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# Aquaculture in Hydropower Reservoirs

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## ABSTRACT

*There is an undoubtedly existing relationship between water, energy, and food and their interaction with the natural environment and mankind. Climate change is the talk of the day in global development discussions as it intensifies water shortages, energy, poverty, food shortages, and environmental degradation. Currently, most of the hydropower dams constructed in Africa are majorly built to store water for agricultural purposes, control flooding, and generate electricity. Notable projects include the seven forks hydropower stations located on the Tana River in Kenya; Aswan high dam in Egypt; Grand Renaissance dam in Ethiopia; Kariba dam in Zimbabwe and Akosombo in Ghana. Since agriculture is the major source of livelihood in Africa, the construction of dams is key for socio-economic development. Many countries in Africa have adopted crop farming and livestock farming but have neglected fish farming. Fish farming is mainly carried out in the natural water resources which highly makes it to be at risk within a climate change ecosystem. Climate change has led to the high and low fluctuation of water levels in the natural water bodies. This highly affects fish farming negatively and has led to the extinction of some fish species. To curb the problems faced by fish farming arising from climate change there is a need to create mitigation measures to ensure an adequate supply of fish in Africa. One of the mitigation measures is incorporating caged aquaculture in hydropower dams. Having caged fish farming will not only increase the fish supply but also increase income generation and food security across Africa. The paper followed a desktop research approach and provide detailed analysis of the relations between the availability of water, energy, and food in regard to fish production. A proposed conceptual framework for caged aquaculture systems was presented in this study as a means of promoting sustainability in food and agricultural production. The study further provided feasible climate-friendly food systems and blue justice approaches that can be adopted by the key stakeholders.*

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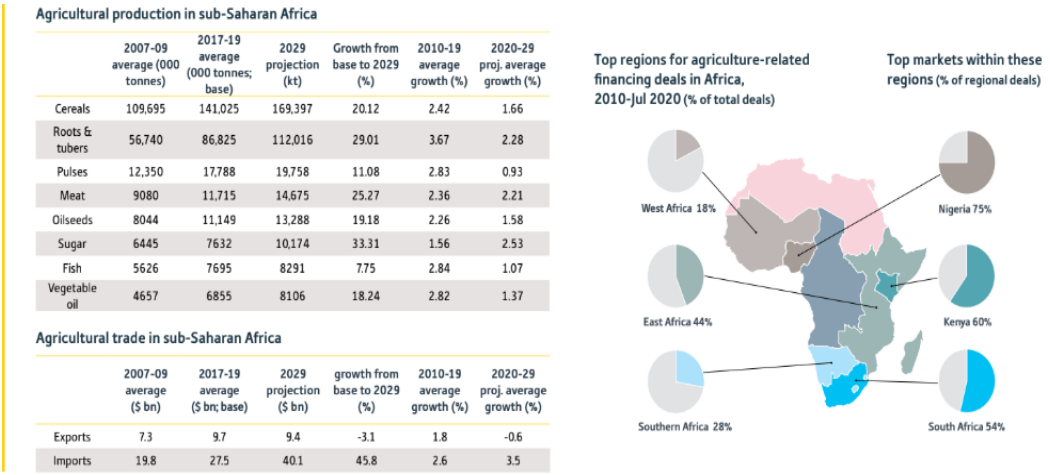
## INTRODUCTION

Africa is home to 60% world's arable land with the potential to meet both its needs and the rest of the world's needs (Popp et al., 2019). The agricultural sector remains to be the most valuable economic sector in the continent contributing about 14% of sub-Saharan Africa's GDP (OECD/FAO,

2020). According to the data collected by World Economic Forum on Africa, 70% of Africans depend on agriculture for their livelihoods. Agriculture in Africa involves crops, livestock, and fish farming. Crop farming accounts for 75% of agriculture with corn, wheat, and rice being the major crops. On the other hand, livestock and fish farming account for 25% of agricultural production which clearly shows the abandonment of the two sectors (OECD/FAO, 2020). Figure 1 below shows the agricultural production in Sub-Saharan Africa from 2007 to 2019 and its projection growth rate between 2020-2029. From the statistics above, it is clear that the fish production is still lagging behind in comparison to other agricultural produce.



Agricultural production in sub-Saharan Africa

| | 2007-09 average (000 tonnes) | 2017-19 average (000 tonnes; base) | 2029 projection (kt) | Growth from base to 2029 (%) | 2010-19 average growth (%) | 2020-29 proj. average growth (%) |
|---|---|---|---|---|---|---|
| Cereals | 109,695 | 141,025 | 169,397 | 20.12 | 2.42 | 1.66 |
| Roots & tubers | 56,740 | 86,825 | 112,016 | 29.01 | 3.67 | 2.28 |
| Pulses | 12,350 | 17,788 | 19,758 | 11.08 | 2.83 | 0.93 |
| Meat | 9080 | 11,715 | 14,675 | 25.27 | 2.36 | 2.21 |
| Oilseeds | 8044 | 11,149 | 13,288 | 19.18 | 2.26 | 1.58 |
| Sugar | 6445 | 7632 | 10,174 | 33.31 | 1.56 | 2.53 |
| Fish | 5626 | 7695 | 8291 | 7.75 | 2.84 | 1.07 |
| Vegetable oil | 4657 | 6855 | 8106 | 18.24 | 2.82 | 1.37 |

Agricultural trade in sub-Saharan Africa

| | 2007-09 average ($ bn) | 2017-19 average ($ bn; base) | 2029 projection ($ bn) | growth from base to 2029 (%) | 2010-19 average growth (%) | 2020-29 proj. average growth (%) |
|---|---|---|---|---|---|---|
| Exports | 7.3 | 9.7 | 9.4 | -3.1 | 1.8 | -0.6 |
| Imports | 19.8 | 27.5 | 40.1 | 45.8 | 2.6 | 3.5 |



**Figure 1: Agricultural production in Sub-Saharan Africa.**

Fish farming is an important sector as it is highly considered for raising nutrition and self-sufficiency. The majority of fish produced in Africa is caught from the natural freshwater lakes such as Lake Victoria which is the major fish source for Kenya, Uganda, and Tanzania (Sutandar Zainal, n.d.). However, Sub-Saharan Africa is only contributing 1% of the total global fish production with 90% of the fish consumed in Africa being imported from Asia(OECD/FAO, 2020). Africa has been experiencing seafood deficiency with the deficiency increasing by 13% every year since 2001 (Satia, 2011). The major challenges contributing to low fish production include illegal fishing, overfishing, lake, and ponds siltation, inadequate water in the ponds and lakes during droughts, flooding of water resources, poor lake and ponds maintenance, inadequate and low-quality fish feeds, and lack of good quality fingerlings (Tweddle et al., 2015). The major problems experienced by fish farming are highly attributed to climate change which is rapidly increasing across the world(Downing et al., 2014). There is an urgent need to mitigate and curb the impacts of climate change on fish farming through the adoption of new techniques and technology. Research has shown that increasing farmed fish production will not only provide enough fish for the continent but also will increase the continent's GDP (Kobayashi et al., 2015). Generally, the overall growth of the agricultural sector is the center of reduced poverty levels, industrialization, food security, intra-African trade, and also bolstering the global trade between Africa and the rest of the world (Desiere et al., 2018).

## HISTORY OF AQUACULTURE

To increase fish production both in Africa and in the rest of the world, aquaculture has been adopted(Kobayashi et al., 2015). Aquaculture is the breeding, rearing, and harvesting of fish, aquatic plants, shellfish, and other organisms in freshwater and marine environments(Brummett et al.,

2008). As pinpointed by FAO (2018), aquaculture was first introduced in Africa in the 20th Century with the main of satisfying colonial recreational fishing needs. Later on, between the 1940s and 1950s aquaculture was introduced as a means of sustainable food production to improve livelihood in rural areas through the provision of protein food, employment creation, supplementing income generation, and farming diversification to reduce the risks of crop failure(Kobayashi et al., 2015). Aquaculture began in Africa with about 300,000 active production ponds on the entire continent(Satia, 2011). However, despite aquaculture being introduced long ago, the industry hasn't grown (FAO, 2018).

According to FAO (2020), the African continent's contribution to the world's total aquaculture production is 2.7% which is significantly low. Research shows that out of the 54 countries in Africa only Ghana, Nigeria, Uganda and Egypt have substantial quantities of fish production (Adeleke et al., 2020). About 99% of the fish produced in Africa is from the inland freshwater ecosystem with tilapia and African catfish being the dominant `indigenous and abundant species. Over time new aquaculture systems have been introduced in Africa such as the use of tanks on land and the use of cages in marine and lakes (Brummett et al., 2008). According to OECD-FAO Agricultural Outlook 2020-2029 report, by 2020 6.2million people in Africa were employees in the aquaculture sector. The sector has shown a high potential for significant contribution to increased food security, creating employment, and economic growth (OECD/FAO, 2020),(Kobayashi et al., 2015).

## METHODS AND MATERIALS

### Description of the study area

In order to achieve the objectives of the study as far as cage fish farming is concerned, the research was carried for the East Africa region. The region is among 5 regional socio-economic and political blocks in Africa (Chemelil, 2016). East Africa normally refers to countries such as Kenya, Tanzania, Uganda, Rwanda and Burundi (ibid). However, according to the United Nations arrangement of topographical counties, East Africa Community has 19 countries throughout the eastern parts of Africa. As indicated in the Figure 2 below, the region of east Africa has abundance of both natural and man-made water bodies. This has signified the relevance of doing the research in that area. Fish farming and water resources are naturally inseparable ingrediencies.

Lake Victoria is the largest water source in the region and there is an existence of cage fish farming in Lake Victoria, Tanzania (Munguti, 2021). The research further focused much on Tanzania in line with the theme of the Zanzibar Water Conference 2022 theme within energy-water-food nexus. As indicated by the figure, the region has great potential for fish production. Once cage fish farming system is adopted hydropower Tanzania, it will cascade to other countries in the region and hence promote food security, boost nutrition, reduce poverty levels in both urban and rural areas.

### Current Status of Aquaculture in East Africa

Aquaculture has high market potential in East Africa. The industry is still in its early stages but has been growing rapidly and indicating the potential for first-rate viable performance. Currently, 75% of East Africans from the four countries regularly consume fish with 30% of them considering it as their major source of protein. The East African population (Uganda, Kenya, Rwanda, and Tanzania) is expected to double in the next 30 years from 175 million to 350 million hence increasing the demand for proteins (Rothuis et al., 2014). Therefore, there is substantial current and future market opportunity for the industry. East Africa is

blessed with good climatic conditions and has rich immense water resources such as rivers and lakes such as Lake Victoria, and Lake Tanganyika, with good water quality parameters for fish production.


**Figure 2: Map of East Africa, (FAO, 2020).**

The Freshwater lakes are a natural home of the Tilapia species which show that the environmental conditions are excellent for growth and there is a strong, varied pool of wild hereditary material to develop (Downing et al., 2014).

Figure 3 shows the aquaculture value chain processes from the hatchery to final consumer. According to FAO (2018), the actual fish consumption in the 4 East African countries is approximately 1,300,000 MT per year. The demand for local fish is higher than the supply and this gap is expected to widen in the coming years due to the projected population growth in the region.


**Figure 3: Aquaculture Value Chain (Rothuis et al., 2014).**

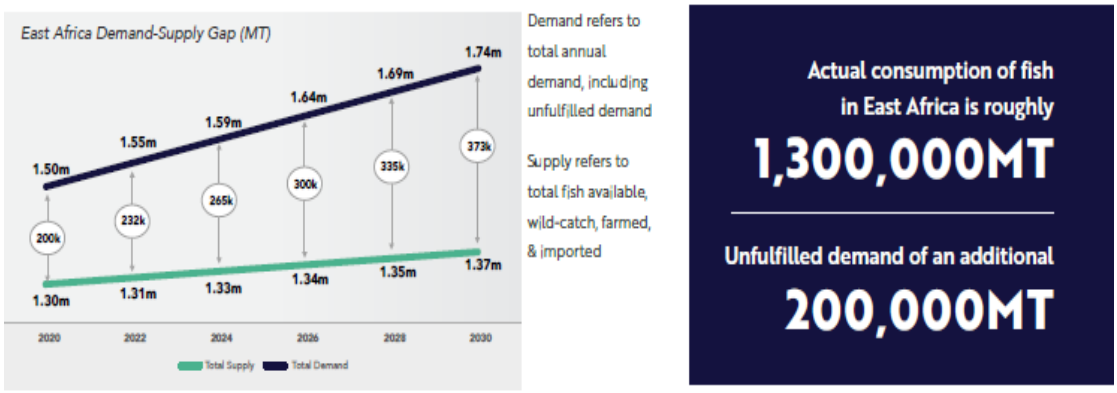



**Figure 2: Fish demand and supply in East Africa (FAO, FAOSTAT Statistical Database, 2018); Rothuis et al., 2014).**

Figure 4 shows the East Africa demand-supply gap of fish. The overall fish production is mainly by wild catch, imports, and aquaculture. The wild catch is accountable for the vast majority of the fish produced in the region with tilapia species being the major component of the wild catch fish (Rothuis et al., 2014). Lake Victoria is the major source of wild catch for Kenya, Uganda, and Tanzania. The imports are mainly from Asia, especially China (OECD/FAO, 2020)(OECD/FAO, 2016).

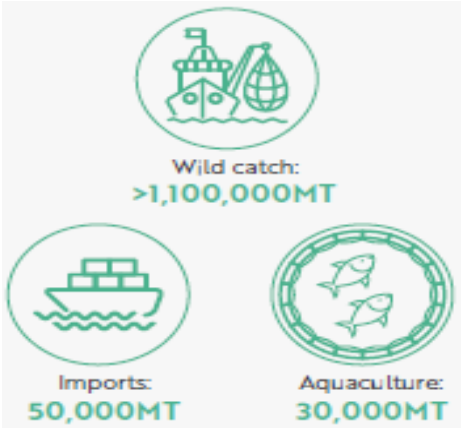



**Figure 3: Distribution of fish production in East Africa (Rothuis et al., 2014).**

The figure above shows the total amount of fish produced from the three major sources of fish production in Kenya, Uganda, Tanzania and Rwanda. Aquaculture is majorly practiced on a large scale in freshwater lakes, for instance Lake Victoria in Kenya, Uganda, and Tanzania, Lake Tanganyika in Tanzania, and Lake Kivu and Lake Muhazi in Rwanda. The aquaculture in these lakes is majorly through caged fish farming. Small-scale farmers carry out their fish farming in ponds (Rothuis et al., 2014). The aquaculture industry in the region is still in its initial stages and it has shown great progress over the past few years. The progressive growth of the industry is attributed to the widening of the supply-demand gap that has attracted high fish prices across the region. This is mainly due to the overfishing of regional wild fish stocks which has resulted in volume stagnation despite the increase in demand (Arjo Rothuis, 2014). In addition, research has shown that the farmed fish has the potential to supply protein more affordably and sustainably than other fish sources hence promoting aquaculture (Kobayashi et al., 2015). Covid-19 also led to a reduction in fish imports from Asia, therefore encouraging more fish farming to meet the demand (OECD/FAO, 2020). The governments in the four East African countries have been supportive by offering numerous concessions and licenses to private investors and investing in high-quality inputs including fingerlings and feeds. The government investments in quality inputs have led to reduced capital costs which are expected to continuously reduce over the next 3-4 years hence increasing the profit margins and

encouraging more investors to venture into the industry (Arjo Rothuis, 2014).

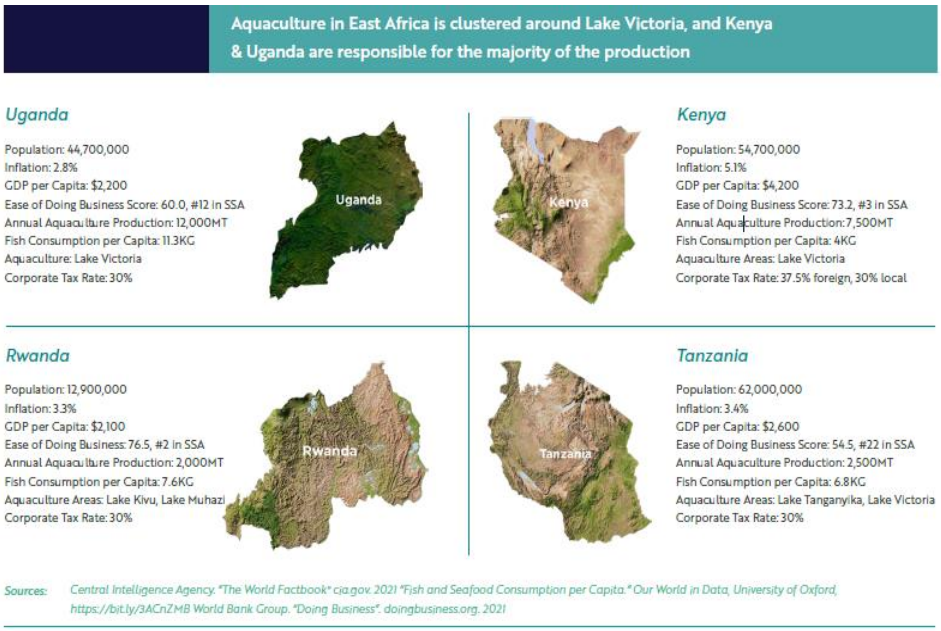



**Figure 4: Aquaculture production in East Africa (Rothuis et al., 2014).**

Figure 5 shows statistics of the four East African countries, which includes the population of each country, the fish consumption per capita, the aquaculture areas and the annual aquaculture production of each country.

## Aquaculture Systems in Tanzania

Aquaculture in Tanzania is not a new field, it started in 1949 (Ng'Wigulu, 2021). It was known to be practised in freshwater. It is believed that though local fish farmers are benefiting tremendously the significance of aquaculture in contributing to the national or household food basket is not well recognised. Unlike in other countries such as China, Indonesia, Vietnam among others where fish/aquaculture production in commercial/domestic production has contributed to significant levels in food security, job creation, income generation and environmental management (Ng'Wigulu, 2021 and FAO, 2020). Despite having started in 1949, commercial fish farming in Tanzania is still viewed as a new venture. The industry is still done as a subsistence farming method at household levels mainly by people who reside closer to coasts and inland regions (FAO, 2020). The recent available statistics show that in 2014, about 9 raceway systems and 20134 ponds were established while in the year 2016, 18900 people were practicing fish farming across Tanzania (Munguti, 2021 and Ng'Wigulu, 2021) with an average production of 3 840 tonnes of fish per annum. Such production rates total income accumulated to 22 000 million Tanzania shillings (Mukolozi et al., 2020 and Ng'Wigulu, 2021). Since the production of fish remains minimal, it also affects the marketing process. FAO (2012) further notes that the majority of the yields are sold or consumed locally with some exceptions of a few farmers who export their products to neighbouring countries. Such exports are of lesser substance. This causes the reliance and promotion of fish production to be neglected. Even the benefits of aquaculture production to nutrition, food security and financial improvements is still undermined in the country, in East Africa and the whole continent (Wetengere, 2011).

The water-energy-food nexus has not been well recognised in Tanzania as a lot of

water reservoirs are not being utilised for fish production. Tanzania is blessed with an abundance of water sources but it also still imports aquaculture products from as far as China, India and other countries. Poverty levels, malnutrition and undernourishment are still common phenomena, particularly in the rural and informal-peri urban communities in Tanzania (Mulokozietal.,2020). Furthermore, FAO (2012) showed that fish farming and the whole aquaculture industry has not contributed significantly to the GDP as it stands at 1% (Ng'Wigulu, 2021). Fresh water production of fish has since been on the decline since 1992 declining from 16000 tonnes to 1400 tonnes in 2008 (FAO, 2020). It is most welcome to lobby, promote and focus more of other alternative aquaculture production systems such as to adopt to the cage culture in hydropower reservoirs. Hydropower reservoirs have tremendous advantages over any other available water sources in Tanzania as far as cage culture is concerned. In addition, other water sources can also be used for cage fish farming to boost the yields. Even though the cage culture was ventured into in the 1940s, it is astonishing that its practice in Africa is still so little. Tanzanian fish production is dominated by freshwater aquaculture and mariculture systems while the latter is taking the lead. At peak, mariculture production rate is around 3 800 tons per hectare per year (Ng'Wigulu, 2021). With all limitations and unreliability of aquaculture systems in Tanzania, it is still on the lead across the continent (FAO, 2018). The major reasons being that the country has abundance of natural and man-made reservoirs.

The graph above shows aquaculture development trends in Tanzania in a period of 10 years. It is clearly labelled in the chart that all aquaculture varieties are on the increase. The production rates are on average positively increasing in all categories. The period 2013-2015 demonstrates a stable-slightly decline of the produces thought on a positive level.

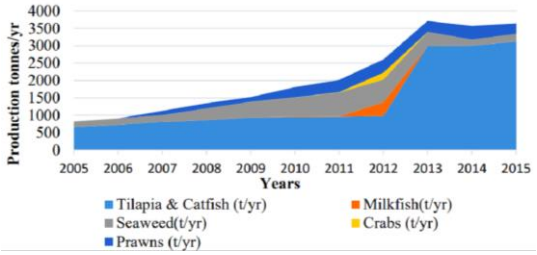



**Figure 8: Aquaculture Development in Tanzania (Ng'Wigulu, 2021).**

## Lake Victoria in East Africa

The lake is a natural transboundary water body that shares boundaries with 3 East African countries - Uganda, Kennya and Tanzania Ng'Wigulu (2021). It is a source of water for various uses including transportation, fish production, tourism and defence activities among other uses but just to mention a few. It is lying in a shallow depression of an average depth of 35m. the lake occupies ana area of around 68 800 square kilometres. The lake has a total length of about 400km and a width/breath of around 320km squared (ibid).

## Cage fish farming in Lake Victoria, Tanzania

Based on the literature available, cage fish farming is practised in Lake Victoria though at minimal level as observed by Ng'Wigulu (2021). Cage culture was introduced in Lake Victoria in the year 2005 with limited positive results to date (Bwathondi, 2005). Even though Lake Victoria is a natural water source, high initial investment demands for cage culture has negatively affected such a lucrative venture. The main categories or factors that requires high initial cost include expert hiring, inputs, cage construction/insertion and management among other matters. It is still not easy for the fish farmers or the government to high advanced technologies in cage culture and hence the pace in which cage culture develops remains slow. The cage culture is prominent in Lake Victoria but it is contributing a mere small proportion towards food security and income generation (Bwathondi, 2005).

The management, implementation, permits application process and vernacular techniques are all working against the desire of many fish production entities in Tanzania. Just like many other countries, Lake Victoria is a public water reservoir, it is associated with conflicting interests among interested parties relating to management, usage, control and monitoring. It is characterised by what is referred in this study as aquaculture systems operational chaos. It is also significant to make it clear here that the cage fish farming practiced in Lake Victoria, Tanzania was started as a feasibility and experimental projects (FAO, 2020). Besides being an experimental project, Njiru et al., (2019) noted that several special and environmental pre-assessments systems were developed in Lake Victoria to establish the potential impacts of cage fish farming in the reservoir. Notable most likely negative impacts of the cage system in Lake Victoria include eutrophication, (Bwathondi, 2005), spreading of diseases or parasites, competition among farmers, mixture of cage fishes with wild fishes among others (Munguti, 2021). With the potential environmental impacts outlined, there have no data or empirical evidence of the negative impact of cage fish farming implemented in Lake Victoria, Tanzania. The practice of fish farming is mainly controlled by the Fisheries Act of 2003 in Tanzania. It is crucial for researchers, educational institutions, parastatals, government ministries and private entities to promote the implementation of cage culture in Lake Victoria, other natural water systems and in Hydropower reservoirs.

## Cage Fish Farming in Tuyen Quang Dam, Vietnam

The Na Hang Dam locally known as Tuyên Quang Dam is a large hydroelectric dam on the Gâm River near Pác Tạ Mountain in Tuyên Quang Province, Vietnam. It was constructed from 2002 and completed in 2008. It generates 342 MW with a potential to produce 1 200 GWh per year (Thanh, 2021). The dam is a second largest in the north parts of Indonesia. The total construction costs accumulated to US$490 million. The water storage capacity is 2,5 billion cubic meters gross (Johns et al, 2019 and Thanh, 2021). The study used success case stories of cage culture in Indonesia and Vietnam in a bid to try showing the Zanzibar Government and Government of Tanzania that cage fish farming in hydropower reservoirs are implementable projects (FAO, 2020). The Tuyen Quang province have implemented cage systems and has a well-coordinated cage culture development approach. The system is centralised mainly in the districts of Na Hang, Lam Binh, Chiem Hoa, Ham Yen, Yen Son, Son Duong and Tuyen Quang city. The average number of cages has reached to 1,460 as of 2020 which has an estimated output of about 871 tons of fish. The cage farming is expected to grow up to 1910 cages and able to produce 1 654 tons by 2035. The strategic plan is not only limited to cage culture but it further touches other systems such as tilapia fish farming which was recorded to have used farming area of 158ha within a volume of 2000m3 producing total output of about 751 tonnes in the year 2020. Since the project within this province has been successfully implemented, monitored and managed, the expected outcome from both the cage and tilapia farming will reach 12 000 tonnes from an estimated area of about 14 000 hectares tons in the year 2035 (Thanh, 2021).

## Tools and Data for the Study

The research followed a literature review methodology. All the utilised information and data used to finalise this study were obtained from systematic review of peer reviewed papers, government documents, policy briefs, recognised national/regional newspapers. The relevant literature was selected using a systematic review method

within a transparent, objective and systematic process. The criteria involve a search system, collection criteria and screening.

The screening and search approach used key factors, terminologies, indicators and subjects to do literature cleaning and sorting (Table 1). The study assessed the current aquaculture production and cage fish farming systems in Tanzania, East Africa and from a Global perspective. The impact of climate change on aquaculture production was also used to form the base of literature review. In addition to the search criteria used, key contributions of specific research works, studies and projects also complemented our findings. The main sources consulted electronically databases include google scholar articles, Scopus, Web of Science (WoS) and various online databases.

Cage fish farming, Water storage, Aquaculture, Agriculture and Environmental reference lists of up to the year 2022 were also manually searched to identify other relevant articles. The main factors considered during literature review search and criteria are presented below:

**Table 1: State of research related to hydropower and water-energy-food nexus in Africa**

| ***Subject*** | ***Number of Papers*** | ***Indicators*** |
|---|---|---|
| Agriculture and aquaculture | 4 | Sustainability in food and agricultural production, food security |
| Caged aquaculture system and blue justice | 7 | Large dams water management and environmental conservation, pollution in oceans, dams and other water bodies, aquacultute in hydropower dams |
| Climate change and climate-friendly food systems | 3 | Drought, flooding, modified food production systems, sedimentation in hydropower dams |
| Hydropower reservoirs | 5 | Large dams in Africa and their utilisation, sewage disposals in dams, other informal and unregulated activities in large dams |
| Water-energy-food nexus | 3 | Water, energy and food security, relationship among the three factors |
| Africa and East Africa | 4 | Fish production in Africa |
| Governance | 3 | Management, regions, policies, programs, projects. |

## RESULTS AND DISCUSSION

The major concern raised in the study is that fish production strategies in Africa generally and Tanzania to be specific has been dominated by vernacular systems which are backwards, poorly implemented and have yielded limited results in line with the need to boost food security, fish products and employment creation (Bwathondi, 2005). According to Hishamunda (2008), the fish production strategies in the countries of Eastern Africa does not match demand. Most hydropower dams in Tanzania are not being utilized for fish production. It is vital for the relevant stakeholders to really put much resources into aquatic organisms' production including cage fish farming.

The aquaculture development trends across East Africa are biased towards traditional systems, the innovativeness chances are very limited in such levels that one can witness the deterioration of existing aquaculture infrastructure. Just like the ordinary aquaculture systems, the small-scale cage fish farming in East Africa is being practised in the natural freshwater lakes, majorly in Lake Victoria (Ng'Wigulu, 2021). Across the

literature utilised in this research, it has to be postulated that the cage aquaculture system is a lucrative fish farming venture but which has not been fully utilised in Tanzania and other surrounding countries across East Africa despite having abundance of natural and hydropower reservoirs. The region is clear need for appropriate innovation strategies to increase aquaculture production especially adaptation of cage culture in hydropower reservoirs.

## Cage Fish Farming in Hydropower Reservoirs

The cage fish farming popularly referred as cage culture has not been fully implemented especially in natural ecosystems and reservoirs across the continent Africa. The captured fish systems are no longer able to sustain and meet the current demand both in local or global perspectives. The increased nature of aquaculture production has necessitated the rise in demand for alternatives aquaculture approaches such as the cage culture (FAO, 2020). Even though there is potential for adopting the cage culture in Tanzania, it is surprising that it is only practiced at a very minimal level in Lake Victoria as noted by Ng'wigulu (2021). Capture fish production seem to be an old system which is backward and has little impact towards the employment creation, income generation and food security among other parameters. Cage culture for marine, inland and mostly in hydropower reservoirs scarcely used. The thrust in this study is to spearhead the notion that all hydropower reservoirs whether large or small should prioritise cage fish farming (Hishamunda et al, 2018). Caged aquaculture organisms are an example of recent and feasible innovation in the most developed countries with minimum ad-hoc applicable to developing countries. In the 17$^{th}$ century, cage systems were used to transport fish or aquatic organisms for long distances. This made the foundation for the cage fish farming which is becoming popular nowadays though pioneered in Norway in the 1970s (FAO, 2020 and Ng'Wigulu (2021). Cage systems has increased its demand and sphere of influence due to the rapid rise in demand for fish and other aquatic products. Some major factors contributing to the high demand of cage culture include globalisation, climate change, high demand for fish products, declining fish production and poor fish farming methods (Orinda, 2021). Cage fish farming has a great advantage of investment cost reduction as it makes use of existing water sources such as hydropower reservoirs, inland waters, and other natural water bodies.

## Aquaculture in Hydropower Reservoirs – Global Perspectives

Despite little or no documented commercial fish farming in Africa, as already highlighted above, the concept had been fully implemented in Asian, European and other countries across the globe. Notable examples include the cage fish farming project in Saguling and Cirata in Indonesia and Tuyen Quang in Vietnam (Hishamunda et al, 2018). Such aquaculture projects are on the record of being highly successfully due to a number of factors which are both internal and external (FAO, 2018). The most noticed and enabling factors include availability of high-water quality and low water fluctuation in the reservoir and the reservoirs offer extensive ground for large-scale caged fish farming Once the Hydropower is in place, implementation and control of regulations is easy in the sense that many other institutions will have a say on how it is operated. Key stakeholders including the local community organisations are usually given the outright opportunity over the control, utilisation and administration of the reservoir in their areas. This has resulted in the successful implementation cage fish farming in the outlined dams. Additionally, the impact of climate change on man-made reservoirs such as flooding, drying of the dam among other related climate change impacts is minimal compared to natural water lakes or water bodies (FAO, 2018). Major Hydropower reservoirs in Indonesia and Vietnam are located in areas with good climatic conditions

that favours or promotes fish breeding processes with limited costs and hence the existence of bumper fish harvests which are even exported to Africa.

## Fish Farming in Hydropower Reservoirs and the Energy-Water-Food Nexus

The paper introduced hydropower reservoirs as sustainable for practising fish farming in East African countries. East African region is known for having abundance of water resources. Large-scale hydropower reservoirs epitomise the connexion and pathway a reliable water-energy-food nexus as a resource integration platform. Large scale hydropower reservoirs are hysterically known for only providing water for irrigation, recreation and hydro-electric power sources across many African countries. Based on the findings from literature and the ever-increasing demand for fish and fish products, large-scale dams proved to be the most appropriate existing, controlled and reliable infrastructure that can be used to boost fish farming in the region. In addition to the existing large hydropower reservoirs, little resources and manpower are required to implement various fish farming projects since the main investment of reservoir construction was completed already.

Water reservoirs and green water sources proved to be hotspots in the water, food and energy nexus (Munguti et al, 2021). A comprehensive implementation plan of cage fish farming in hydropower dams is overdue in Africa if food security and other related benefits are to be achieved. Based on the findings of the paper, much focus was drawn in which such large water bodies has to be treated as key resource base for food security, income generation, poverty reduction and blue justice preservation. Large-scale hydropower reservoirs by virtue of their management, operations and control approaches should be viewed as reserve base for food security. The results further demonstrated the need for implementation of cage fish farming into regional integration, food security and climate change debates, plans and programs. Even though, it seems easier to implement the aquaculture projects in such reservoirs, it should be emphasised here that the any human controlled activity on earth or universe has its own externalities, in this case fish farming also pose adverse effects into water resources at variable intervals. A nexus cross-roads application is necessary to be introduced in highlighting the use of the nexus as an all-inclusive stage to address water, energy, and food resources.

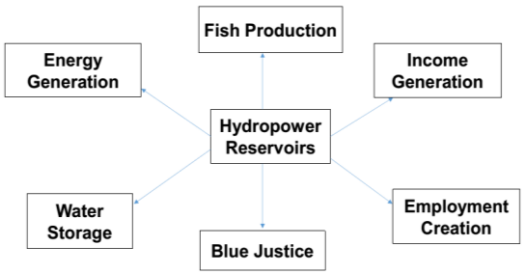



**Figure 10: Energy-water-food nexus conceptualised.**

Figure 10 comprehensively demonstrates and describe the energy-water-food nexus as related to hydropower reservoirs from a general perspective. Usually, the sore reason for construction of huge dams is purposely for electricity generation. However, with the adventurous nature of modern scientists and researchers, the researchers noted the increase of activities, processes and interrelations non-avoidance system that mix energy generation with water storage and fish farming. All other areas indicated in the figure are connected to either one of the 3 major activities (energy generation, water storage and food production) that operates in the hydropower reservoir. The hydropower reservoirs are centrally located and all the identified sectors of the economy and society are directly linked to them. Besides energy generation, the concept demonstrates that such reservoirs are great opportunistic landscapes suitable to boost fish farming in their various methods at affordable costs.

Aquaculture in large hydropower reservoirs can be used as a threshold in the promotion of aquatic lives and hence its significance in advancing the concept of blue justice. Once

the hydropower is operational, the secured and water management systems are applied by virtue of law and this signifies that any other spill-over projects within the project benefits from such arrangements. Once the reservoir becomes operational, both skilled and unskilled labourers are hired, income generation improves and at most the GDP per capita improves. With adequate utilisation of water resources in both farming, aquaculture and energy generation food security is achievable. The thrust in this research is to show the significance of viewing, utilising and promotion of hydropower reservoirs in advancing the energy-water-food nexus as far as fish farming is concerned.

### Hinderances to Cage Fish Farming in Hydropower Dams

There are a number of notable constraints which are almost universal in East Africa or Africa in general that contributed declining cage culture in both natural and man-made reservoirs. Since 2005, the willingness to promote cage culture in Lake Victoria is still facing drawbacks. The major concern is its huge financial demand (Munguti et al, 2021). Since cage farming was started as an experimental project in the lake, it never matured into a real project. The demand for adequate financial or capital has limited the spreading of such a good project to other regions including in all hydropower reservoirs. Cage fish farming in hydropower reservoirs have not been implemented in many countries not only limited Tanzania. Some commercial fish products traders they really prefer to import from Asia, China and Indonesia. The capital investment required to venture into such a business of importation is of less stress than starting their own cage culture (Jones, 2019). There is clear evidence of poor management and implementation systems in aquaculture as one can witness the reliance on old fish farming or harvesting techniques. Lack of skilled personnel is a major delinquent affecting innovation in fish production such as the cage culture (FAO, 2012). Since 2005 when cage farming was done as an experiment in Lake Victoria, Tanzania, up to 2022 there is nothing that has improved. It remains a dead experiment since no one proved to have the critical skills to carry on with the project to its full operational. The regional bodies such as the East African Community has limited support on empowering regional stakeholders and policy makers who has the mandate directly or in directly to spearhead the improvement of aquaculture in their jurisdictions,

## CONCLUSION AND RECOMMENDATION

This study is one of its kind as it has paved way for further research focusing on another alternative means which can be used to further promote cage culture mainly in hydropower dams across the country and region at large. Since cage system is already existing in Lake Victoria, Tanzania, it is therefore vital to prioritise the need for further research on further developing the cage fish farming systems in the country starting with this existing pilot project on how it can be replicated in other man-made reservoirs especially the hydropower dams. It is also important for promoting research and experts on affordable cage fish farming systems in Tanzania as well as to development, implement and supervise viable strategic options, particularly policy and regulatory approaches to model, make use of the promising potential benefits for the nation. Cage fish farming strategies should be applied in manners important for the country to properly make use of benefits from cage fish farming as well as to limit potential environmental, social and social challenges emerging from such projects.

In line with the aim of this study, it is recommendable for key stakeholders to collaboratively work together in developing, implementing and promote feasible measures that enable advanced aquaculture and fish production in hydropower dams in their own regions. There are a number of hydropower reservoirs in mainland Tanzania and Zanzibar such as Hombolo, Kidatu, Kihansi, Mtera and Nyumba ya Mungu (FAO, 2012 and FAO 2020). The introduction of cage culture in the

hydropower reservoirs outlined will highly contribute to economic growth. Such hydropower reservoirs are potential water bodies which has limited capital demands when implementing cage fish farming. The research recommends the application of devolution funding approaches to be used by the Zanzibar government and Government of Tanzania in promoting the aquaculture and fish production sector.

As noted, and observed from fish farming projects in Vietnam, India and China, cage fish farming is a huge unexplored and undermined or neglected venture in Tanzania and Africa at large. It is a potential project that has substantial benefits to the community. The practice of cage fish farming in hydropower reservoirs is key in addressing food insecurity, unemployment and malnutrition. Tanzania has vast unexploited and underutilised potential water resources that can boost aquaculture production. The neglected water bodies include both hydropower reservoirs in their various sizes and other natural water bodies. Even in some regions where fish farming is practiced, the country needs to gear-up their innovation levels or research to actually implement cage culture and other technology-based fish production systems.

The research further recommends the implementation of community-based capacity building programmes in basic and advanced aquatic resource management. The trainings, capacity building and business management basics should be undertaken by water authorities, ministry responsible for fisheries or agriculture, industry and commerce among other entities. A bottom-up approach is necessary in aquaculture production programmes implementation. It is also vital for concerned departments and stakeholders to embrace the implementation of climate-smart fish farming approaches to boost food security, income generation, nutrition promotion and fight all aspects of poverty in both rural and urban areas of Tanzania.

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