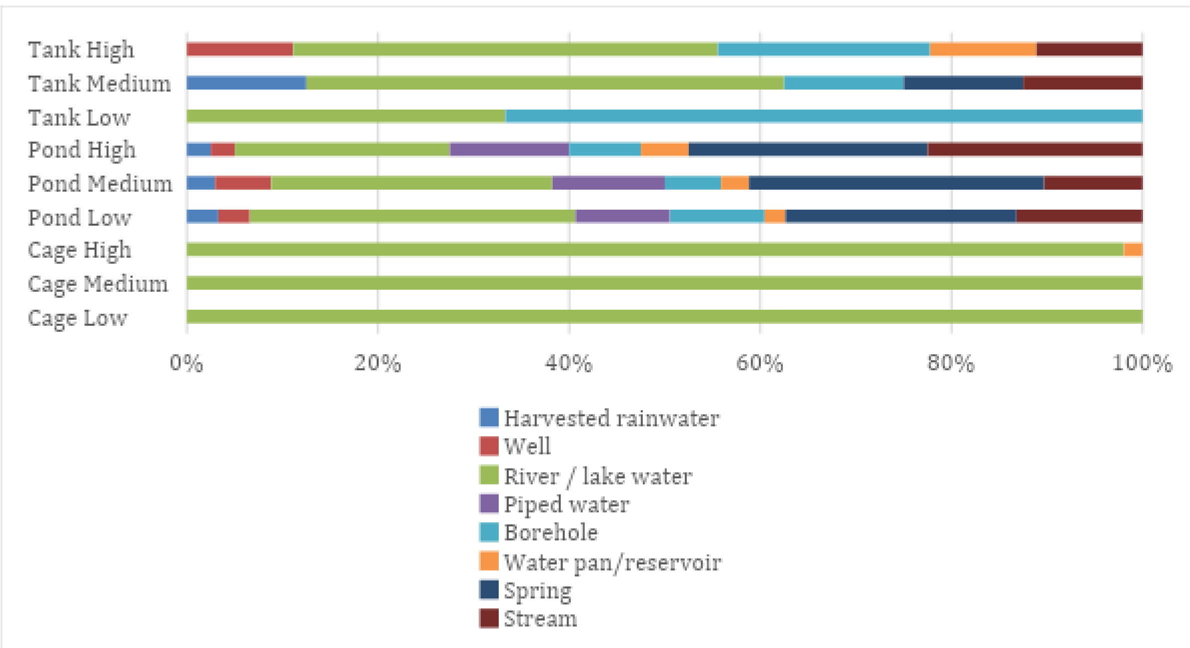

Figure 4:Water sources for Kenyan aquaculture (Obwanga et al., 2020)

As Kenya is categorized as a water-stressed country, Figure 4 shows the source of water used for different types of aquaculture activities in Kenya. The rivers and lakes continue to support Kenyan aquaculture though underground reservoirs and spring waters are following closely behind by percentage.

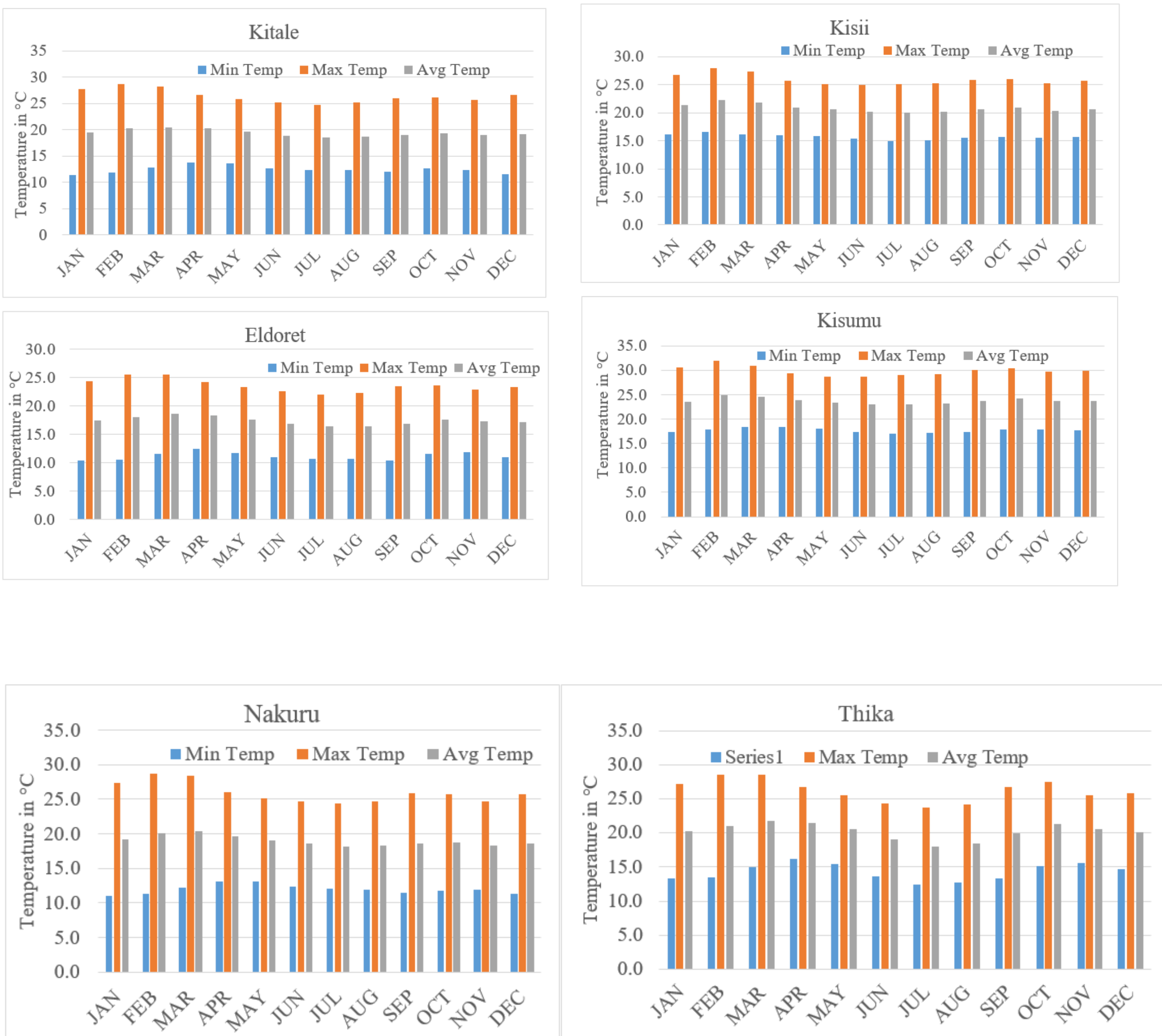

Figure 5: Averaged monthly temperatures of major farming regions in Kenya since 2000-2019.

1.3 Kenyan aquaculture and geothermal energy

Kenya is well endowed with high potential geothermal resources located along the East African Rift. Some geothermal fields and prospects are located within or close to natural wild catch water bodies such as Lakes Naivasha, Baringo, Turkana as well as Lake Victoria. The regions that practice aquaculture in Kenya by percentage are Western 26%, Central 21%, Nyanza 21%, Rift Valley 20%, Eastern 9% and Coast 3%. From Figure 4, Central, Western and Rift Valley regions have average temperatures of 18-20°C and minimum temperatures of 10-15°C. Kenyan central highlands and central parts of Kenyan Rift Valley experience the lowest night temperatures of 8-10°C, especially from June to August, thus rendering them inefficient for outside open ponds aquaculture due to the long periods of fish growth required(Obwanga et al., 2020). Unfortunately, almost 50% of aquaculture activities are carried out in these regions since they have rivers, springs and surface runoff as a source of water. Currently, these regions, Figure 5, have one fish growing season lasting from November to April in unheated aquaculture systems.

As water temperatures control metabolic rates of fish, it is crucial to control pond water temperatures to maximize the conversion of food to growth. For Nile Tilapia and Catfish, the optimal pond water temperatures are 27-29°C; below which fish growth is reduced and above which fish waste energy(Land O'Lakes, 2013). Among the regions that practice aquaculture in Kenya, Nyanza is best suited for non-heated outdoor ponds while Rift Valley, Central and Western Kenya need a temperature-controlled environment for improved growth, especially at night and more so in June, July and August when minimum temperatures drop to 10°C. Generally, for open outdoor ponds in Kenya, Nile tilapia take 12-14 months to develop from fingerlings to 1kg adult fish. Geothermal heating has the potential to reduce the growth period from fingerlings to 1kg adult fish in 6 months or provide two growing seasons per year(Land O'Lakes, 2013). The report done on feasibility studies of collocating aquaculture facilities with geothermal resources found out that the geothermally heated increases the total investment cost by 33% but double total revenues(Land O'Lakes, 2013).

For Kenyan geothermal heated aquaculture systems to operate economically, it is strategic to collocate them downstream of available geothermal projects such as power plants or heated greenhouses to reduce the overall cost of heating infrastructure and well drilling. Since Kenya has many warm and hot springs, Figure 6, most of which have near-neutral immature bicarbonate waters, the aquaculture systems could be located downstream of hot springs to save on pumping and aeration costs.

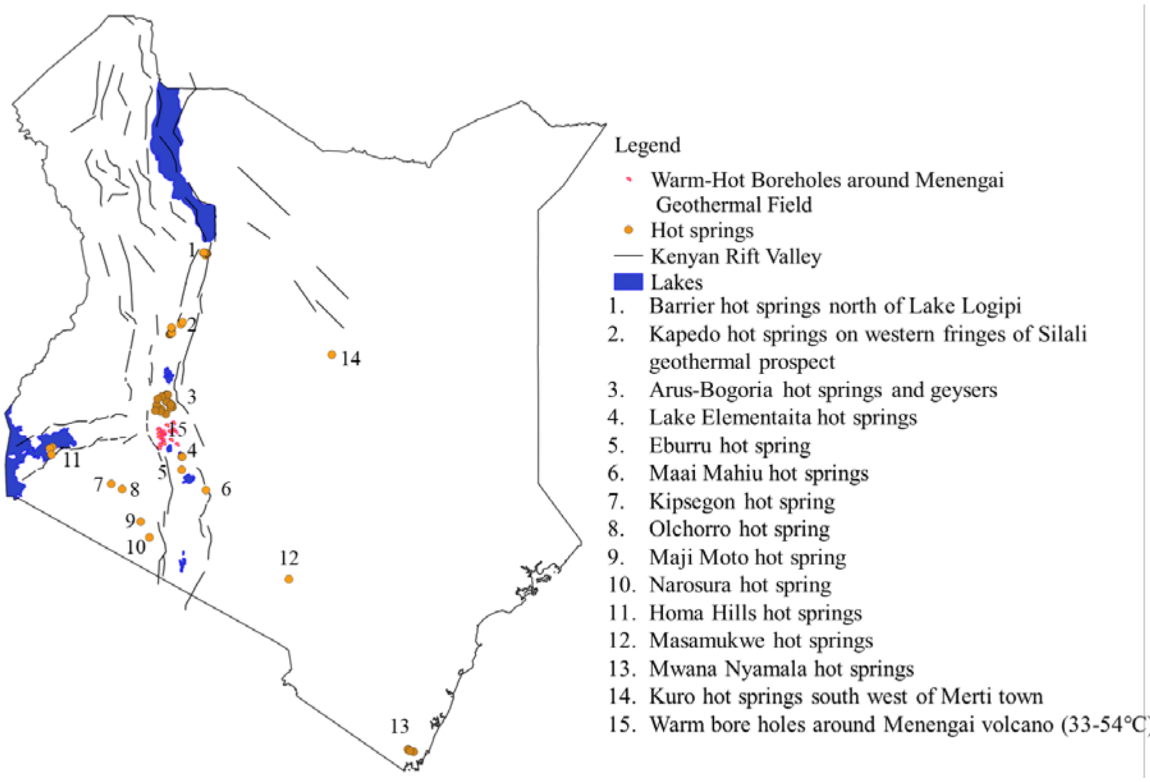

Figure 6: Low enthalpy geothermal resources characterized by warm or hot springs

Currently, only one pilot project for geothermally heated fish ponds exists in Kenya at Menengai geothermal field where two ponds measuring 6m x 5m x 1m are used to culture Nile Tilapia. They are housed in a transparent PVC greenhouse for ease in temperature control and to keep away fish predators, Figure 7.

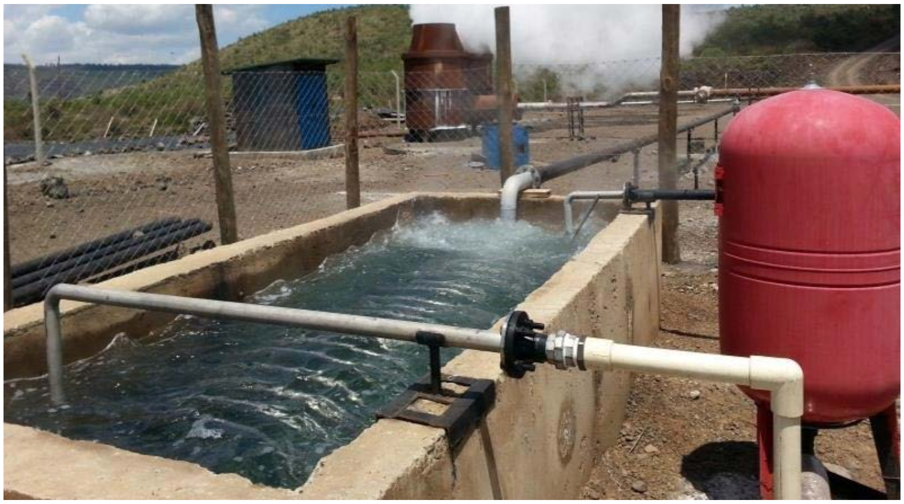

Figure 7: Heat exchanger at well MW_03

Well MW-03 produces 20t/h of steam and 40t/h of brine at a wellhead pressure of 1.5bara. The brine is passed through an open heat exchanger, Figure 6, where cold water is heated to 80°C for cascaded direct use from milk pasteurization to greenhouse warming and eventually to the two pilot project fish ponds at 28°C.

Figure 8: Geothermally heated fish ponds at GDC Kenya growing tilapia

1.4 Energy requirement for optimal operation of fish pond

Semi-intensive and intensive pond fish culture requires energy in feeding (food production and distribution), aeration, pumping energy for water exchange and thermal energy for heating the ponds. Concentrating on Tilapia and Catfish culturing, the energy requirements are dependent on the system being employed. Intensive or semi-intensive practiced on ponds or tanks grown require different energy requirements which is a bit higher compared to caged systems anchored either on rivers or lakes. According to a 2015 report by the Food and Agricultural Organization of the United Nations, 80% of energy is employed to generate and distribute fish feeds, with feeds for tilapia requiring 3.5 times more energy than that for Catfish. However, Catfish requires more energy for aeration(4kW/ha) compared to Tilapia fish(0.75kW/ha)(Muir, 2015).

Kenya receives high insolation throughout the year (4-6kWh/day/m^2 on average) and installation of solar PV panels would take care of pumping and aeration energy requirements in areas that are off the grid. The caged and flow-through systems require less energy in terms of aeration and water exchange pumping. However, intensive recirculation systems such as hatcheries require more energy inputs than all the rest.

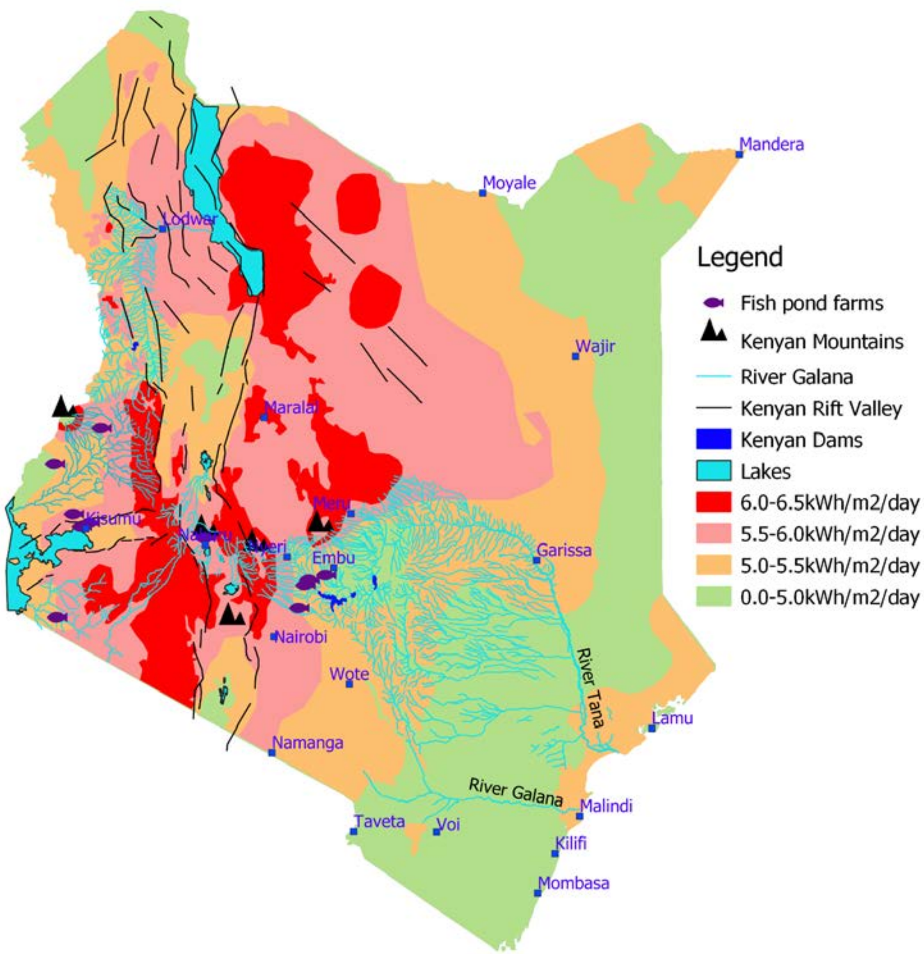

Figure 9: A map of solar intensity distribution with relation to fish farm.

In addition, the harvested fish require cold storage and drying before being transported to the market. Luckily for Kenyan fish farmers, the demand is so high most fish is sold by the farm-gate and little consideration is given to drying and storage.

2.0 Linking geothermal energy to the pond fish farms

Kenya has several geothermal fields scattered along the Kenyan part of the East African Rift. So far three fields, Olkaria, Menengai and Eburru, have been developed for the production of electricity. Paka and Korosi are undergoing advanced exploration with three exploration wells already drilled. The remaining prospects are at different stages of exploration depending on their favorability to provide steam at reduced risks, (Figure 10).

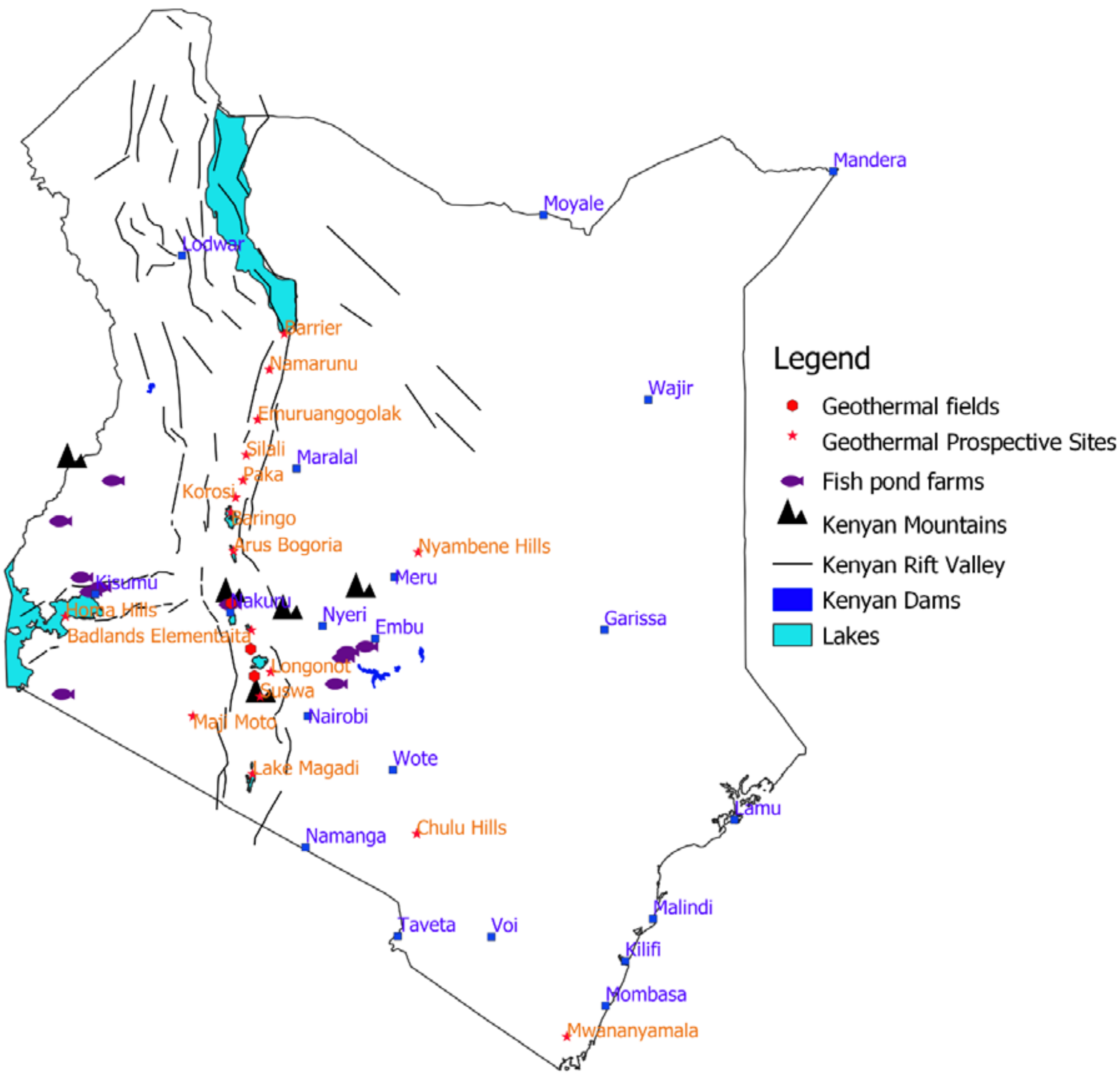

Figure 10: Location of geothermal resources with respect to water bodies

Several geothermal fields and prospects are located close to or within water bodies. Barrier prospect at the southern tip of Lake Turkana, Kikopey hot springs at the southern tip of Lake Elementaita, hot springs around Lake Bogoria as well as the geothermal rich island within Lake Bogoria present good locations of geothermally heated caged aquaculture for both food and tourism fishing as shown in Figure 11. In addition, the proximity of Homa Hills prospect to Lake Victoria and Olkaria geothermal field to Lake Naivasha present a chance of geothermally heated fish ponds within those locations. Currently, the Olkaria field produces more than 4500 t/hr of brine and some so it, especially from wellhead units, is not re-injected but dumped into shallow ponds. This wasted brine could be passed through a heat exchanger and the heated freshwater be piped to nearby farms.

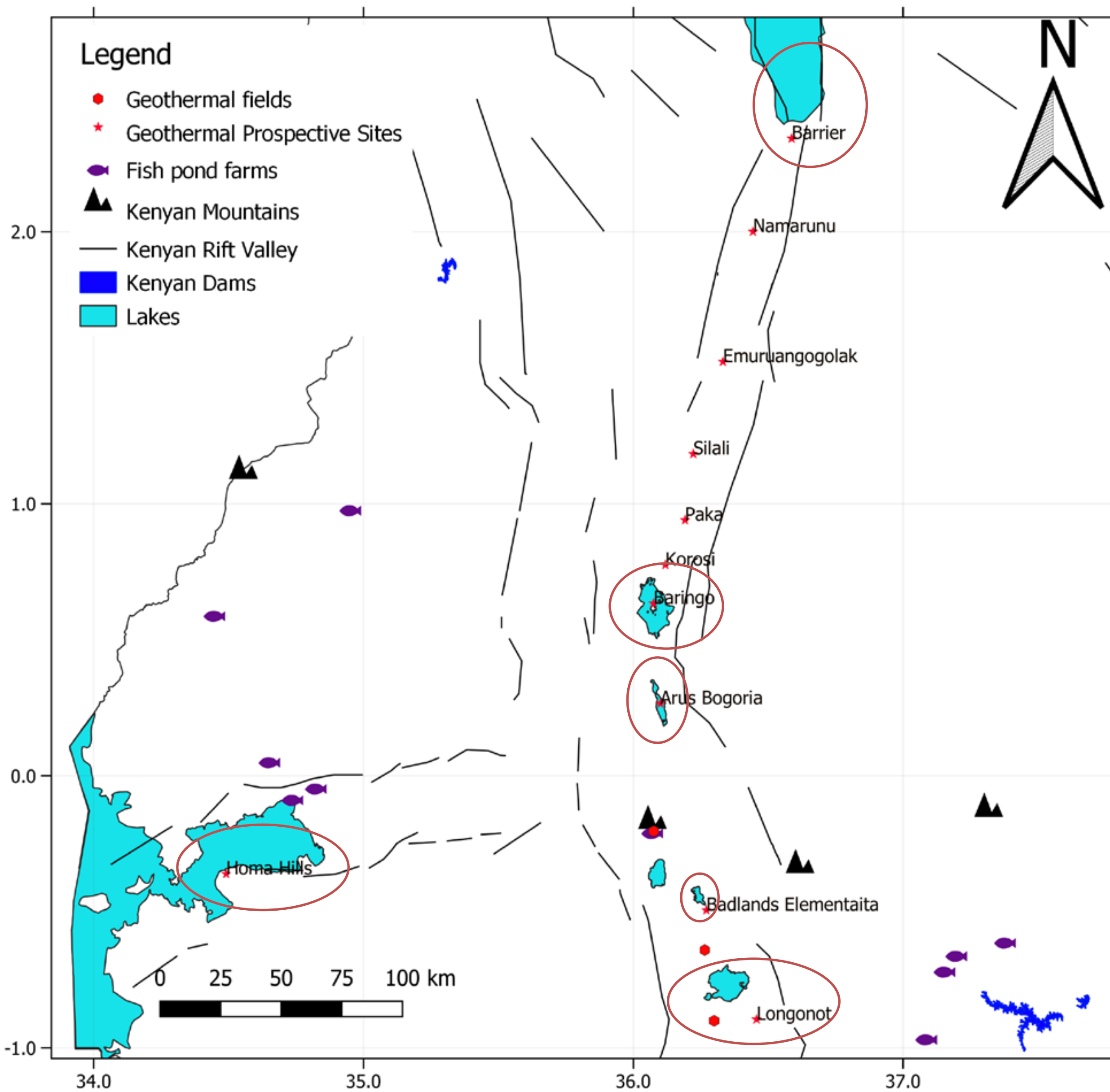

Figure 11: Geothermal resources located within the vicinity of water bodies

Besides, geothermal resources are not just limited to heating ponds, fish drying and processing is another major factor leading to postharvest losses. The losses are dire for dagaa (omena) up to 30% and tilapia up to 10%. Once processed, the fish products require cold rooms for storage. Geothermally powered chillers are more economical to operate and when coupled with PV panels, their operational costs reduce significantly(Ngethe and Jalilinasrabady, 2021).

Cascaded use of geothermal fluids allows heat to flow from high energy demand processes to less energy-demanding processes. In this case, the cascaded use should flow from the absorption chiller to the drier and finally to the pond heating. At the same time, hot water will always be available for disinfecting equipment used to handle the fish.

3.0 Conclusion

Though this is ongoing research and the numerical details are not profoundly brought out, it is clear that most regions within the Kenyan rift valley could improve their production from the injection of geothermal energy. The best locations for geothermally heated fish ponds are regions close to Homa Hills prospect, Olkaria and Menengai geothermal fields and downstream of many warm to hot springs dotted all over the country. The best locations for geothermally heated caged fish culture are Lakes Baringo, Elementaita and Bogoria. Lake Turkana’s water is generally warm at 25-30°C throughout the year hence doesn’t require heating. Collocating of geothermally heated fish ponds to existing geothermal energy utilization projects such as power plants will greatly lower the initial costs required to drill wells and install fluid pipings. Currently, Kenya relies on one growing season per year which could be halved by heating the fish ponds using geothermal energy.

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