GIS Multicriteria Decision Analysis -Nigeria

Fresh water fish farming

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Abstract

The aim of this report is to document the research on freshwater and warm-water fish farming systems zoning and the potential in Nigeria for the African Catfish and Nile Tilapia species. This study is a pilot case for aquaculture geographic information systems multi-criteria decision analysis (MCDA) under the scope of the Hand-in-Hand initiative.

The Nigerian fish farming context and background were assessed through literature review. The modelling methodology was developed from Aguilar-Manjarez and Narh 1998 - A strategic reassessment of fish farming potential in Africa, a geographic information system weighted factors MCDA approach which includes market demand, poverty, infrastructure, inputs livestock and crops, physical geography (soil, slope, water availability), photovoltaic (PV) energy generation potential. Constraints or exclusive criteria were applied to distinct farming system: protected areas, densely urbanized areas, large water bodies, and distance to major roads.

Results consist of a set of models, sub-models, and final mapping outputs which indicate the potential for high return on investment optimal sites aimed at intensive fish farming for both closed catfish (tanks, raceways, ponds, recirculating aquaculture systems) and open tilapia (large water bodies) systems, and zoning at regional and state scale directed at open non-intensive integrated pond systems, with high potential impact on poverty alleviation, improving nutrition, and food security.

Based on optimal natural conditions and large urban or metropolitan area market access, the results show a large growth potential for the intensive systems in the southwest, southeast, and north central regions. The lack, or unreliability, of energy supply and poor transportation infrastructure are major limiting factors on the entire value chain. Alternative PV energy generation has increasing potential from south to north, using it as intensification gives more weight to north and central region sites. Even so, top locations remain in the southeast states. Modelling intensive tilapia cage systems in large water bodies indicates a large untapped capacity, with potential high return on investment sites located in the southwest, central, and north. Development interventions focusing on integrated non-intensive farming systems, targeting SDG goals, have extensive prospects with limitations only in peripheral northern and

northeast arid regions, filtered by poverty above the average most of the priority areas would locate in a central belt, in some areas reaching further north.

Caution is recommended with environmental aspects that might impact long term sustainability. Health and disease management and monitoring also grow in importance as the sector develops. Proposed models should be framed recognizing ethnic and cultural diversity and interventions must consider already existing resource competition issues, already prone to conflict problems in the country and region.

Possible developments in the methodology can include, value chain, socio-economic and fish farming production spatial data. Flood data should be added to the constraints.

Keywords: Aquaculture zoning; Aquaculture Nigeria; Aquaculture spatial analysis; Aquaculture zoning modelling; catfish tilapia zoning; catfish tilapia GIS

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INTRODUCTION

This report documents a pilot case exercise Geographical Information Systems - Multicriteria Decision Analysis (GIS-MCDA) under the scope of FAO's Hand-in-Hand Initiative, for the identification of freshwater fish farming potential regions and sites in Nigeria.

Research questions can be formulated as:

1. *What are the regions and states where fish farming should be promoted for poverty alleviation, improving nutrition, and food security?*
2. *Where are the best sites for intensive commercial closed farming system investment?*
3. *Where are the best sites for intensive commercial Tilapia fish farming open systems?*

Research methodology follows previous exercises for warehouse/storage location (Ghana, Kenya, and Tanzania) and dairy processing plant location in Tanzania. A literature review details sub-Saharan Africa and Nigeria aquaculture fish-farming sector context, background, and perspectives. Modelling assumes a GIS-MCDA methodology applying weighted factors (AscoughII et al., 2019; Boroushaki & Malczewski, 2010; Malczewski, 2006).

Fish farming suitability/potential zoning modelling is based on specific sub-models, criteria, and spatial constraints. It builds from Aguilar-Manjarrez and Narth study on warm-water and temperate-water fish farming suitability in continental Africa (Aguilar-Manjarrez & Narh, 1998), a raster based GIS-MCDA using fish-farm and land-quality factors, with sub-models and categories of criteria:

1. Constraints (urban areas, large water bodies, protected areas)

2. Water requirement

3. Soil and terrain suitability

4. Inputs – crops and livestock

5. Farm-gate sales - as a measure of population density classification.

6. Potential yields.

7. Urban market size and proximity.

Sector growth, data availability, and fish farming systems have considerably evolved since the 20th century. Base data is updated, as well as sub-models, criteria weighting, and constraints reviewed.

Two distinct zoning efforts were delineated.

The first at a broader scale, intends to identify states or regions where investment can positively impact poverty, hunger, malnutrition, and food security:

- Extensive to semi-intensive small-scale integrated farming systems.

The second pursues the location of high return on investment sites for intensive commercial aquaculture systems, for both:

- catfish closed intensive farming systems.
- Tilapia open intensive farming systems using cages in large water bodies (LWB).

Separate zoning efforts are developed for each farming systems or model, based on specific farming system theory, which implies distinct criteria combination and weighting, and is conditioned by a different set of constraints.

Three models were developed for:

1. Open non-intensive integrated fish/crop farming systems using ponds or small waterbodies.
2. Catfish closed Intensive systems – using closed/semi-closed-circulation technologies: recirculating tanks, raceways, flow-through systems, and ponds.
3. Tilapia open intensive systems in LWB – using open-net pens/ cage techniques in public waters.

Location analysis data modelling characterize physical geography conditions, supply, demand, infrastructure/accessibility, and alternative energy potential, using the following criteria:

1. Physical geography
    a. Water requirement
    b. Soil

    c. Terrain suitability (slope)

2. Supply
    a. Feed - crop production (Fischer et al., 2012)– crop by-products.
    b. Livestock – animal density (Robinson et al., 2014) – livestock by-products.
3. Demand - Human population density and urban areas.
4. Infrastructure - Transportation network (accessibility).
5. Photovoltaic (PV) potential – Closed systems Intensification potential using alternative energy.

The transportation network infrastructure is modelled as raster-based travel time/cost analysis (Mulrooney et al., 2017) and accessibility/infrastructure travel time/cost to market is processed for large urban areas.

Applied constraints (depending on specificities of the farming system):

1. Urban Areas.
2. Protected Areas.
3. Large water bodies.

Final mapping exclusive criteria for intensive closed systems:

1. Distance to major roads.
2. Access to IT - mobile broadband coverage.

There is no modelling input data on actual existing fish farming activities.

The project is developed using open-source GIS software QGIS 3.10.14-A Coruña and open-data sources. Mobile broad band coverage data is derived from Collins Bartholomew's Mobile Coverage Explorer datasets.

This document is structured in 6 main sections: 1. Context and Background, 2. Fish Farming Zoning Modelling, 3. Data Sources; 4. Vector Data Pre-processing/Editing; 5. Data Editing Geoprocessing - Sub-Models, 6. Suitability/Potential Modelling, with Introduction and Conclusions with results, recommendations, closing remarks on assumptions and possible pitfalls, and future development. In Annex: Accessibility model algorithm diagram.

GIS Multicriteria Decision Analysis

Spatial decision problems involve a set of geographically defined alternatives and multiple and sometimes opposing assessment criteria. Alternatives are commonly assessed by many intervenient (decision-makers, stakeholders, interest groups).

GIS multicriteria decision analysis GIS-MCDA consists of a method to convert and combine spatial data/geographical information and decision-makers criteria to attain evidence for a decisionmaking process. GIS capabilities are enhanced by MCDA procedures, techniques, and algorithms for structuring decision problems, to design, evaluate and prioritize alternatives.

Integration of GIS and MCDA provides a replicable model, improves communication between project participants or decision-makers, can offer a different perspective of problem and solution, helping to redefine initial specification and/or criteria.

GIS multicriteria analysis methods are usually presented in a three-stage hierarchy of: intelligence, design, and choice.

In the intelligence phase, data are acquired, processed, and exploratory data analysis is performed.

The design phase should entail the formal modelling/GIS interaction development of a solution set of spatial decision alternatives. The integration of decision analytical procedures and GIS functions is critical for supporting the design phase.

The choice phase involves selecting location alternatives from those available. Specific decision rules are used to evaluate and rank alternatives.

The three stages of decision making do not necessarily follow a linear path.

From a critical standpoint it can be stated that, while quantitative data analysis and evidence gathering through GIS modelling certainly contributes to attaining evidence for decision-making processes. It is a complex set of socio-economic, political, cultural, ethno-anthropological aspects, and power relations which shape processes and govern decision-making.

Modelling is as good as the input data. Its quality and reliability support the extent to which conclusions can be trusted, and these are just as sound as the analysis conducted. From that prism, specification and objectives define modelling assumptions and approximations and can always produce distinct answers (Kitchin, 2014b).

Data are both social and material do not just represent the world but can actively produce it, are not mere raw material of information and knowledge, do not exist independently of ideas, techniques, technologies, people, and contexts that produce, process, manage, analyse, and store it. Positionality is always present even when “data speaks for itself” (Kitchin, 2014a).

1. CONTEXT AND BACKGROUND

According to OECD-FAO Agricultural Outlook 2021-2030 (OECD & FAO, 2021), fish production, trade and consumption all contracted in 2020 due to COVID19. Decline in aquaculture production is a consequence of the strict lockdown in the People's Republic of China (China), the world leading producer and exporter, but also from restrictions in port access impacting on both capture production and aquaculture supply (inputs seed/feed).

In the 2021–2030-decade, world fish production is projected to grow at 1.2% and aquaculture at 2.0% p.a. Lower growth rates compared to the previous decade reflect policy changes in China, aiming at sustainability and environmental protection, feed cost, reduced productivity gains, and competition for land. By 2030 aquaculture is anticipated to supply 57% of human fish consumption overtaking capture production by 2027.

Sub-Saharan Africa

The population of the Sub-Saharan Africa (SSA) region was 1,106,957.90 in 2019, and with an annual growth rate of 2.5 % was projected to reach between 1.5 and 2 billion by 2050. Unemployment rate was around 6.1% for the same year. Although poverty headcount ratios, in percentage of population, have fallen from over 60% in the 1990s to close to 40% in 2019 there are great disparities between countries and subregions (World Bank[1])

Per capita fish consumption in Africa is projected to decrease as the fast-growing population outpaces the growth in production, weakening the ability to meet SDG targets.

Aquaculture production in SSA is predominantly inland and freshwater. The types of operations found are subsistence, small- scale market-driven, and large industrial scale. From 2004 to 2014 there was a seven-fold increase in production with an average percent growth rate (APR) of 2%. The first sales value of the 2014 production was US$1.6 billion, mainly of indigenous ubiquitous species of tilapia and catfishes. Seven countries (the Federal Republic of Nigeria, the Republic of

[1] https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ZG

Uganda, the Republic of Ghana, the Republic of Kenya, the Republic of Zambia, the Republic of Madagascar, and the Republic of South Africa) concentrated 93% of production (Satia, 2017).

This sector has experienced a steady growth based on indigenous species, genetic and feed improvement, government, and development agencies support and a large growing demand.

Some of the commonly identified constraints and risks miss supporting data and are poorly assessed in existing literature: environmental impacts and health/food safety related, social impact, land and water competition, employment, value chain growth.

Risks like climate change impacts or social and regional conflicts are also merely mentioned.

Recent fish farming growth has been driven by an increasing importance for improving food security, job creation, economic growth, and resource use. It is supported by external assistance from FAO and other development partners, donor organizations and investors, and growing private sector participation.

Nigeria

Nigeria is the largest fish consumer in Africa. Fish accounts for nearly 40% of animal protein intake, and a per capita consumption of 13.3 kg/year. Despite a growing production, there is a large production consumption deficit, and demand was about four times production in 2014 (Emmanuel et al., 2014)

The country is the largest aquaculture fish producer in sub-Saharan Africa (Emmanuel et al., 2014; WorldFish, 2018). Over the past 35 years, production has grown around 12% a year, from 6,000 metric tons in 1980 to nearly 307,000 in 2016. This growth was essentially on freshwater fish farming, with catfish species totalling 64% of production (2015) In the same period there was a decrease in captures due to over-fishing, habitat destruction and pollution (Adewumi, 2015; Emmanuel et al., 2014). In 2018 fish farming represented 34% of the national fisheries, employing about 475,000 people, and contributing 4.5% to GDP (WorldFish, 2018), production totalled 291.3 thousand tons (FAO, 2020).

Most of the territory offers unique natural conditions for fresh warm water fish farming, such as abundance of water, optimal temperature amplitudes, and geographic conditions for marine and brackish water aquaculture.

There are over one hundred potential indigenous fish species with high demand and market value, high growth rate, and able to sustain high stocking densities.(Anetekhai, 2013)

Aquaculture was introduced with socio-economic objectives of supplementary income generation, improving nutrition and employment, and recently the focus has changed to production and the consumption deficit. (Emmanuel et al., 2014; WorldFish, 2018). Currently fish farming is essentially understood as a mean to increase fish production and youth empowerment, targeting poverty reduction, improved food, and nutrition security.

Cultured fish species

African catfish, tilapia, carp and Heterotis niloticus.

African catfish species Clarias spp. and Heterobranchus spp. are the most cultured (Adeleke et al., 2021; Adewumi, 2015; Amosu Albert Oluwatobi et al., 2017; Emmanuel et al., 2014; Obwanga et al., 2018; Satia, 2017; WorldFish, 2018). Catfish accounts for over 80% (Anetekhai, 2013).

Several market and biological factors are determinants for the catfish success. It has high market acceptance, because its resistance to severe environmental conditions, it can be market alive, and is not reliant on good transportation infrastructure, cold chain, and storage (Anetekhai, 2013). Catfish species are also exceptionally resistant to stressful, intensive production systems, with high densities, low oxygen, and waste build-up conditions, gaining weight with low feed conversions at low cost. Finally, there was availability of high-quality Dutch variety original stock from the Central African Republic catfish hatchery FAO project in the late 1970s.

Value chain

Given the poor transportation infrastructure and unreliable electric grid, post-harvest value chains tend to be short and simple, with more complexity in more productive states (Lagos, Ogun, Delta and Rivers) (Nukpezah et al., 2020). Fish products are marked and sold live, fresh, and smoked. Cold chain/cold storage facilities are very limited, and there is no major processing, nor distribution capabilities. Existing processing industry is largely small-scale smoked and dry catfish. Value chain development is in large part dependent on infrastructural improvement.

Efforts should target small scale industries producing for local and international markets and following international standards through certification (Anetekhai, 2013).

Mariculture

Potential needs scrutiny, while some literature states the existence of large suitable unexploited areas, others identify major constraints resulting from: pollution of anthropogenic activities in coastal areas; adverse natural conditions like shallow continental shelf or exposure to ocean swells; political preference for oil and gas exploration and limited technical know-how of indigenous marine/coastal fish species (Amosu Albert Oluwatobi et al., 2017).

Production systems and models

Three major production systems can be found in sub-Saharan Africa – earthen ponds, cages and concrete or earthen lined tanks (Satia, 2017). Open systems cage farming (tilapia and catfish) in large water bodies is the most profitable with low capital investment per unit of fish production. The less-costly pond non-fed system is undeveloped but has high potential to improve food and nutrition security. Closed systems recycling and land-based pump systems are limited by lack, or unreliability, of energy grids.

Secondary Production Systems, dam ponds, integrated agriculture systems, and aquaculture associated to rice still have a large growing potential.

All freshwater extensive, intensive and semi-intensive, open and closed production systems and techniques, can be found in Nigeria - flow through, ponds, cages, tanks and recirculating systems (Adeleke et al., 2021).

Catfish Clarias species and their hybrids production is commonly divided in two major stages:

1. Fish hatchery—production of fingerlings and juveniles.
2. Pond culture—earthen/dug-out, concrete tanks, cage/pen culture, fiber tanks, intensive recirculation and FTSs (raceway).

Cage culture is still incipient (Obwanga et al., 2018)

A large set of production models are possible to find:

- Backyard/cottage farming - most common with ponds.
- Integrated farming - fish, poultry and or crop.
- Hatcheries.
- Hatchery and table fish production.
- Public/private/cooperative.
- Catfish hospitability/recreation business

(Amosu Albert Oluwatobi et al., 2017 Anetekhai, 2013).

Intensive catfish production in "Fish Farming Estate" model using Recirculatory Aquaculture Systems is currently considered the most productive. (Obwanga et al., 2018). The cooperative public/private peri-urban aquaculture model using ponds or concrete tanks, is based on shared investment in management, security, development of hatcheries and high-quality fish feeds. (Miller & Atanda, 2011). With a relatively fast return on investment, it has attracted mediumscale investors to 'fish farming villages' (fish farm estates) in some cases reaching several hundred tanks cooperatively managed and located in peri-urban areas and has been fundamental to credit access.

The 'fish farming village" results from market factors and government intervention. States fund a main/central farm, managed/explored by private sector under cooperative schemes and servicing smaller farms (satellite farms). It results from farmers associations and government collaboration: FISON (Fisheries Society of Nigeria) and CAFAN (Catfish Farmers Association of Nigeria), and the Federal Department of Fisheries (FDF), benefiting from international development agencies and donor's support. This innovative model originates in the country's southwest strong cooperative and business-minded orientation of Yoruba ethnic group, with both professional support organizations FISON and CAFAN originating in the region.

The increasing importance of the tank farming systems is explained by its lower construction and maintenance cost compared to ponds (that require more expertise). Besides that, tanks allow scalability and can be built inside house compounds, limiting climatic constraints relevance, and providing improved security.

According to a recent survey in the southern states, the most common aquaculture system techniques operated by small holders and small production facilities in Nigeria (Nukpezah et al., 2020) were:

- Earthen ponds (58%)
- Concrete tanks (38%)
- Fiber-plastic tanks (12%)
- Tarpaulin tanks (15%)
- Collapsible ponds
- Cage aquaculture
- Flow-through raceway
- Recirculating aquaculture system
- Burrow pit

There is a clear predominance of the earthen pond and concrete tanks, totalling 96% of the systems and techniques surveyed, implying a large intensification potential in using flow through and recirculating systems, considered the most profitable and productive, and with less environmental impact.

There are no consistent data sources or studies on I**ntegrated Aquaculture-Agriculture systems**, or the use of small water bodies for small-holder fish farming in Nigeria.

Integrated systems in small holder farming systems can have a direct impact on poverty alleviation, hunger, and malnutrition. In general, they are considered sustainable and environmentally friendly, based in reusing and recycling of crop by-products, help land/soil regeneration, push the reuse of idle land, and contribute to natural fertilization when in conjunction with irrigation small water bodies (SWB). (Musuka & Musonda, 2013; Mwayuli et al., 2010; Oribhabor & Ansa, 2006; Rasowo et al., 2010)

A study in the Lake Victoria basin on improving farm yields, income, and environmental sustainability, through Integrated Aquaculture-Agriculture of fish-horticulture-poultry in smallscale rural farmers, exposes evidence on the potential of increasing crop yields and income, with benefits of soil regeneration and waste reuse. Integrated systems permitted reduction of inputs, using vegetables for feed, and the recovery of idle land for fish culture (Mwayuli et al., 2010).

The integrated system provided fish and increased vegetable production, ensured recycling of farm waste and nutrients in the farm. The study identified opportunities for processing surplus crops in the wet season for fish feed and to value-added small-scale processing of fish products.

Another study in the Niger Delta (Bayelsa, Rivers and Akwa Ibom states) demonstrates integrated systems environmental sustainability, focusing on organic waste reclamation, recycling and reuse in integrated fish farming.(Oribhabor & Ansa, 2006). Integration reduces input costs and helps to solve waste disposal by generating fish alternative feed. In the integrated system the farm is an ecosystem, crops are producers, livestock and fish are consumers, aquatic and soil organisms are decomposers.

Rice and fish farming is a specific integrated system to consider for income diversification, food security and nutrition strategies.(Rasowo et al., 2010). Rice and fish can be produced concurrently, enhancing crop productivity, and at the same time optimizing water, land, and labour resources. Small-scale decentralized hatchery for fingerlings production in rice fields was also successfully tested.

Rice cultivars size and growth period are locally sensitive that imply field studies for identification of specific cultivars and the definition of potential areas.

Some challenges can be presented by socio-cultural or biophysical factors. Socio-cultural factors might include the educational status of farmers or gender division of labour. Biophysical factors entail the specific rice paddy environment - temperatures, oxygen levels or water turbidity - can be a constraint even for high resistant Catfish and Tilapia species. Rice -fish integration was found to bring benefits to subsistence farmers improving and diversifying nutrition and increasing income possibilities.

Another case study, on the contribution of Small Water Bodies and Small-holder aquaculture poverty alleviation and household food security in Zambia (Musuka & Musonda, 2013), demonstrate small holder aquaculture improves rural household food security and better nutritional status, and diversification of income generation and employment.

This investment in small water bodies and small holder fish farming must be consistent with regional specificity. It must consider issues such as low productivity, high level of abandonment or seasonality, constraints in extension services, training, fish seeds fingerlings, feed cost, and poor marketing.

The lack of strong institutions, financial services, failing extension services, and seeds forces the development resources to change from the subsistence non-intensive systems to the intensive commercial alternatives. That acknowledgement, however, comes from industry experts. Even though the investment in subsistence small-scale farming has failed in the past, at least for a visible fast production/productivity growth, the reasons are not clearly identified. There is no qualitative or quantitative evidence on successful cases that directly impact smallholder livelihoods in Nigeria.

Policies

In the 2010s, Nigeria's Federal Government promoted Catfish Farming through infrastructure development, awareness creation, training, policy formulation and implementation, and adhering to international conventions. (Anetekhai, 2013) State and Local government, NGOs, private sector, and other stake holders sponsored homestead catfish farming, cage culture, recirculatory systems, and the establishment of fish farm estates. This was completed through input supply and subsidy, enlightenment programmes, training, supporting catfish farmers co-operatives, and creating centralized fish markets.

Policy recommendations are related to the creation of an enabling environment. The harmonization of strategies, programmes, and legislations, like exportation and import substitution, and easing of collateral requirements for credit, coordination on feed and seed (genetic improvement) are part of this environment. As well as the development of rural infrastructure, the creation of food processing zones, and cluster farming. Some are environmental concerns like the recommendation of framework of regulations targeting sustainability and environmental impacts. (Adewumi, 2015)

More recent policies and strategies concerns have shifted to the supply gap towards commercialization. This promotes the role of private investment, specific farming systems and the key role of professional associations. (Obwanga et al., 2018)

The current national policies align with the African Union Ten Years Aquaculture Action Plan for Africa 2016-2025 (Anetekhai Agenuma et al., 2016). They are the strategic objective of sustainable aquaculture development through the creation of an enabling environment(Udo & Dickson, 2017), as well as the research and dissemination of best practices. The Action Plan targets market-led aquaculture investments, accelerated growth rates, a better enabling environment, strengthening of Public-Private Sector Partnerships (PPPs) policies harmonization, and institutional and legal frameworks for aquaculture in shared ecosystems.

Critical observations affirm that the current regulatory and policy framework misses a link between the distinct policy goals, specific types of aquaculture, and specific support measures to be developed (Satia, 2017).

While recent policies do not focus much on subsistence small-scale farming systems, poverty alleviation, hunger, and nutrition goals, The WorldFish NIGERIA STRATEGY 2018–2022 does maintain that concern. In one hand, the overall objective is to improve the contribution of fish to the income, livelihoods, and nutrition of the rural poor, tackling undernutrition and hunger. On the other hand, research aims at supporting sustainable growth, livelihood, and nutritional benefits, but also accelerating the private sector and partners to invest in and scale high-potential fish production and value chain models.

These two distinct objectives, perhaps not always compatible, come in line with previous policy paths on the social development goals. At the same time, they focus on the supply consumption gap, private sector and development support on investment and scaling high-potential fish production and value chain models.

Challenges

Most cited challenges and constraints are: feed, seed, infrastructure, policies, and regulation.

Feed quality , efficiency, and availability issues are reflected on the cost of quality imported aquafeeds and estimated to represent 80% of operation (Udo & Dickson, 2017) (WorldFish, 2018). However, the livestock feed industry improved considerably positioning the country as one of the world's largest emerging feed producers. This fast growth is founded on raw materials availability and ongoing research on suitability of unconventional inputs. On the policy aspects, custom duties are in place for agricultural produce used in aqua feed production. Therefore, the Nigerian aqua feed industry has potential for commercial feed production(Udo & Dickson, 2017).

Seed fingerlings production is limited in both genetic quality and quantity, contributing to a high input cost. There is limited adoption of improved hatchery management practices (Digun-Aweto & Oladele, 2017) due to cost of acquisition and facility management, non-availability of inputs, poor information, and technical support.

Poor or missing basic infrastructure impact the entire value chain. There are no large distribution or processing facilities, cold storage/chain, transportation infrastructure is poor, and energy distribution network is missing or unreliable[2]. Energy costs also sum up to operational costs, which limit productivity and intensification.

Policies and regulation pose several challenging and impacting aspects. Previously, some of the challenges are complex credit access, poorly implemented programs and policies, poor sector data collection, lack of export certification processes, weak incentives to cooperative and associations. Recently, there is lack conducive policies, missing health strategy, absence of surveys and data collection on production and socio-economic characteristics of producers, and the need of further research. Still in 2018, there was a low implementation of legal framework

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[2] https://dlca.logcluster.org/display/public/DLCA/2.3+Nigeria+Road+Network

https://www.newsweek.com/nigerias-national-power-grid-collapses-plunging-parts-country-blackout-1590930

https://theconversation.com/solar-power-could-stabilise-nigerias-electricity-grid-and-save-it-money-117266 and no clear jurisdiction in administrations with changing policies and bureaucracy. However, the 'fish farm estate' model success pressed the government engagement in infrastructure provision and financial institutions in easing credit (Obwanga et al., 2018).

Additionally, marketing factors can be associated to missing or poor infrastructure, but likewise related to socio-cultural factors like technological and value chain model transfer or related to policy in the case of export strategies and certifications. Management skills are also critical, and authors stress the inexistence of data collection and record keeping, weak feed and pond management, water quality and disease control. Among institutional, technological, and sociocultural issues, there are identified limitations in technology awareness, adoption, knowledge transfer, cultural traditional relation to land property, and social problems impacting on predation/security.

Finally, the least studied, but with relevance growing in parallel to production, there are environmental, disease, and land/water competition challenges. Integrated irrigated-cropaquaculture model based on reservoirs in drought-prone areas can have a positive impact on sustainability (Satia, 2017). The recirculation systems also have low water requirements and output effluents, reducing fishing pressure, and no negative impacts of fish escapes are reported (Miller & Atanda, 2011). But environmental impact consideration is largely missing and legally a full environmental impact assessment is required for exploration larger than 30 hectares. Little research and data are available on these negative impacts: eutrophication, reduction in dissolved oxygen, production of toxic microorganisms, toxicity on aquatic ecosystems, disruption of fish assemblage in the wild, and genetic pool impact. Although there are documented challenges with water PH and acidic rain (Akpabio & Inyang, 2007) in some states, and an observed increase in effluents such as, phosphorus and nitrogenous substances, organic matter, faecal wastes, medicated and uneaten feed, chemicals (medicants, feed additives, antibiotics, fertilizers, disinfectants, hormones, therapeutants and anaesthetics) (Adewumi, 2015) with most producers discharging untreated waste waters directly on river streams (Folorunso et al., 2021). Impacts can potentially increase land and water competition issues. Finally, health and disease challenges are largely unconsidered. There are no surveys, surveillance, diagnostic or available guidelines on biosecurity (WorldFish, 2018).

With significant potential reducing effects in the long term, environmental impacts seem overlooked. Improving productivity should promote environmentally sustainable production and extension technologies (Adewumi, 2015) and can be accomplished through planning, increased management and monitoring capacity, defining correct diets, and feeding strategies.

2. Fish Farming Zoning Modelling

The analysis adapts Aguilar-Manjarrez and Narh approach to modelling warm-water and temperate-water fish farming potential in continental Africa. The 1998 technical paper follows Kapetski work - Strategic assessment of warm-water fish farming potential in Africa (Kapetsky, 1994), in adopting a raster based geographic information system approach, multi-criteria decision analysis, using fish-farm and land-quality factors.

Modelled criteria and constraints include sub-models/categories of criteria:

1. Constraints -urban areas, large water bodies, protected areas (exclusive criteria).
2. Water requirements – precipitation, evapotranspiration, seepage.
3. Soil and terrain suitability – soils, slope.
4. Input – crops and livestock (manure).
5. Farm-gate sales - population density classes.
6. Potential yields - number of degree days within optimal temperature range *(*air temperature, wind speed).
7. Commercial farming modelling adds urban market size and proximity.

Data availability permits updating to higher resolution and disaggregation, and farming systems evolution imposes a revision of sub-models, criteria/factor weighting, and constraints.

Original sub-models and models were adapted considering most farmed species, the African catfish, and the Nile tilapia, for commercial (intensive) and small-scale (semi-intensive/extensive) farming systems.

With distinct objectives and business rules, modelling is based on specific criteria, criteria weighting, and different constraints or exclusive criteria.

Small-scale, extensive to semi-intensive, pond integrated farming systems modelling target poverty alleviation, hunger, malnutrition, and food security. The zoning objective is the identification of potential regions and states. Natural and physical geographic criteria are considerably more relevant if compared to access to market and infrastructure. Farmgate sales measure classified population density ranges, which allow zoning matching to the existence of small local market and subsistence consumption, but not large enough for intensification.

Non-intensive integrated systems are low risk with many positive environmental effects.

Final analysis focus is on regions with poverty above the national average.

Commercial intensive systems, using both open and closed aquaculture techniques, modelling goal is the identification of top high return on investment sites.

Catfish intensive closed-systems spatial distribution is essentially defined by good accessibility to input (feed/seed) and output markets (large urban areas), and the intensification is considered as using closed-circulation technologies like re-circulating tanks, raceways, flow-through systems, and inland ponds. Utilizing constructed or assembled manmade materials, these are based in water reuse and can be placed indoors or in compounds. These techniques are significantly less dependent on physical geographical criteria as water balance, climate, soil, and due to energy requirements, its adoption is still limited by poor and unreliable electric distribution networks. Modelling intensification uses alternative solar power/photovoltaic (PV) potential for energy generation.

Access to IT and a maximum distance to major roads area added as final exclusive criteria.

Open intensive systems consider tilapia pen/cage techniques in large water bodies (LWB). The main location factor is the existence of a reservoir or dam but are also dependent on high accessibility to input and output markets. Open-net pens/ cage techniques in public waters have low initial investment, low energy requirements, and low-cost harvesting. Disadvantages come with higher environmental risk from exchanges with surroundings, conflicting water uses and sometimes inadequate legal frameworks.

All modelling criteria, constraints, and steps is detailed on 5. Data Editing Geoprocessing - SubModels, and 6. Suitability/Potential Modelling.

3. DATA SOURCES

The following data sources are used in modelling:

1. ***Collins Bartholomew*** - Mobile Coverage Explorer raster data representation of the area covered by mobile cellular networks around the world. The dataset series is supplied as raster Data_MCE (operators) and Data_OCI (OpenCellID database).
2. **FAO:**
   - A strategic reassessment of fish farming potential in Africa (Aguilar-Manjarrez & Narh, 1998) data layers: Potential Yields and Soil Suitability
   - FAOStat
   - Rivers of Africa
   - Inland Waters of Africa
   - Geo-referenced database of dams (Africa), Airports, Ports.
   - WaPOR water productivity data for precipitation an evapotranspiration timeseries from 2009 to 2020 - https://wapor.apps.fao.org/catalog/WAPOR_2/1
3. **FAO and IIASA. Global Agro Ecological Zones** version 4 (GAEZ v4) - https://gaez-data-portalhqfao.hub.arcgis.com/
4. **GLW Gridded Livestock of the World** - Gridded Livestock of the World – Latest – 2010 (GLW 3) (harvard.edu) (Gilbert et al., 2018).
5. **HydroSHEDS (Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales)** – DEM- Void-filled elevation raster(30 sec)(Lehner et al., 2006) - https://www.hydrosheds.org/page/availability
6. **FAO GAEZ v4 – Theme 5 –** Actual yields and production - spatial distribution of harvested production (1000 tons).
7. **OpenStreetMap -** Map of the world built by volunteers and released with open-content license. Community mapping using wiki-style collaborative editing software. The data was downloaded in ESRI SHP file format for the selected countries available at: http://download.geofabrik.de/. (Ramm, 2019).

8. **<u>THE WORLD BANK - World - Photovoltaic Power Potential</u>** (PVOUT) - Global Solar Atlas - https://datacatalog.worldbank.org/dataset/world-photovoltaic-power-potential-pvout-gisdata-global-solar-atlas
9. **<u>UNEP-WCMC and IUCN (2021), Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WDOECM)</u>** [Online], May 2021, Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net.
10. **<u>WorldPop</u>**
    - **<u>Human Population Density 2020 – WorldPop2020</u>** - Estimated total number of people per grid-cell 1km.
    https://www.worldpop.org/geodata/summary?id=24777.
    - **Nigeria consumption-based poverty map for 2010** showing proportion of residents living on less than $1.25 a day (Tatem et al., 2013)

4. Vector Data Pre-processing/Editing

This step is partially automated and includes data gathering/download, selection/edition by location and attribute, and the creation of a country database *vector geopakage*[3]:

1. ***OSM Road layer (gis_osm_roads_free_1.shp)*** – Selected by location and attribute to generate a major roads layer. A comprehensive description of the features can be found in (Ramm, 2019). Lack of data on road network conservation, quality, and speed limit for most of the network imposes a conservative approach.
    - Attributes fclass = 'motorway' OR 'trunk' OR 'primary'.
2. OSM Railways (gis_osm_railways_free_1.shp) – Selected by location.
3. OSM Point-of-Interest Layer (gis_osm_pois_a_free_1.shp) – Select by attributes to generate layer Banks.
    - Attributes: 'bank'.
4. OSM Transport Layer (gis_osm_transport_free_1.shp)
    - Attributes: 'ferry_terminal'; 'railway_station'; 'railway_halt'.
5. ***OSM Places Layer (gis_osm_places_free_1.shp)*** - Selected by attribute to generate major human settlements layer.
    - Attributes: 'city'; 'town'; 'national_capital'.
6. ***FAO Data - Ports; Airports; Secondary Airports*** - csv file formats - FAO http://rkp.review.fao.org/geonetwork – selected by location for the country.
7. ***FAO Major rivers*** - Rivers of Africa derived from the World Wildlife Fund's (WWF).
8. ***FAO Inland Waters*** – Clipped by country bondaries.
9. **FAO Geo-referenced database of dams (Africa)**: Point layer clipped by country borders to be used in conjunction with FAO Inland waters and Google Satellite for production of a Nigeria Dams (polygons) layer.
10. **UNEP-WCMC and IUCN** (2021), Protected Planet: The World Database on Protected Areas

[3] http://www.geopackage.org/

(WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-

OECM): Datasets were Clipped for NGA, merged the several layers and overlapping polygons combined.

Data is edited extracted/clipped using country borders.

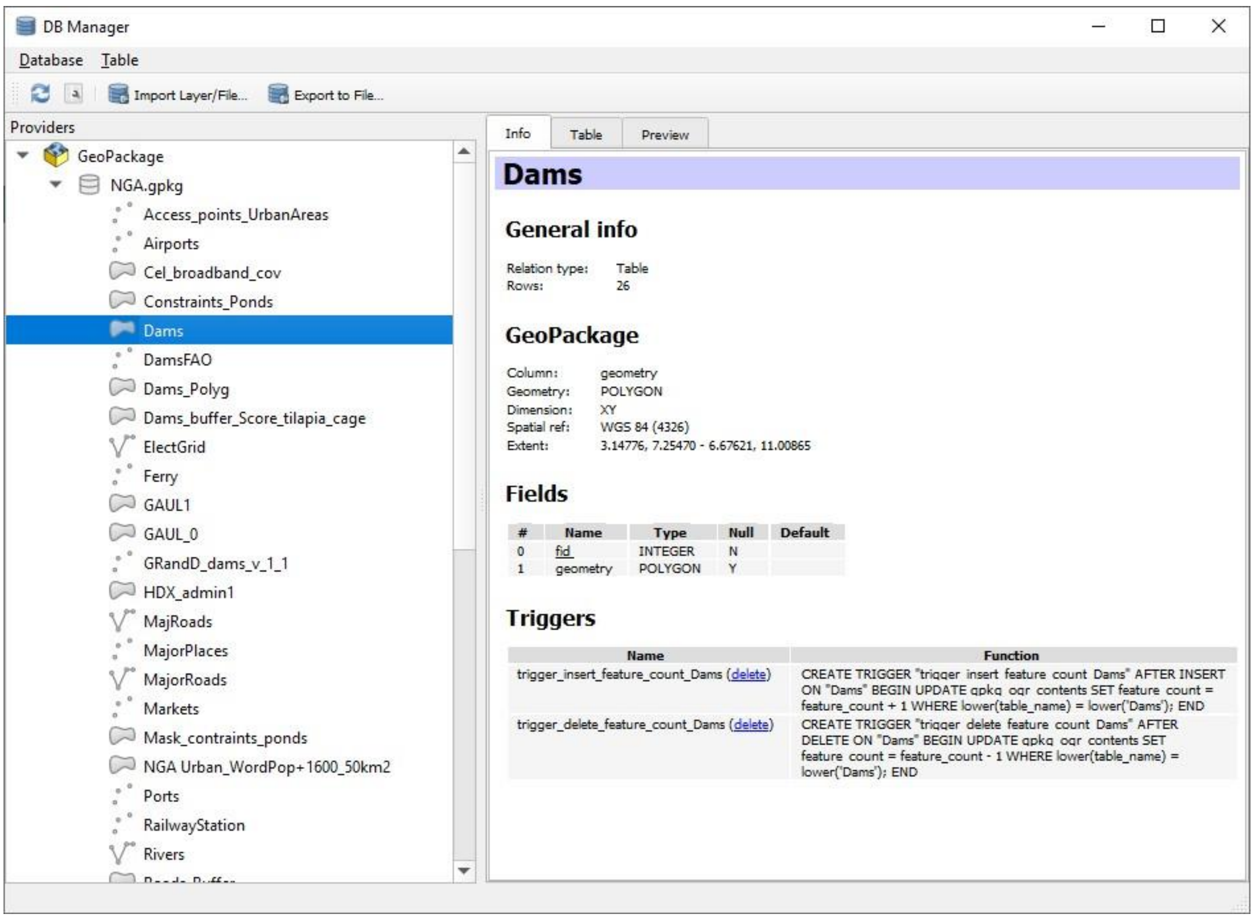

Figure 1 - Geopackage

5. DATA EDITING GEOPROCESSING - SUB MODELS

This section details modelling, editing and geoprocessing steps.

5.1 Infrastructure/ Market Accessibility

Accessibility data processing (travel time/cost surfaces) is partially automated with an algorithm (python script)

The calculation of time/cost distance surfaces is based on some assumptions:

1. Major urban areas are defined using population density above 1600 habitants per square kilometre and a contiguous area larger than 50 km². Accessibility to large urban areas (cities) is calculated to major roads layer and major urban areas intersection points.
2. Lakes (inland waters) are represented by polygons; infrastructure network layers consist of linear features.
3. River navigation is considered for segments with Strahler number higher than 7[4].
4. Road travel time/cost is modelled for cargo freight vehicles, tertiary and local traffic roads are not included; road network conditions are poor[5].
5. Lake and river navigation are treated as surface (polygons) not taking into consideration navigation infrastructure (points), it is assumed for small to medium cargo crafts.

The general steps to produce accessibility maps (travel time surfaces) are:

1. Rasterization vector layers.
2. Creation of cost friction surface.
3. Computation of a cumulative time/cost layer from/to points.

[4] https://www.jayconrod.com/posts/66/the-strahler-number

[5] https://dlca.logcluster.org/display/public/DLCA/2.3+Nigeria+Road+Network

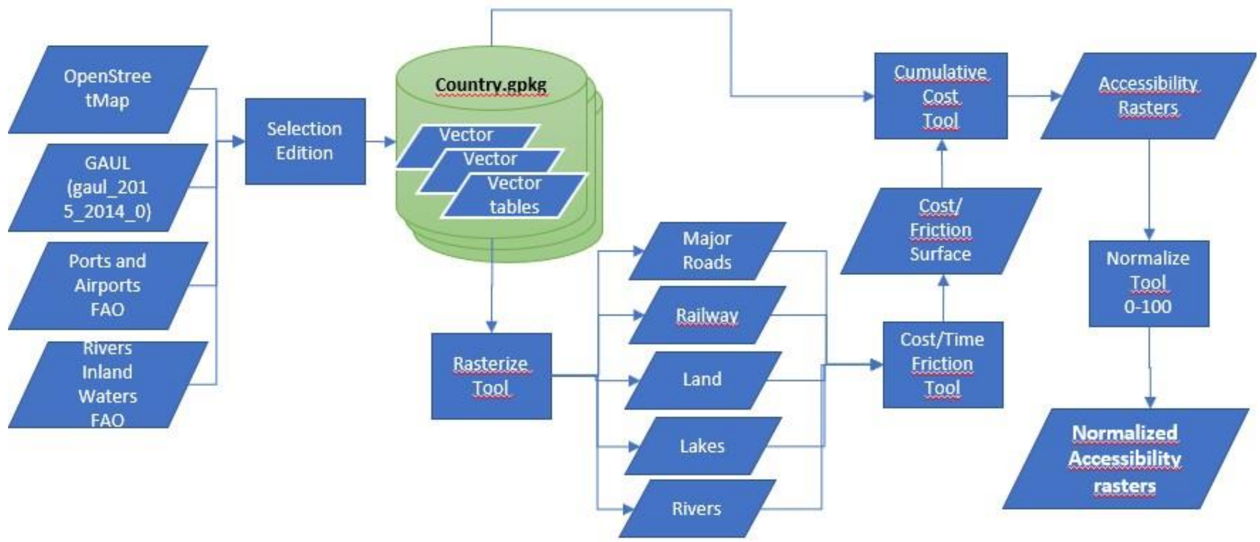

Figure 2 - Accessibility modeling flowchart

1. ***Rasterize* Tool** *(SAGA raster normalization tool)* – Communication/transportation network and surfaces conversion from vector to raster, 1km cell grid burning a value for an average time (minutes) to cover a cell for the considered transportation mode ((a) land/walk, (b) major roads/vehicle, (c) railway/train, (d) navigation.
    - Modelling values:

Land (a)	10
Major roads (b)	1
Railway (c)	0.6
Navigation (d)	3

The rasterization outputs 1km raster grids with the modelling value per cell. Modelling value - speed - parameter can be changed/adapted to a different specification.

2. ***Cost/Friction Tool*** *(GRASS r.series tool)* – A cost or friction surface is obtained overlaying (a), (b), (c), (d) grids, propagating the minimum cell value.
3. ***Cumulative Cost Tool (****GRASS r.cost tool)* – Service Area – The cumulative cost/accessibility maps are produced selecting a central point, or points, and defining service areas.

Calculation of accessibility to major urban areas considers the threshold urban>1600 habitants/km², area>50km² (52 urban regions in Nigeria). Accessibility is calculated using roads layer intersection points with urban areas (639 access points).

Assuming the large production consumption deficit, cross border trade (demand), accessibility to large regional cities was not considered.

4. ***Normalization*** –Units are normalized/scaled (0 to 100) for location score calculations (weighted sum). Lower accessibility value (time or cost) corresponds to 100 (high accessibility).

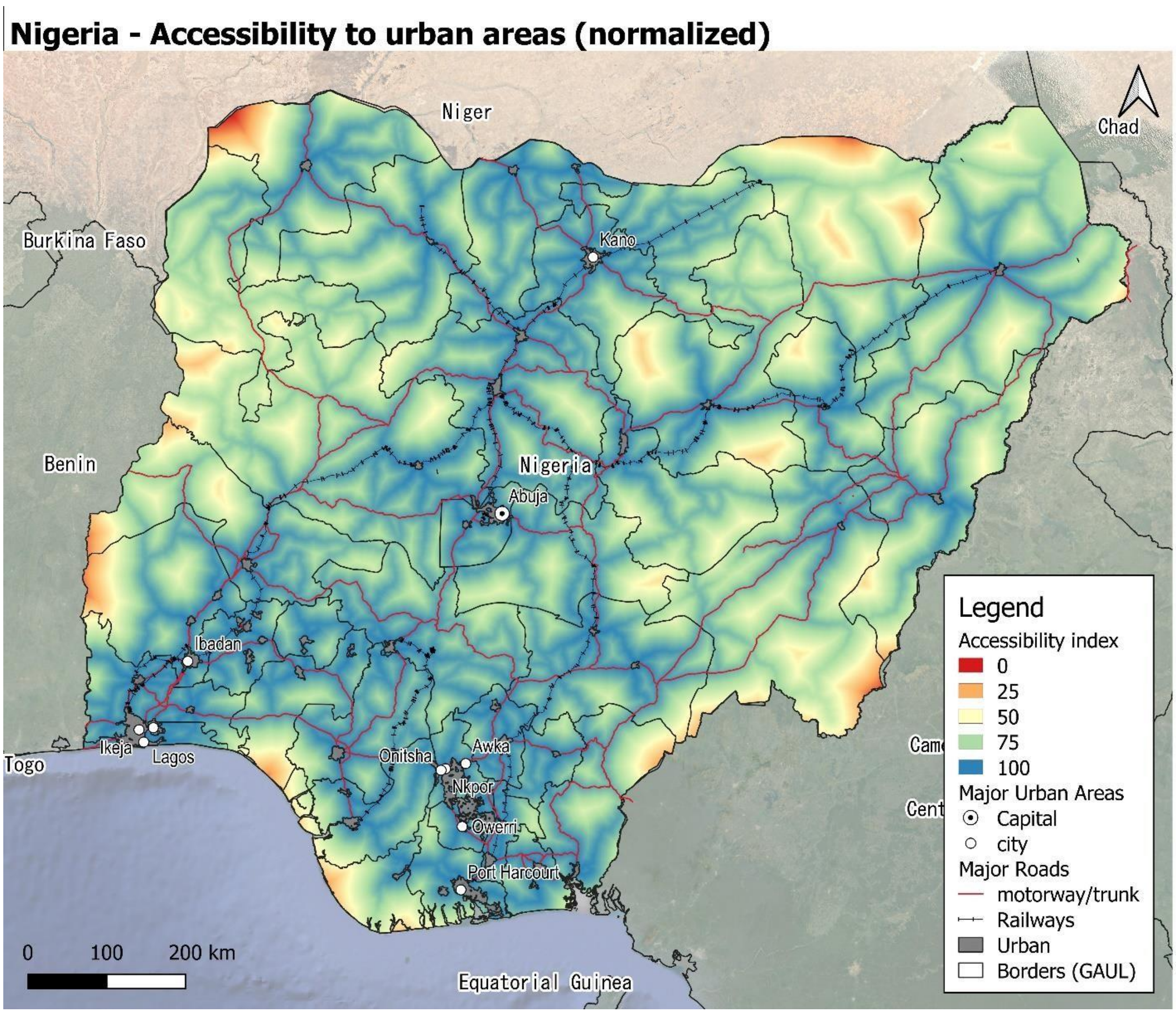

Figure 3 – Normalized accessibility to large cities and metropolitan areas

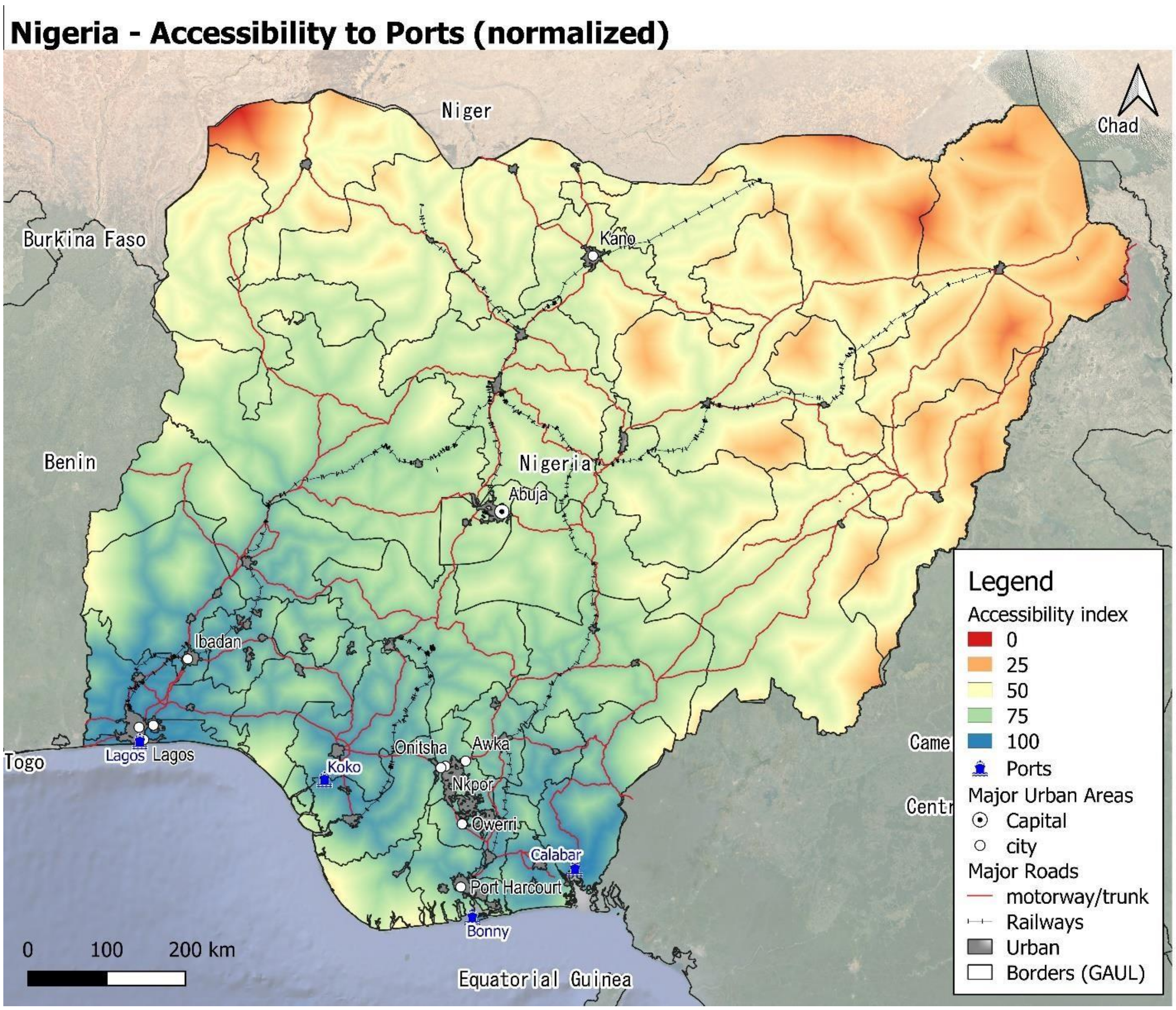

Figure 4 - Normalized accessibility to ports

5.2 Market/demand Criteria

Market demand criteria are built on population density and accessibility, using as base data WorldPop2020 human population density estimates for 2020 (1km grid/raster).

5.2.1 - Cities/Urban areas

Large urban or metropolitan areas were defined as having more than 1600 habitants/km² and covering an area larger than 50km², resulting in a total of 52. The following steps applying: 1. ***Raster calculator tool:*** to produce a 1/0 layer - 1 = PopDens>1600

2. ***Polygonise tool*** - converts the raster/grid to vector polygons.
3. ***Geometries (Check validity /fix geometries tools):*** Polygon geometries are checked for errors and validated.
4. ***Field calculator tool***: create a new field “Area” where *$area* ($km^2$).
5. Export>save features as: UrbanAreas
6. ***Select by attributes***: * FROM UrbanAreas ” WHERE “Area”>50km^2.
7. Export>save selected features as: Major UrbanAreas.
8. ***Zonal statistics tool:*** calculates statistics from WorldPop2020 raster for each polygon feature of vector layer Major Urban Areas.

Three major urban/metropolitan regions should be given special consideration: Lagos 15.7 million habitants, Kano 7.3 million and the southeast Igbo region Onithsa/Awka/Oweri triangle with 5.4 million.

5.2.2 Farmgate sales

Farmgate sales criteria sub-modelling applies Aguilar-Manjarrez and Narh classification to 2020 population density data:

- Class 4 - Very suitable: 150-300 [h/km^2]
- Class 3 – Moderately suitable: 25-149 [h/km^2]
- Class 2 – Marginally suitable: 1-24 [h/km^2]
- Class 1 – Unsuitable: <1 and >300 [h/km^2]

WorldPop data is classified with the following sequence:

1. SAGA Raster tools – reclassify values: 1-4 pop density classes.
2. ***Normalization*** –Units are normalized/scaled (0 to 100) for location score calculations (weighted sum).

5.3 Physical geography conditions

5.3.1 Water Balance

Water availability is estimated using an annual balance. Water sub-model used WaPOR precipitation and evapotranspiration monthly time-series from 2009 to 2020 for calculating a mean water balance layer, through the following steps:

1. ***Clipping*** to country borders.
2. ***GRASS r.series tool*** – mean value calculation.
3. ***Raster calculator tool***: modelling values: (Precipitation *1.1) - (evapotranspiration*1.3).
4. ***GRASS r.ressamp.stats*** - Resampling using aggregation (matching raster resolution).
5. ***SAGA raster normalization tool*** – grid scaling normalizing (0-100)

5.3.2 Soil and terrain suitability for ponds

Soil suitability sub-model is directly adopted from Aguilar-Manjarrez and Narth data assuming there is no substantial change in conditions since. It represents limitations for fishpond construction and uses FAO soils units, acid sulphate layer; organic layer; lime requirement; clay content; depth to water table; salinity/alkalinity; gypsum content; soil depths.

Slope is updated using higher resolution data (Watershed DEM 30s) and the modelling method steps are:

1. ***Clipping*** – Digital elevation model (DEM) and Soil data to country borders.
2. ***GDAL Slope tool****:* DEM to slope transformation (in degrees).
3. ***SAGA Raster tools – reclassify values*** – Slope layer classification (4 classes)
    - Class 4 - Very suitable: <2
    - Class 3 – Moderately suitable: 2 - 5
    - Class 2 – Marginally suitable: 5 - 8
    - Class 1 – Unsuitable: > 8
4. ***Raster Calculator tool***: Soil and terrain suitability for fishponds = (1.5X soils) + Slope

5. ***SAGA raster normalization tool*** – grid scaling normalizing (0-100)

SoilSlope sub-model values are used for modelling small scale extensive to semi-intensive integrated farming systems using ponds.

Intensive commercial closed systems modelling use slope data separately.

5.4 Inputs

5.4.1 Crops

Crop products and by products can be used directly as feed or as raw materials for feed mills. Local aquafeed production can be determinant for fish farming sustainability and competitiveness.

Top crop commodities were selected from FAOSTAT production data and averaged for the latest 5-year period 2015-2019.

CROP	PRODUCTION (t)
Cassava	57,453,488.2
Yams	50,235,383.2
Maize	10,906,006
Oil palm fruit	9,105,034.8
Rice, paddy	7,696,879.6
Vegetables, fresh nes	7,269,278.4
Sorghum	6,993,020.2
Rice, paddy (rice milled equivalent)	5,133,818.6

Selected crop commodities represent 77.93% of a total production with a mean yearly value of 154,792,909 tons.

Crop input sub-model uses GAEZ production spatial data, geoprocessing is:

1. ***Clipping*** – To country borders.
2. ***GRASS r.series tool*** – top crop aggregation (sum).
3. ***SAGA raster normalization tool*** – grid scaling normalizing (0-100)

5.4.2 Livestock

Livestock input can be considered for both organic fertilization (manuring) or the use of its byproducts (blood, bones etc.) for feed ingredients. Different production systems requirements imply distinct sub-models.

5.4.2.1 Open non-intensive and integrated production systems (ponds and small water bodies)

Sub-model uses chicken and duck density grids from GLW. Livestock is considered for manuring, feeding, and as natural aerators in the case of duck-fish integrated farming.

As feed, integrated systems benefit from chicken and duck nutritious rich faeces and poultry direct feed wasting. (Oribhabor & Ansa, 2006). As organic fertilizing (manuring) it contemplates that chicken are mostly farmed enclosed, employing cages and feeders, thus consisting of the best manure source.

Input sub-model uses GLW production spatial data:

1. ***Clipping*** –to country borders.
2. ***GRASS r.series tool*** – duck and chicken density aggregation (sum).
3. ***SAGA raster normalization tool*** – grid scaling normalizing (0-100)

5.4.2.2 Intensive production systems

Intensive production systems usually do not use organic fertilizing and are artificially fed. Research as identified slaughterhouse waste by-products as viable, low-cost alternatives ingredients to both industrial and small-scale feed mills.

Livestock is modelled as feed input, aggregating Goat, Sheep, Pig, Cattle, animal density, weighted by the average live weight (LW), adopting Tacon 1989 and Vincke 1985 values, in (Aguilar-Manjarrez & Narh, 1998):

- Goat: 30kg
- Sheep: 30kg
- Cattle: 210kg
- Pig: 63kg
- Chicken: 2.2kg

Modelling steps:

- ***Clipping*** – individual livestock layers to country borders.
- ***GRASS r.series tool –*** animal density aggregation (weighted sum): (*goat X 0.089) + (sheep X 0.089) + (cattle X 0.626) + (pig X 0.188) + (chicken X 0.007).* ○ ***SAGA raster normalization tool*** – grid scaling normalizing (0-100)

5.4.3 Photovoltaic energy generation potential

Closed faming systems intensification is bound by availability and reliability of energy supply. Considering that a large part of the territory has no grid access and that the existing network has serious stability and quality issues, the model inputs an alternative energy source, photovoltaic power potential (PVOUT), average daily total in kWh/kWp, as a measure of intensification potential. Data processing involves: ○ ***Clipping*** –to country borders.

- ***SAGA raster normalization tool*** – grid scaling normalizing (0-100) ○ Raster resampling/aligning.

6. Suitability/Potential Modelling

The zoning effort targets Catfish and Tilapia farming systems using dissimilar technologies and differently affected in location by competing criteria or factors:

1. Extensive to semi-intensive open systems using ponds or small water bodies.

2. Peri-urban intensive/commercial catfish closed (semi-closed) systems using ponds, tanks, RAS, flow through or recirculation.
3. LWB Intensive Tilapia farming systems using cages.

The following sections detail selected criteria, weighting, and applied constraints.

6.1 Extensive/semi-intensive systems

Extensive/semi-intensive and integrated small-scale farming systems, for both Catfish and Tilapia, are the most dependent on natural and geographic factors or criteria. Feeding can be based on natural food supply (from the SWB), from integrated systems (crop/livestock waste), or additional complementary feeding resourcing to on farm or locally produced feed.

Assumptions

1. All territory permits high or very high potential yields (crops/y) - number of days where temperature amplitudes are within the optimal growth range.
2. Water availability is suitable or very suitable for most of the territory - criteria weighting could be lowered and weighting transferred to farmgate sales.

Considered criteria:

a. Farm-gate sales.
b. Water Balance.
c. Soil/Slope - (1.5X soils) + Slope.
d. Byproducts inputs (Crops/Livestock) (1.5X ChickenDuck) + CropAggGAEZ).

Constraints:

a. Urban areas.
b. Protected areas.
c. Dams and Large Water Bodies.

6.1.1 Location Score / Multicriteria weighted sum

Using GRASS r.series tool, a location score is obtained by way of a simple arithmetic weighted sum of normalized/scaled grids, theoretically varying from 0 to 100:

("WaterBalance" X 0.5) + ("Soil/Slope " X 0.25) + (“Byproducts” X 0.125) + (”FarmgateSales” X 0.125)

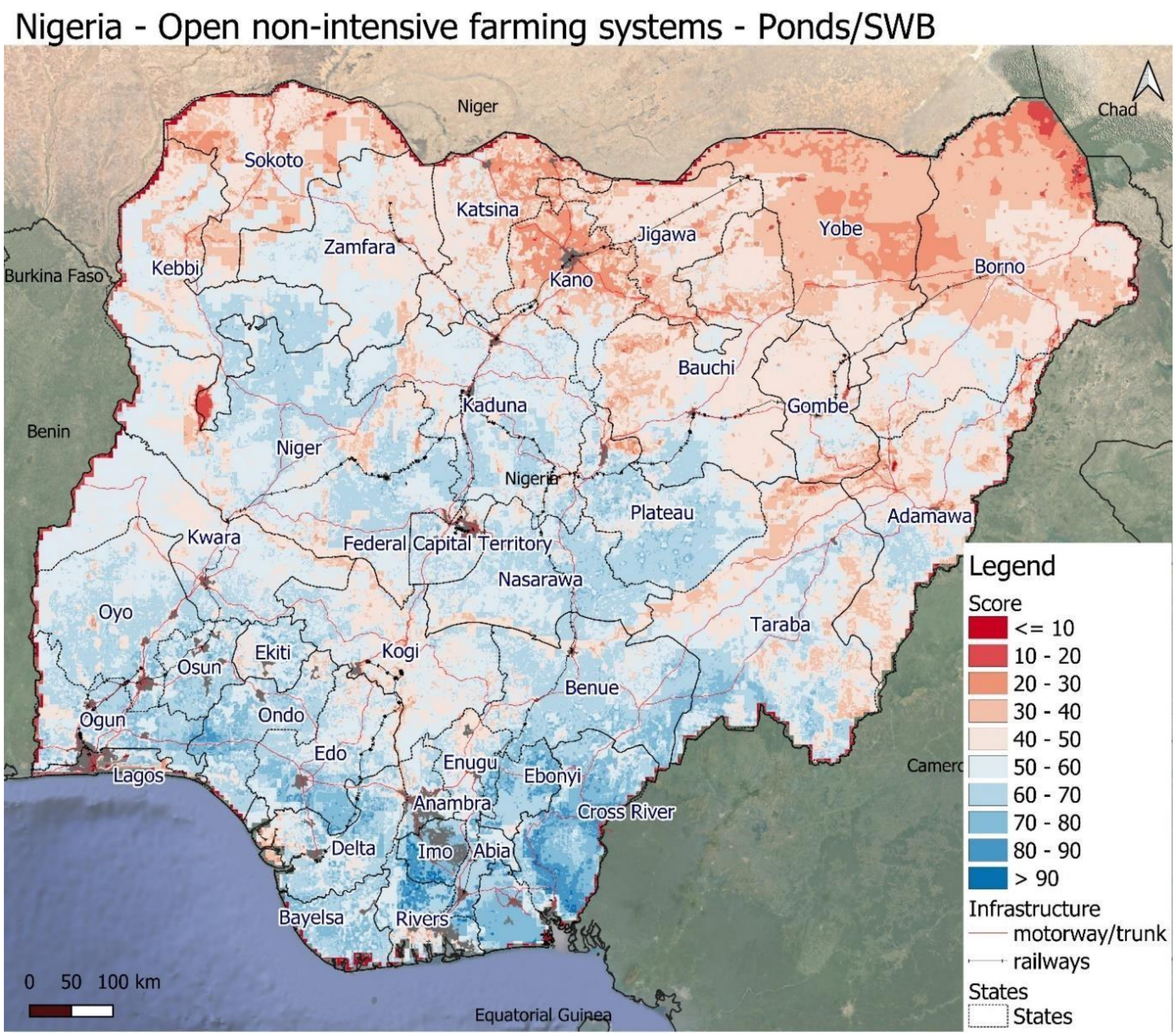

Figure 5 –non-intensive and integrated farming potential

A high potential is present in most of the territory, but higher potential areas can be found in southern and central states. North and northeast regions bordering Chad and Niger present the lowest potential.

6.1.2 Constraints and Final Location Mapping

The following constraints are applied:

a. Urban areas.

b. Protected areas.

c. Dams and Large Water Bodies.

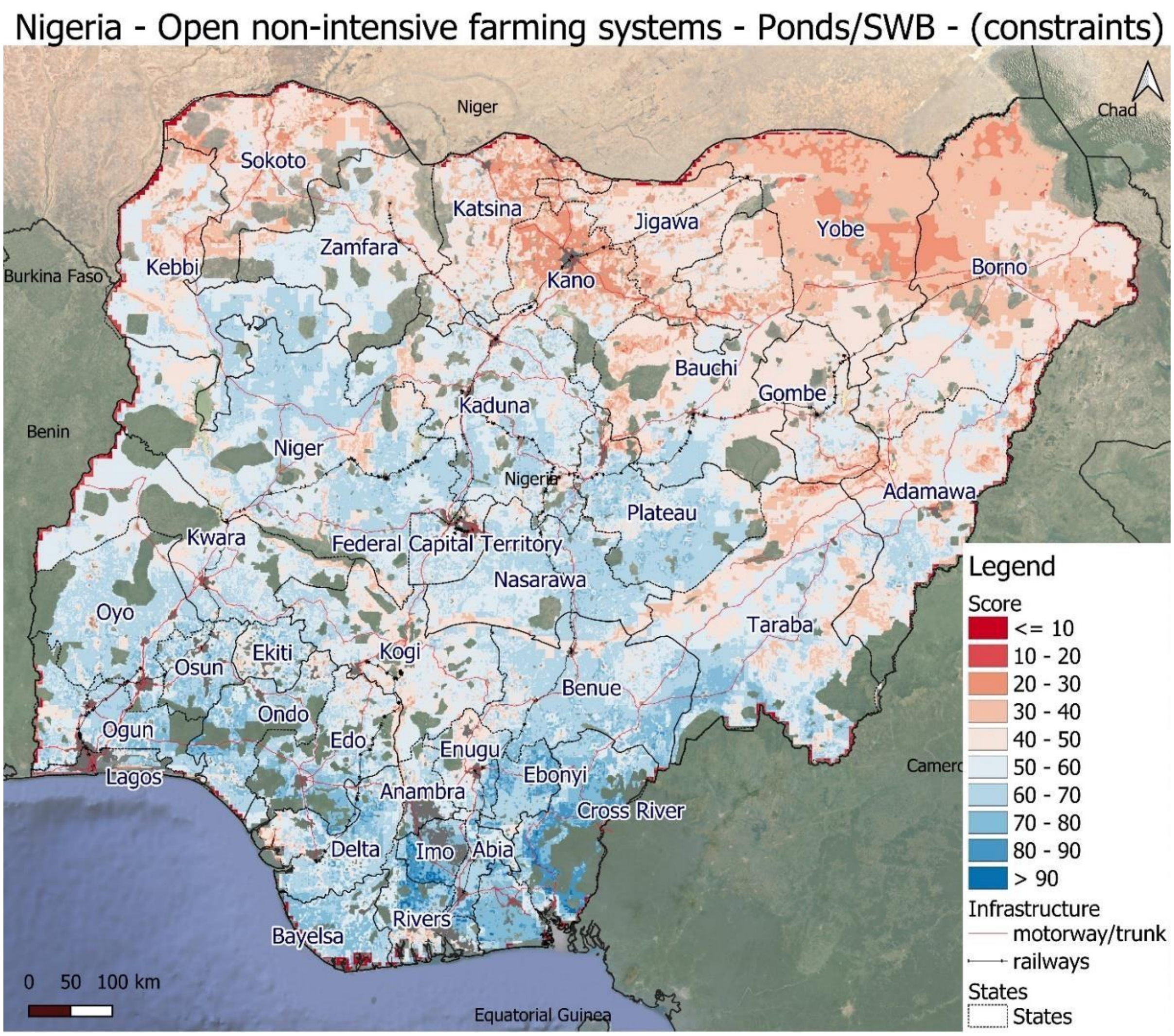

Figure 6 –non-intensive and integrated fish farming potential (constraints)

Final maps with constraints reinforce the pattern: Southern and central north regions high potential for low input fish farming, with the southern States of Imo and Rivers and Cross Rivers showing close to optimal conditions. Northern states Kebbi, Sokoto, Katsina, Kano, Jigawa, northeast Yobe and Borno, have weak conditions, but still some limited areas indicate the minimum requirements for small-scale and subsistence fish farming.

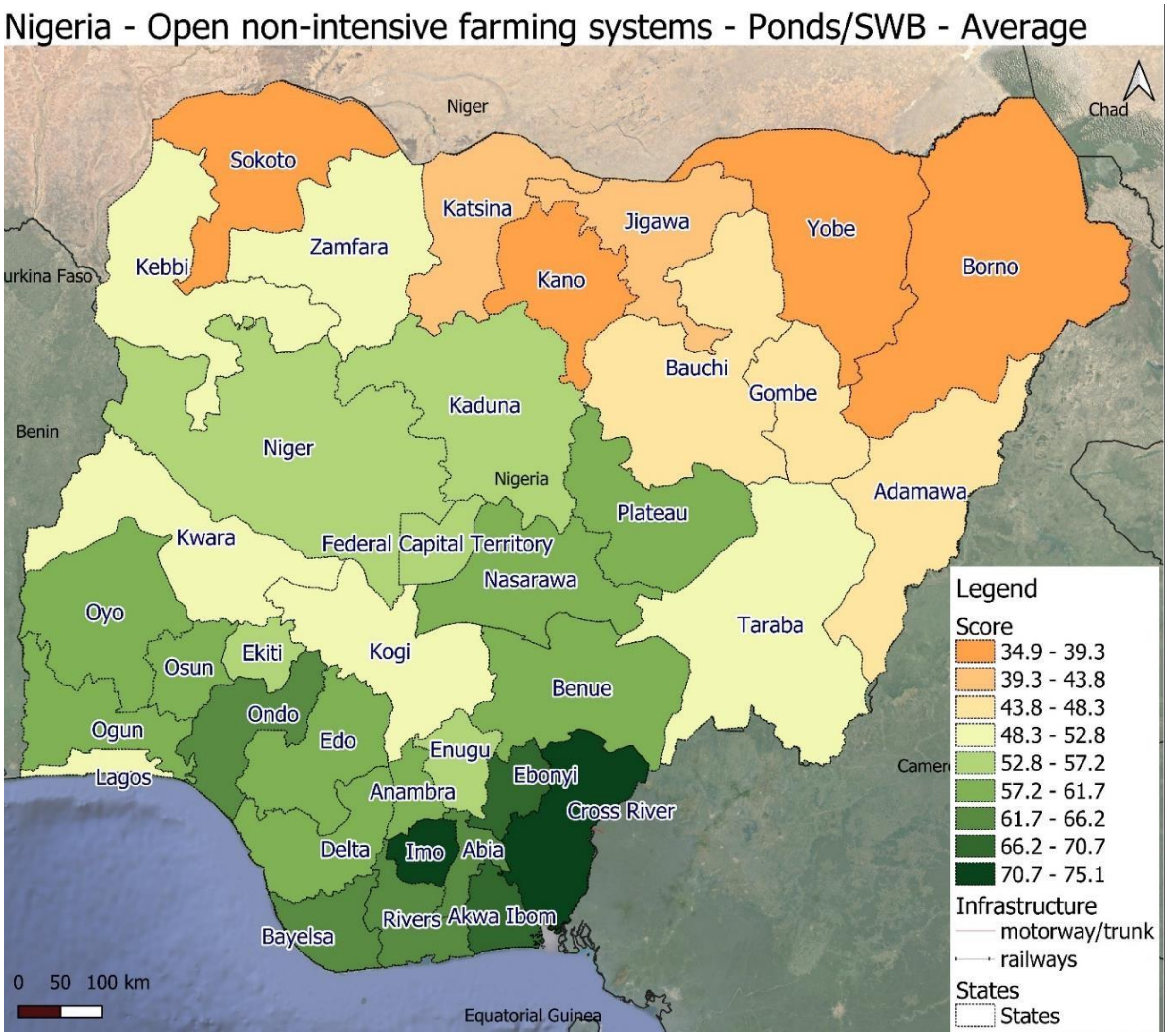

Figure 7 - State average location score open non-intensive farming systems

Analysing at state averaged score reveals south and southeast states Imo, Akwa Ibom, Ebonyi and Cross River have excellent conditions, northern and northeast states show low potential. Another interpretation highlights that most states score above 50, confirming widespread good conditions for fish farming.

6.1.3 Constraints and Final Location Mapping with poverty

The analysis was also performed using consumption-based poverty from WorldPop (2010). Although outdated (2010), it is assumed that the population segment escaping extreme poverty is essentially located in southern states and consisting of the urban middle class. Still, poverty spatial patterns persist, with rural/urban and south/northern divides.

For this example, the score map with constraints is filtered using poverty above the national average.

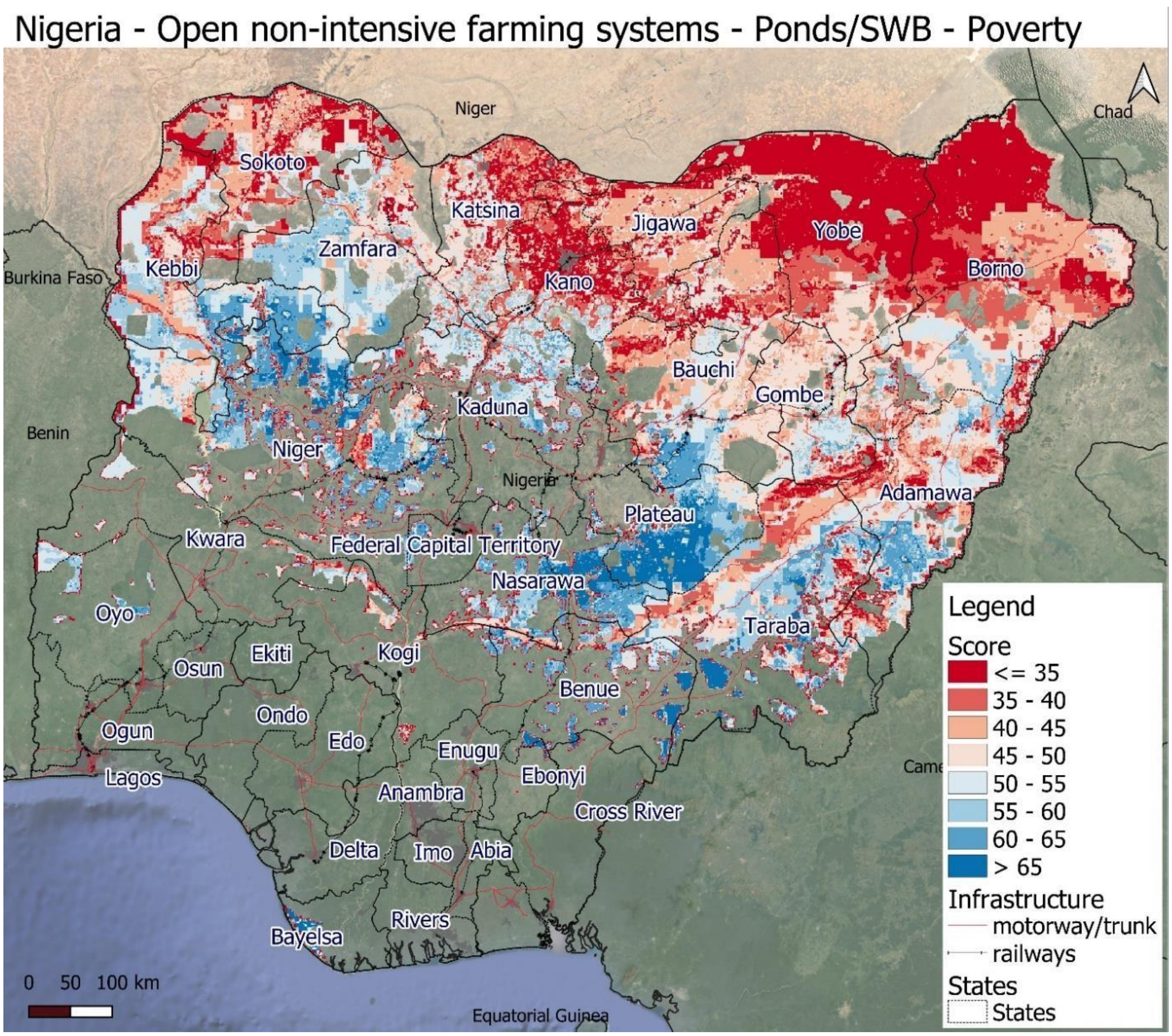

Figure 8 - Figure 4 – Extensive/ non-intensive and integrated catfish farming potential with poverty

Considering above the average poverty the middle belt and some northern Nigeria states should be targeted for interventions: Kebbi, Niger, Zamfara, Kaduna, Plateau and Northeast Taraba and Adamawa. Smaller sub-state scale zoning can also be delineated for other Northern and Northeast regions states. Additional substate scale analysis could be pursued using high resolution poverty data.

Prudent interpretation and usage of output is advised; poverty data is the percentage of people living under 2USD/day and the national average was 83% (WorldPop 2010).

6.2 Peri-urban intensive catfish closed (semi-closed) systems

Intensive closed farming systems adoption is limited in most of sub-Saharan Africa by poor and unreliable energy distribution networks (Satia, 2017). Solar power/photovoltaic (PV) can supply the operational needs [6] of closed systems pumps and aerators, to provide oxygen, to move water into and through the system, and to purify the water. Suitability/potential modelling introduces as intensification measure PV potential alternative energy generation.

It is assumed that closed systems techniques using ponds, tanks, RAS, flow through and recirculation are considerably less dependent on natural or physical geographical criteria. These techniques require much less water availability being based in reuse/recirculation. Most tank systems can be placed indoors or compounds, improving security, but also lowering climatic limitations. Tanks are produced with manmade artificial materials, concrete, steel, fiberglass, or plastic. Some can even be dismantled and reassembled, so land and soil requirements are similarly minimal. Water balance is even less relevant considering that the suitability modelling does not weigh up groundwater resources.

Closed containment farming methods pose smaller environmental risks due to controlled exchange between farm and environment. It reduces pollution, fish escapes, negative wildlife interactions, parasite, and disease transfer. In recirculation methods water is treated and recirculated, with minimal wastewater discharges.[7]

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[6] https://thefishsite.com/articles/photovoltaic-applications-in-aquaculture-a-primer

[7] https://www.seachoice.org/info-centre/aquaculture/aquaculture-methods/

Assumptions

1. All territory permits high or very high potential yields (crops/y) - number of days where temperature amplitudes are within the optimal growth range.
2. Water balance is positive, there is water availability in most of the territory (even without ground water input).
3. Closed intensive systems are not dependent on soil characteristics.

Considered criteria.

a. Market accessibility (large urban areas).
b. Water Balance (water requirements).
c. Crop input (CropAggGAEZ) - availability of agricultural by-products.
d. Livestock input (weighted animal density aggregation) - availability of livestock by-products.
e. Slope - terrain suitability.
f. Farm-gate sales - as function of population density.
g. Photovoltaic (PV) energy potential.

Constraints

a. Urban areas.
b. Protected areas.
c. Dams and Large Water Bodies.

Exclusive criteria

a. Mobile broadband coverage
b. Maximum distance to major roads

The exercise presents alternative outputs with and without PV.

6.2.1 Intensive closed systems location score (without PV)

Using GRASS r.series tool, a location score is obtained by way of a simple arithmetic weighted sum (normalized/scaled grids), theoretically varying from 0 to 100, with the following weighting: *(“Accessibility MajorUrbanAreas” X 0.5) + ("WaterBalance" X 0.2) + (“CropsInput” X 0.1) +*

(“LivestockInput” X 0.10) + ("Slope " X 0.05) + (”FarmgateSales” X 0.05)

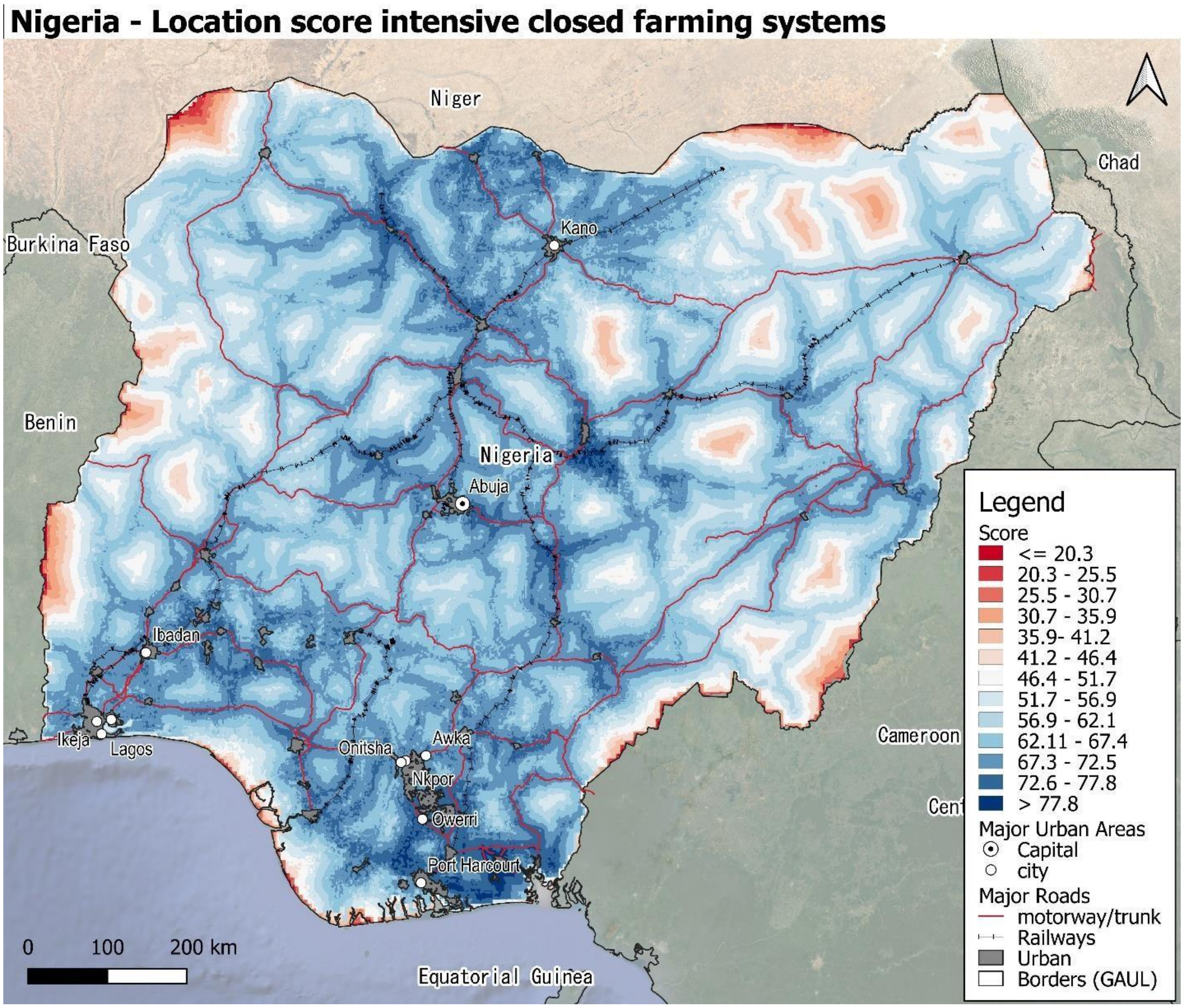

Figure 9 - Intensive closed catfish farming systems potential

Due to less dependence on both soil and water, intensive closed commercial farming systems suitability spatial pattern is more pervasive than for open non-intensive systems. The large metropolitan/urban areas pull is highlighted since the demand factor is of major importance.

Main contiguous urbanized and metropolitan regions should be given special consideration: Southwest Lagos 15.7 million habitants, Kano in the north with 7.3 and the southeast Igbo region Onithsa/Awka/Oweri triangle with 5.4 and close to Port Harcourt 3.4. Although corresponding to small to medium cities when compared to metropolitan areas, central Nigeria cities around federal capital Abuja also reveal high score areas.

6.2.2 Intensive closed systems location score - with PV

Using GRASS r.series tool, a location score is obtained by way of a simple arithmetic weighted sum (normalized/scaled grids), theoretically varying from 0 to 100, with the following weighting:

("Accessibility MajorUrbanAreas" X 0.5) + ("PVPotential" X 0.15) + ("CropsInput" X 0.1) + ("LivestockInput" X 0.10) + ("Slope " X 0.05) + ("FarmgateSales" X 0.05) ("WaterBalance" X 0.5)

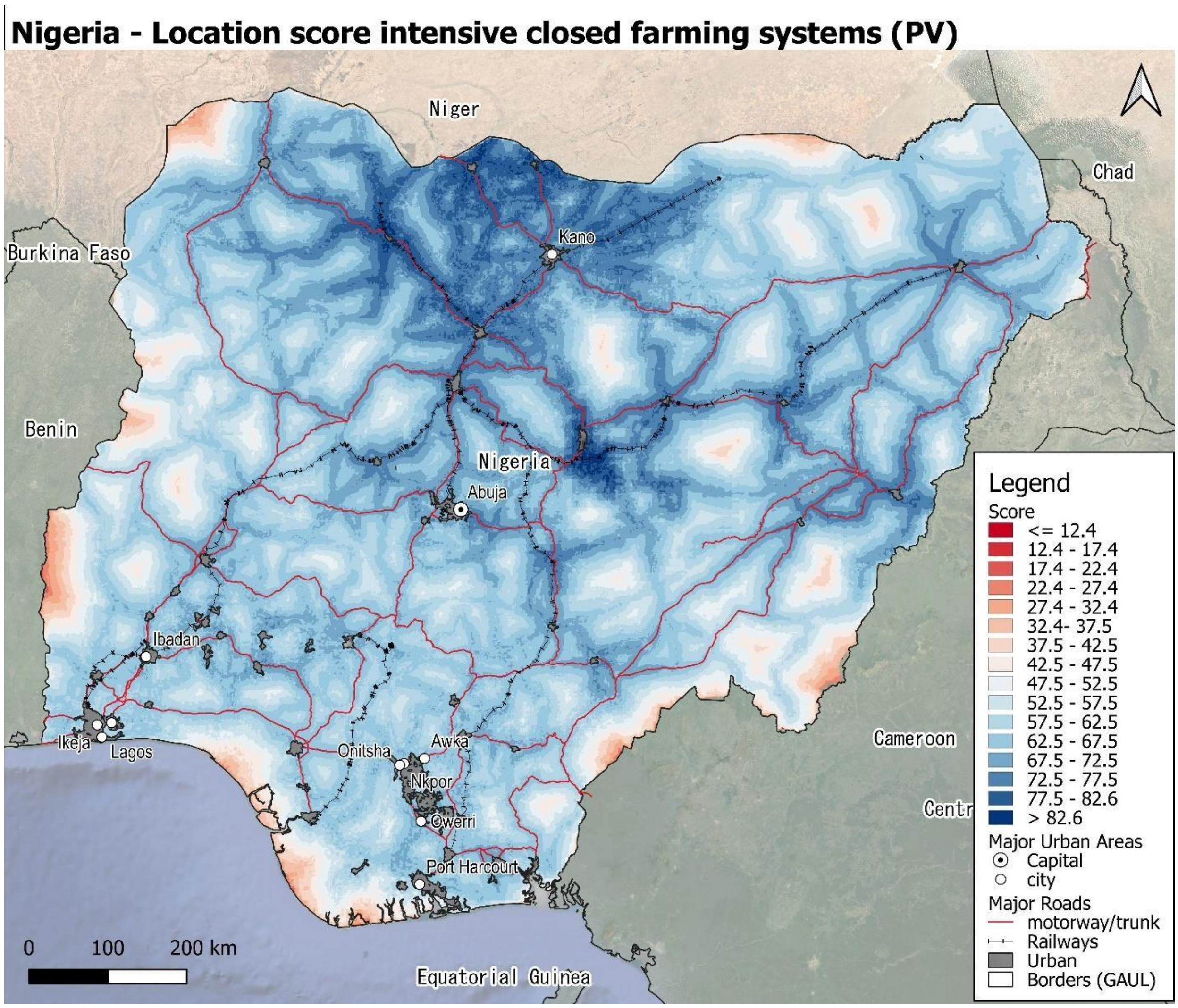

Figure 10- Intensive closed catfish farming systems intensification potential PV

Using PV energy generation as location factor highlights central and northern regions where er PV potential is higher.

Population density defined, market/demand factor, can be misleading. Large urban population concentration in Kano metropolitan but neither poverty nor purchase power are considered.

6.2.3 Constraints

A set of common constraints are applied to score maps:

d. Urban areas

e. Protected areas.

f. Dams and Large Water Bodies

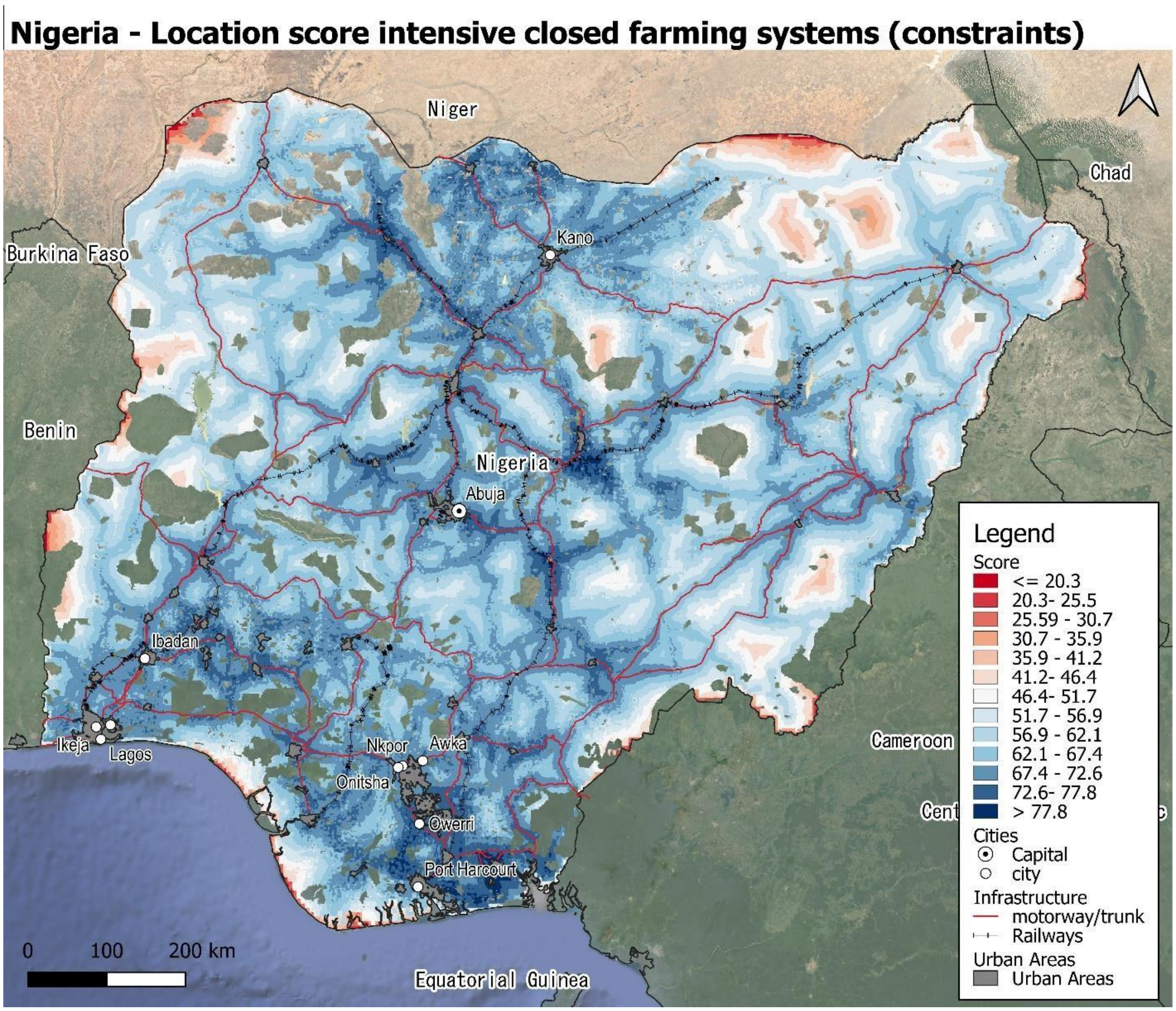

Figure 11 - Intensive closed catfish farming systems potential (constraints)

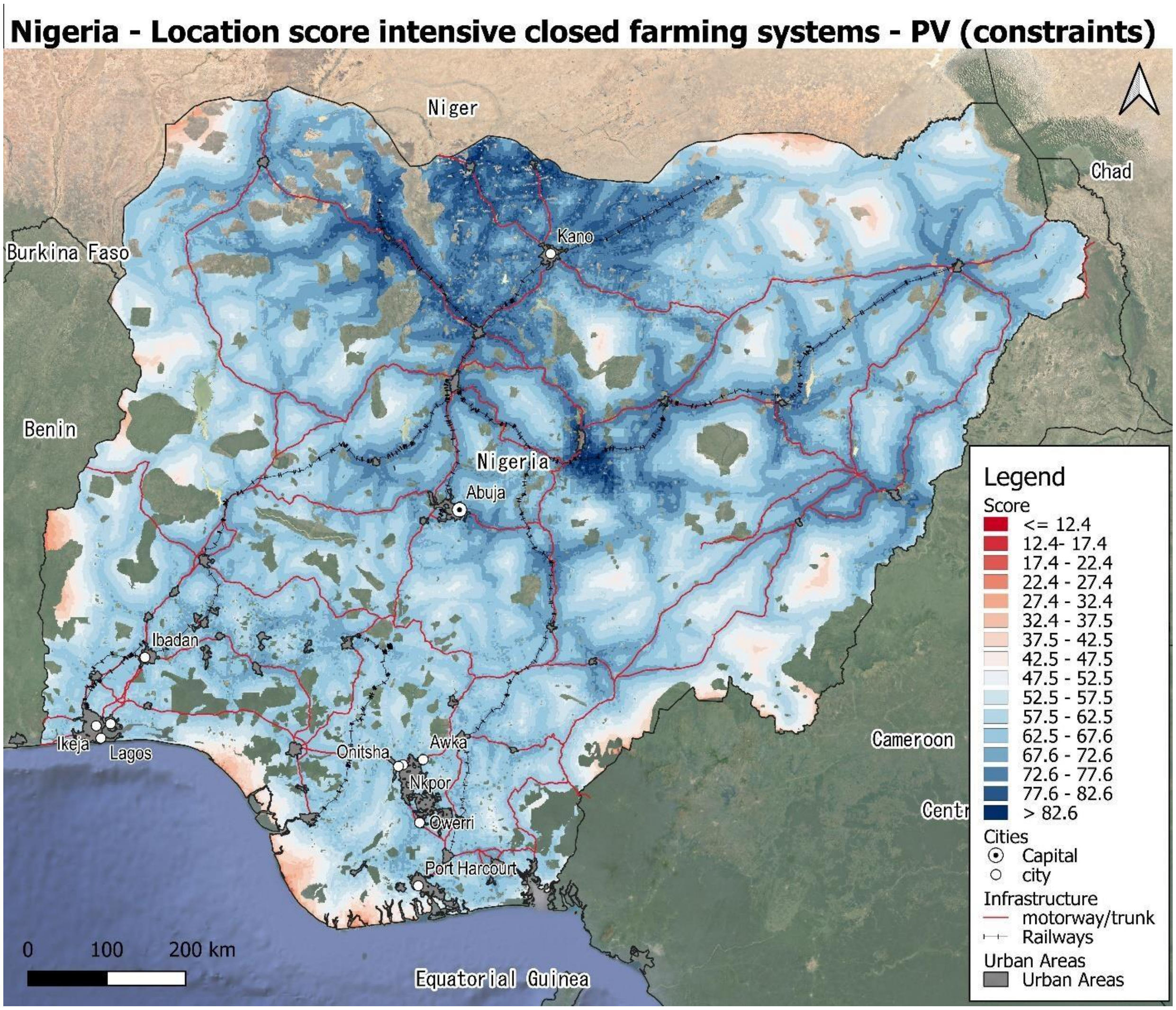

Figure 12 – - Intensive closed catfish farming systems intensification potential PV (constraints)

6.2.4 Final Maps

Final location mapping objective is identifying optimal theoretical investment sites, employing as exclusive criteria, a defined distance to major roads, and access to ITC (mobile broadband coverage).

ITC usage has a growing importance in marketing, helping to reduce information asymmetry between traders and producers, allowing information access to support operations, microcredit apps/tools, and innovative digital finance using for example blockchain technologies. Innovative applications can also be envisioned in fields like disease monitoring or management.

Access to finance, linear distance to bank agency location, is not utilized due to poor base data.

Final mapping follows the subsequent procedure:

- ***Buffering*** – the tool computes a buffer area for all the features in an input layer using fixed or dynamic distance:
    - Major roads - 2km (0.018 degree) buffer radius.
- ***Intersection*** - extracts the overlapping portions of features in the Input and Overlay layers: Roads_Buffer and Mobile_Broadband_coverage.
- ***Dissolve*** - Takes the intersection vector layer and combines the features into a new feature, a single polygon.
- ***Clip Raster by Mask Layer*** – The grids are extracted using the polygon.
- ***Raster Calculator***:
    - Final recommended top score sites are selected using the 95 percentile and raster calculator: *“raster”>95th percentile X “raster”*
    - Setting the value 0 as *no data*: *((“raster” >0) X “raster”)/ (((“raster” >0) X 1) + (“raster” >0) X 0)))*

Closed intensive catfish systems map outputs are presented at regional scale, where top locations are identified, in central and southern states.

For closed intensive catfish systems intensification via alternative PV power input, output map is produced at regional scale for North/North central states.

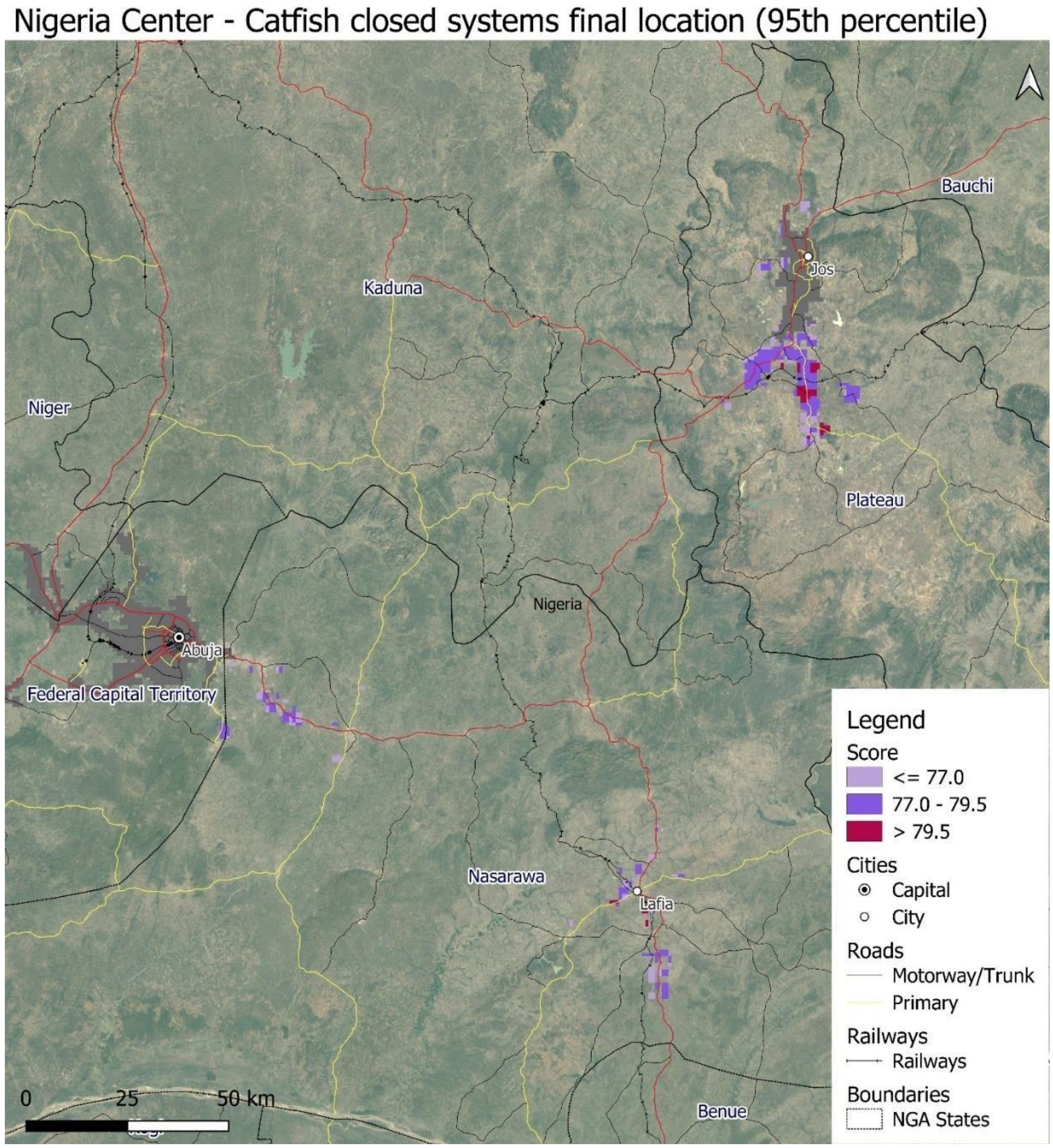

Figure 13 – Catfish closed/semi-closed farmed systems final sites central Nigeria

Intensive closed systems top score sites in the central region concentrate in Plateau state, with a larger area around the city of Jos, and in smaller areas in Nasarawa state, reflecting Abuja Federal Capital Territory market weight.

South and Southeast region states high levels of urbanization include several mid to large cities/urban areas. Top locations are predominantly in Rivers and Akwa Ibom States. Smaller areas with lower score sites can also be found in Imo, Abia, Cross River and Ebonyi.

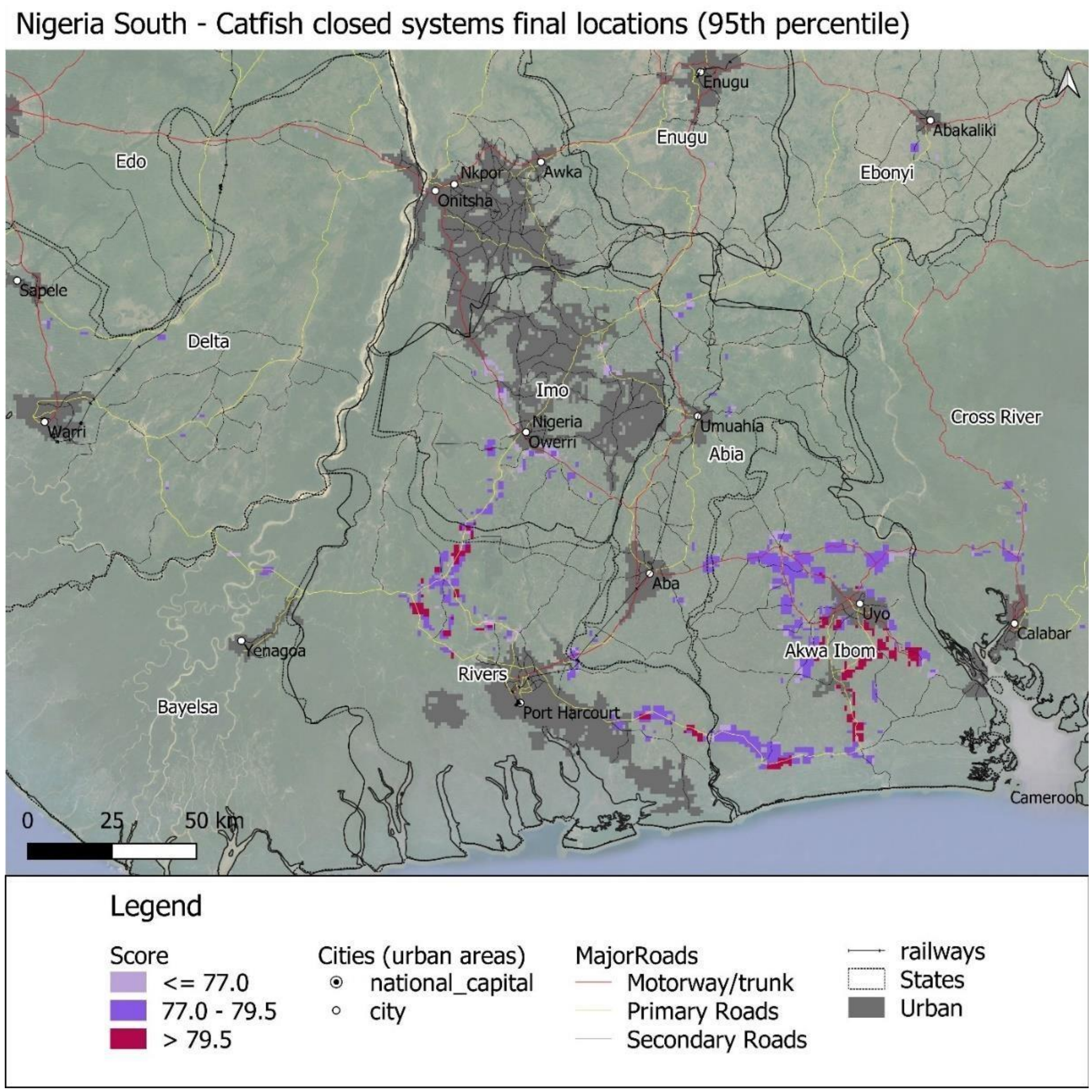

Figure 14 - Catfish closed/semi-closed farmed systems final sites south Nigeria

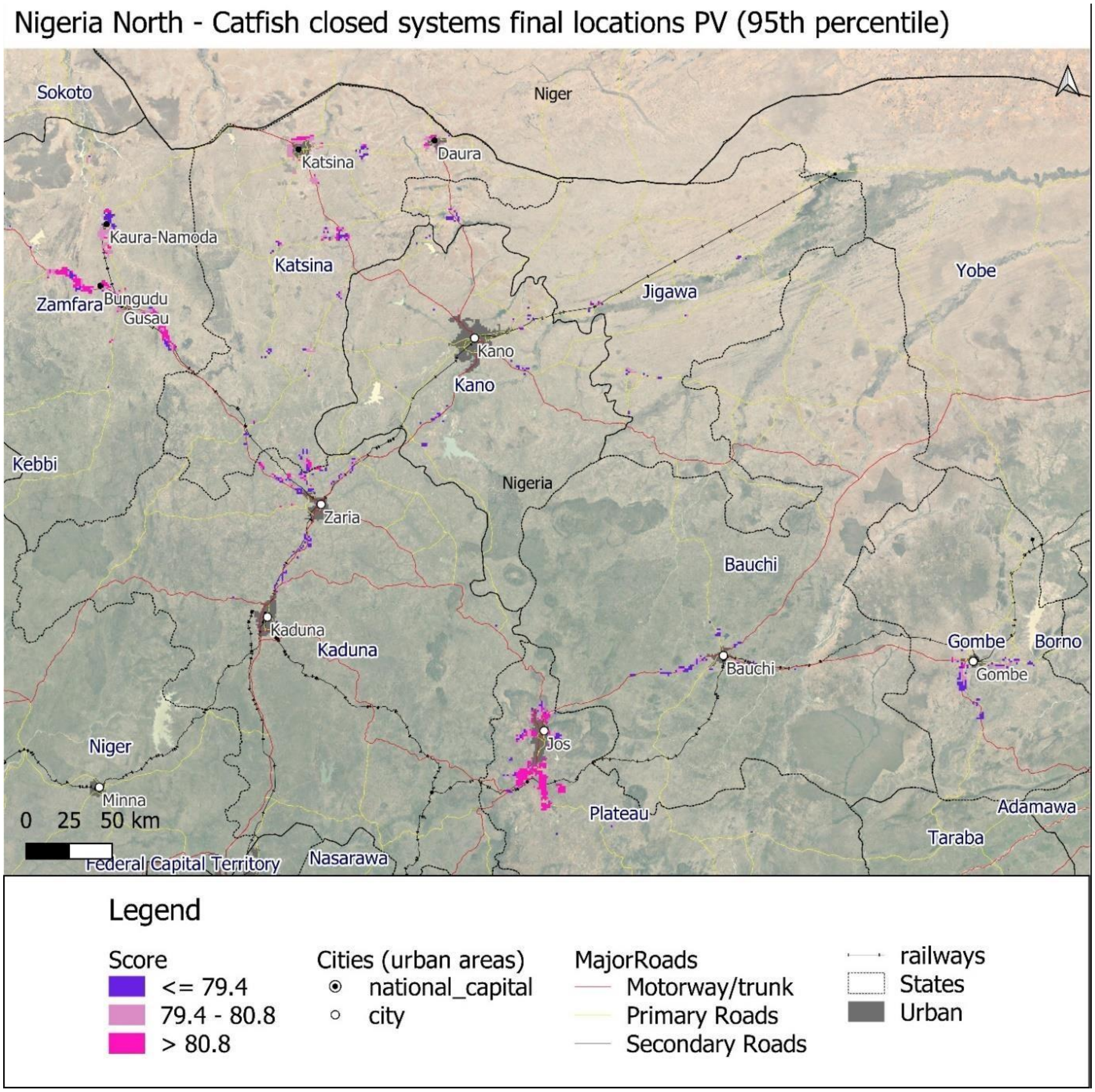

Figure 15 - Catfish closed/semi-closed farmed systems final sites (PV)

Final top score maps using PV energy generation potential as criteria show a sparsely distributed location pattern from centre to north of the country. North central region, Plateau State capital, Jos city concentrate the largest top potential areas, in smaller extensions in the Northeast region in Gombe and Bauchi, and Northwest region in Kaduna, Zaria, Katsina, and Zamfara states.

It must be emphasized that modelling demand/market criteria does not take into consideration poverty and purchase power.

6.3 Open intensive farming systems - tilapia in LWB

Intensive tilapia farming using cages in LWB are considered one of the most profitable fish farming systems. Requiring low initial investment, they are generally located in public waters and have low construction or energy requirements when compared to closed systems. Additionally, tilapia breeding cycle is interrupted in cages, simplifying seeding management, and augmenting productivity, and harvesting also comes at low cost.

The disadvantages of open aquaculture systems result from exchanges with surrounding environment, transferring waste, chemicals, parasites, and disease, and with a much higher potential for fish escape. These systems are more vulnerable to predation and poaching, and farming in public waters face competing interests and its legal status might not be well defined. Not all LWB offer appropriate conditions.

LWB cage farming in Nigeria is undeveloped and with noticeable large untapped potential. That can be partially explained by the fact that tilapia post-harvest value chain is more demanding than the mostly marketed alive, resistant catfish. Large scale distribution requiring cold chain/storage is blocked by incipient infrastructure deployment - rural electrification, alternative energy sources and road infrastructure.

A total of 82 LWB were manually digitized using Google Satellite images and joined with FAO Georeferenced database of dams (Africa) to generate a polygon layer. There are inconsistencies between FAO georeferenced dams and the existing. Some dams are projected, under construction or halted, while other existing digitized dams or reservoirs are not georeferenced in FAO data.

Modelling procedure differs from previous analyses since the single defining location factor is the presence of a LWB.

Criteria considered (score):

a. Market accessibility (large urban areas).
b. Water Balance - measure of seasonal impact on water availability.
c. Crop input (CropAggGAEZ) availability of agricultural by-products.

d. Livestock input (weighted animal density aggregation) availability of livestock byproducts.

- Accessibility to ports - considers that currently, high quality/performance tilapia feed, is imported.

Constraints

e. Protected areas.

Assumptions

1. The entire territory permits high or very high potential yields (crops/y) - number of days where temperature amplitudes are within the optimal growth range.
2. Water availability in very high for most of the territory.

6.3.1 Location Score / Multicriteria weighted sum

Using the GRASS r.series tool, a location score is obtained by way of a simple arithmetic weighted sum (normalized/scaled grids). Varying from 0 to 100, with the following weighting:

("Accessibility MajorUrbanAreas" X 0.55) + ("CropsInput" X 0.15) + ("LivestockInput" X 0.15) + ("WaterBalance" X 0.1) + ("Accessibility Ports" X 0.05)

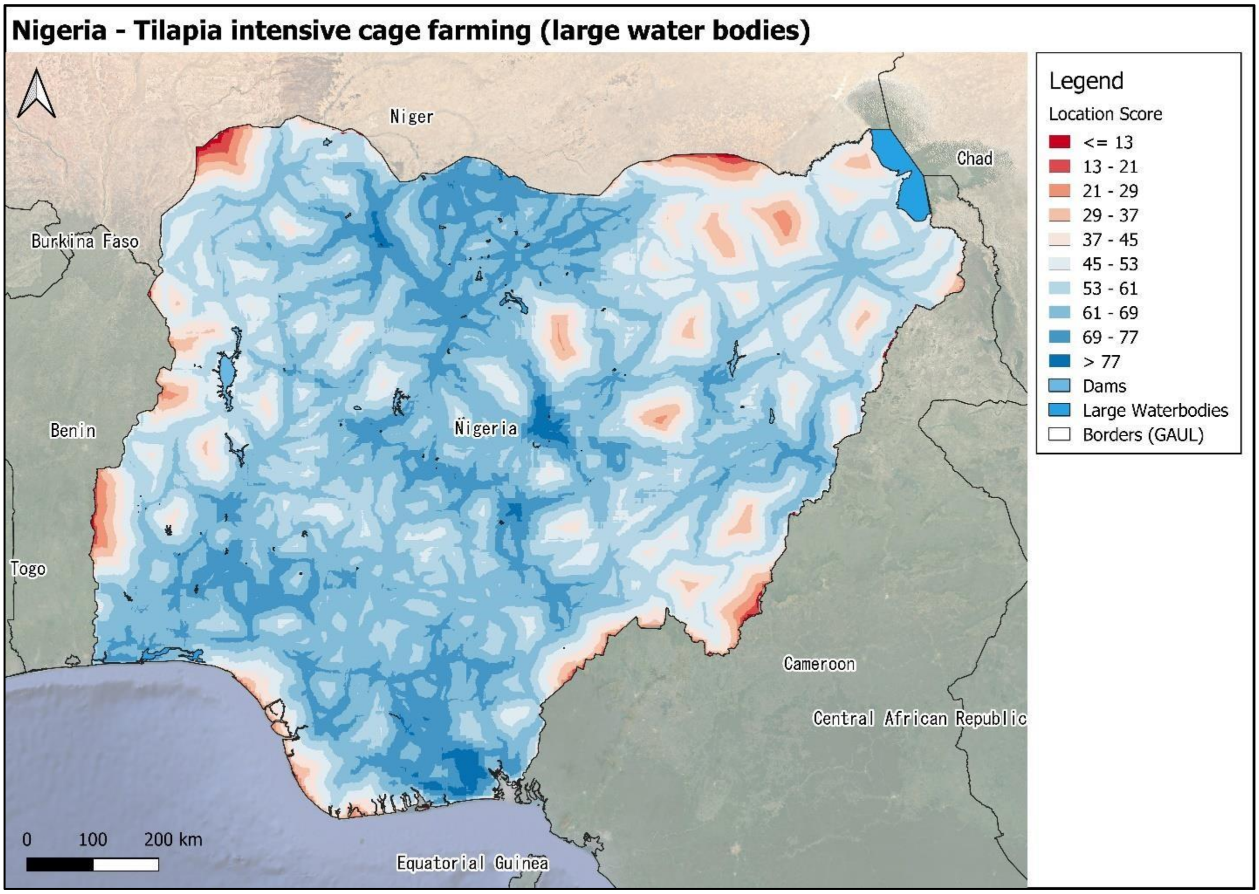

Figure 16 - Tilapia intensive systems score

6.3.2 Constraints and Final Location Mapping

Final location method differs from previous modelling since the defining factor is the presence of a LWB:

1. ***Clipping*** - Location score mapping is clipped using a dams 1km buffer polygon layer.

2. ***Zonal statistics tool*** - Extract the maximum (max) score value from the grid layer to the Dams buffer layer polygons.
3. ***Dams Buffer layer symbology*** - set to graduated and classified, using the max value, and equal count (quantile) method with 10 classes.
4. Visual display of the top class (90th percentile).
5. **Visual inspection** – for possible overlap/conflicts with protected areas.

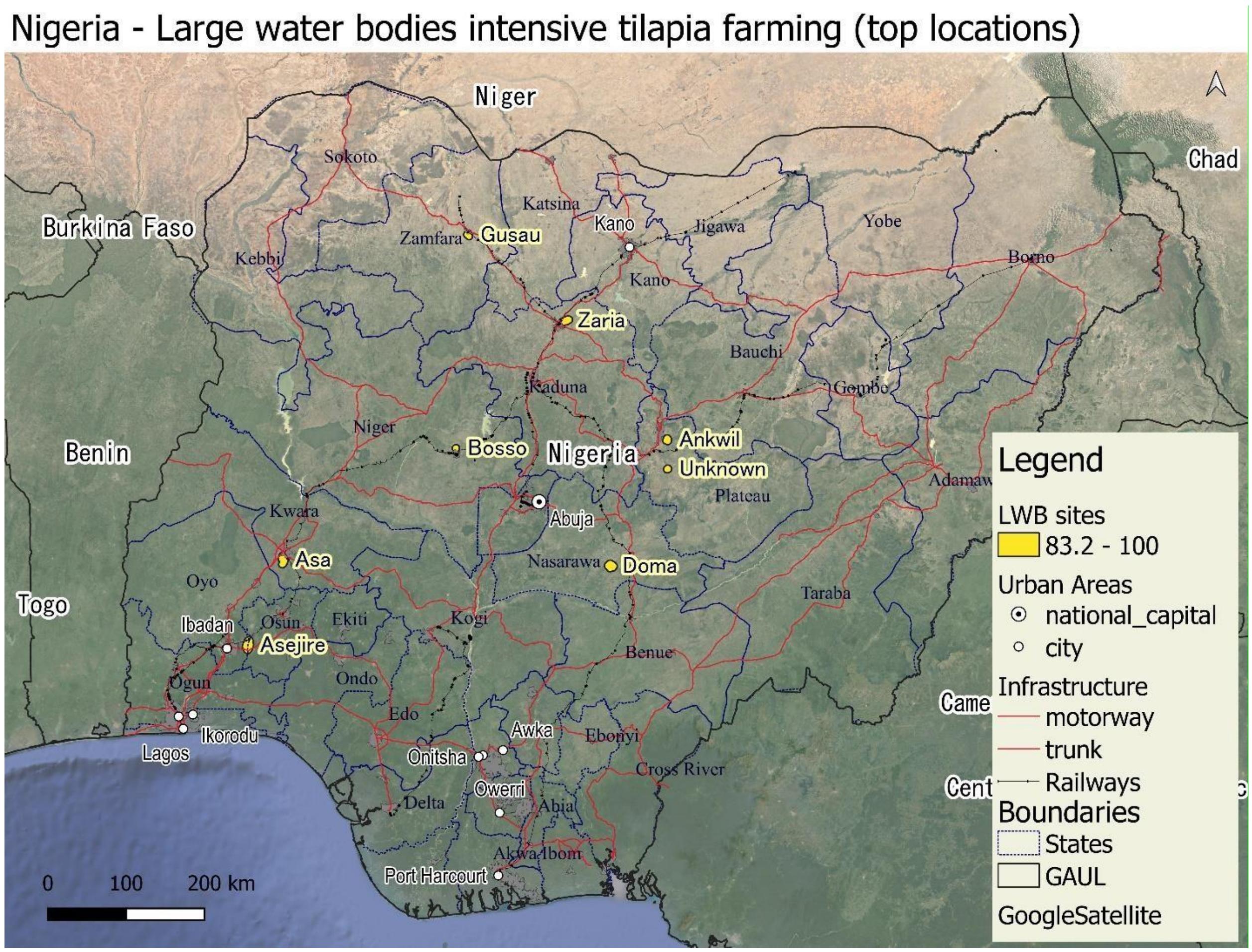

Figure 17 – Large water bodies intensive tilapia cage farming recommended sites.

Top recommended sites for Tilapia cage farming are:

- Southwest region - Asejire Dam (Osun).
- North-Central Region - Asa Dam (Kwara) Bosso dam (Niger) Doma dam (Naswara), Ankwill and “unknown” dams (Plateau).
- Northwest Region: Zaria dam (Kaduna) and Gusau Dam (Zamfara).

Doma dam site might possibly conflict with Doma national forest reserve.

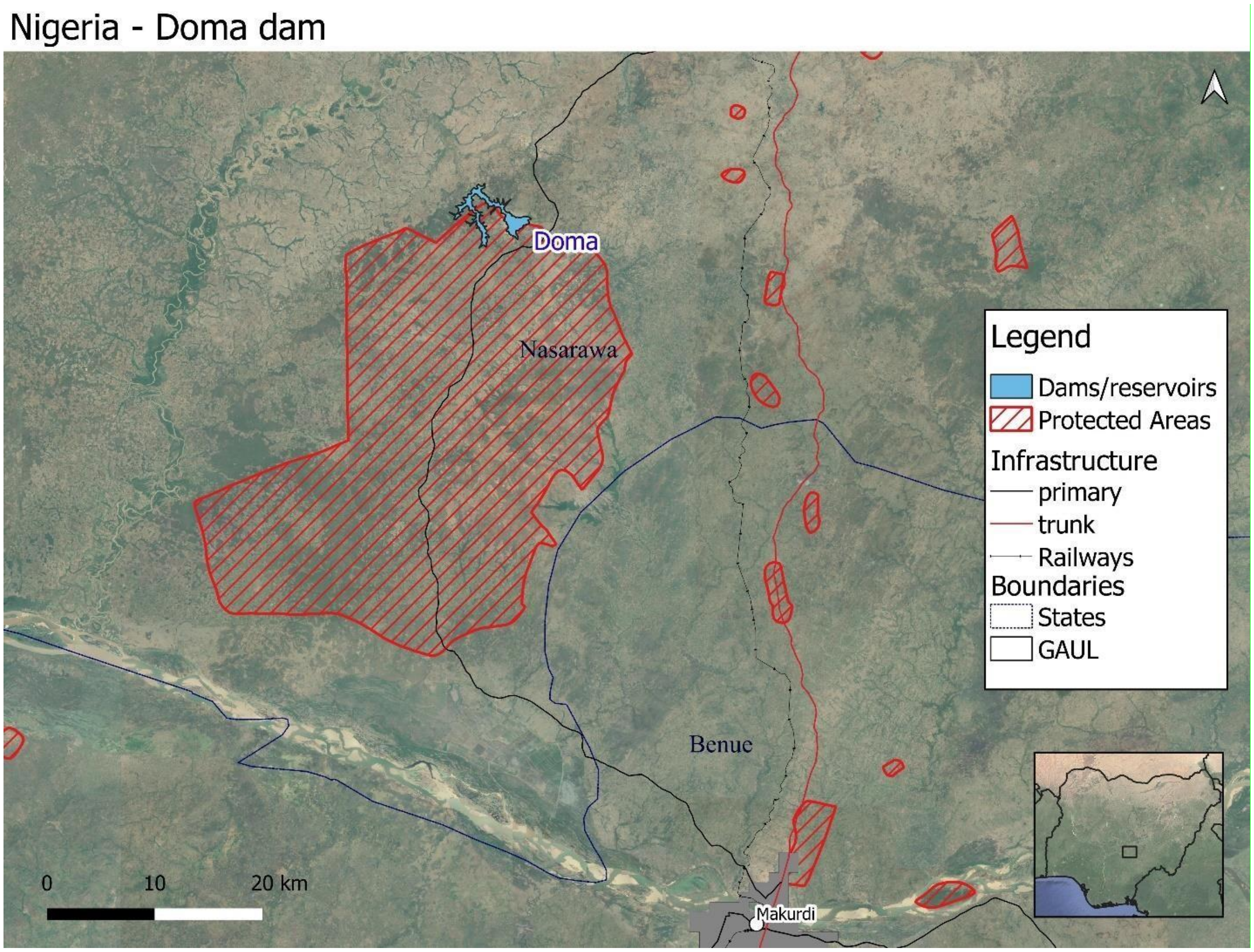

Figure 18 - Doma dam and Doma national forest reserve

CONCLUSIONS

This section includes conclusions, closing remarks on modelling assumptions, results discussion, and some of the possible future developments.

The unique natural conditions of Nigeria provide an abundance of water and perfect temperatures for warm-water fish farming. These conditions make Nigeria the leading aquaculture producer in sub-Saharan African region. But the country is also the largest fish consumer in Africa, and with a growing urban middle-class population, there is rising demand and the large supply deficit is reinforced by a decline in capture fisheries productivity.

Nigeria’s fish farming “success” story is closely linked to the African catfish species adaptation to local conditions, resistant to hi-densities and hard conditions, and marketed alive. The success of commercial catfish farming is associated with the “fish farming village” estate, a cooperative, public/private peri-urban framing model, originating in Nigeria’s southwest, linked to Yoruba ethnic group culture, associative /communal, business oriented, and adapted to the relationship to land and property of many sub-Saharan region traditionally animistic ethnic groups.

Current policies focus on sustainable aquaculture development via the creation of an enabling environment, through research and dissemination of best practices, commercial and private driven market, and targeting the production/consumption deficit. Critics, however, point out missing links between policy goals, specific types of aquaculture, and support measures to be developed.

The many factors that are limiting the fast development within aquaculture are: inputs (feed and seed), infrastructure, policies, and regulation. However, numerous marketing, management, technological, and socio-cultural issues, are growing proportionally with production as well as sustainability problems such as: environmental impacts, lack of disease monitoring and management, and land and water competition.

Many production models, systems, and techniques can be found, and find suitable conditions to prosper. Production has a large expansion margin, of either small-scale extensive to semiintensive, or for intensive commercial farming systems.

Departure research questions were formulated as:

1. *What are the regions and states where fish farming should be promoted for poverty alleviation, improving nutrition, and food security?*
2. *Where are the best sites for intensive commercial closed farming system investment?*
3. *Where are the best sites for intensive commercial Tilapia fish farming open systems?*

Research methodology followed previous *GIS MCDA* exercises for warehouse/storage and dairy processing plant location. A literature review details aquaculture fish-farming sector context, background, and perspectives. Modelling follows a GIS-MCDA methodology employing weighted factors, (AscoughII et al., 2019; Boroushaki & Malczewski, 2010; Malczewski, 2006) and applying constraints and exclusive criteria.

Fish farming suitability/potential zoning develops from Aguilar-Manjarrez and Nath study on warm and temperate freshwater fish farming suitability in continental Africa. It is a raster-based GIS-MCDA using fish-farm and land-quality factors, with sub-models and categories of criteria:

1. Constraints (urban areas, large water bodies, protected areas).
2. Water requirement.
3. Soil and terrain suitability.
4. Inputs – crops and livestock.
5. Farm-gate sales - as a measure of population density classification.
6. Potential yields.
7. Urban market size and proximity.

Sector growth, fish farming systems, and data availability, all substantially evolved since late 20th century, thus imposing data updating and reassessment of the modelling criteria, weighting, and constraints.

Two distinct zoning efforts were defined:

1. To define and suggest states or regions where investment can positively impact poverty, hunger, malnutrition, and food security - Extensive to semi-intensive small-scale integrated farming systems.
2. To select the best possible sites (high return on investment) for intensive commercial systems, for both:
    a. catfish closed intensive farming systems using re-circulating tanks, raceways flow-through systems, and ponds.
    b. tilapia open intensive farming systems in large water bodies (LWB).

Distinct **farming systems modelling** are developed based on specific theory, thus defining specific criteria combinations, weighting, and applying separate constraints:

1. Open non-intensive and integrated fish/crop farming systems – using ponds or small waterbodies.
2. Catfish closed Intensive systems –closed/semi-closed-circulation technologies: recirculating tanks, raceways, flow-through systems, and ponds.
3. Tilapia open intensive systems in LWB – using open-net pens/ cage techniques in public waters.

Modelling criteria cover: physical geography conditions, supply, demand, infrastructure and accessibility, and intensification potential (PV):

1. *Physical geography conditions:*
    a. Water requirement.
    b. Soil.
    c. Terrain suitability (slope).
2. *Supply*
    a. crop production– feed.
    b. Livestock – animal density –feed and organic fertilizing.
3. *Demand* - Human population density – farmgate sales and markets (urban/metropolitan areas).
4. *Infrastructure* - Transportation network (accessibility ports and urban/metropolitan areas).
5. *Energy* - Photovoltaic (PV) potential – Intensification potential.

Infrastructure and demand (market) sub-models involve raster-based travel time/cost analysis (Mulrooney et al., 2017) and is processed for large urban/metropolitan areas and ports.

Applied constraints (according to farming system specificities):

1. Urban Areas.
2. Protected Areas.
3. Large water bodies.

Final mapping **exclusive criteria** for intensive closed systems:

1. Distance to major roads.
2. Access to IT - mobile broadband coverage.

Results

Spatial decisions involve a set of alternatives and multiple assessment criteria. GIS-MCDA proposes a method to convert and combine spatial data, and decision-makers criteria to attain evidence for an informed decision. More importantly, it provides a replicable model, improves communication, offers diverse problem and solution standpoints, and helps refining specification and/or criteria.

From a critical standpoint, we can state that while data analysis and evidence gathering through GIS modelling can contribute to support decision-making processes, a more complex set of socioeconomic, political, cultural, ethno-anthropological aspects, and power relations shape and govern most decision-making.

Modelling is also as good as the input data. Its quality and reliability support the extent to which conclusions can be trusted, and these are just as sound as the analysis conducted. From that prism, specification and objectives define assumptions and approximations, and can always produce distinct answers.

Open non-intensive integrated fish/crop farming systems - ponds or small waterbodies – Large potential areas and higher score areas are in southern and central states. North and northeast regions bordering Chad and Niger are considered unsuitable. Excellent conditions are found in southern states of Imo, Rivers and Cross Rivers. Nevertheless, some north and northeast sates show substate regional and local scale potential

Analysis using consumption-based poverty (areas above the national average), identifies middle belt and some northern Nigerian states as possible targets for interventions (Kebbi, Niger, Zamfara, Kaduna, Plateau and Northeast Taraba and Adamawa). Smaller sub-state scale zoning can be found in Northern and Northeast states, and further analyses should be conducted at the corresponding scale.

The intensive closed farming systems adoption is limited by poor and unreliable energy distribution networks. The closed/semi-closed-circulation technologies are the re-circulating tanks, raceways, flow-through systems, and ponds. They are considerably less dependent on natural or physical geography criteria. These methods pose smaller environmental risks due to controlled exchange between farm and environment. The final location mapping and optimal theorectical investment sites are employed within an exclusive criteria of distance to major roads and access to IT (mobile broadband coverage).

Without PV Spatial distribution pattern is more pervasive than extensive to semi-intensive farming systems. Top locations can be found in central, south, and southeast regions. Major urban/metropolitan regions must be given special consideration: Southwest Lagos 15.7 million habitants, Kano in the north with 7.3 and the southeast Igbo region Onithsa/Awka/Oweri triangle with 5.4 and close to Port Harcourt 3.4.

The central region top sites are concentrated in Plateau state around the city of Jos, and in smaller areas in Nasarawa state due to Abuja Federal Capital Territory market proximity.

The South and Southeast states' level of urbanization point out the top sites in the Rivers and Akwa Ibom States. Smaller areas with lower score can be found in Imo, Abia, Cross River, and Ebonyi.

Using the PV potential as an intensification measure highlights central and northern regions. The North central region, Plateau State capital, and Jos reveal the largest top areas. Smaller extensions are found in the Northeast region, Gombe and Baushi, and Northwest region in Kaduna, Zaria, Katsina, and Zamfara states.

It must be stressed that farmgate sales and market sub-models considers solely the population density dimension and not poverty or purchasing/acquisitive power.

The tilapia open intensive systems in LWB using open-net pens/ cage techniques, are considered one of the most profitable but with downsides from exchanges with the surrounding environment. LWB cage farming is undeveloped with a noticeable large potential, one of the causes being incipient infrastructure deployment.

A total of 82 LWB could be digitized using Google Satellite images and joined with FAO Georeferenced database of dams (Africa).

Zoning differs from other models since the defining factor is the presence of a LWB

Top recommended sites (LWB) for Tilapia cage farming are:

- Southwest region - Asejire Dam in (Osun).
- North-Central Region - Asa Dam (Kwara) Bosso dam (Niger) Doma dam (Naswara), Ankwill and “unknown” dams (Plateau).
- Northwest Region: Zaria dam (Kaduna) and Gusau Dam (Zamfara).

Recommendations

Caution and examination should be considered over intensification and growth within aquaculture development, as well as sustainability and possible impacts. Environment, health and disease, and land and water competition challenges have not been properly assessed, and objective assessment of ethnic, cultural, religious, socio-political diversity, and conflict issues should frame proposed interventions.

Environmental issues are missing from the equation for most of the industry literature. Integrated farming systems can positively impact sustainability, recirculation techniques have low water requirement and output effluents. Fish farming can also reduce fishing pressure. Still, little research and data are available on impact issues like eutrophication, reduction in dissolved oxygen, production of toxic microorganisms, toxicity on aquatic ecosystems, and disruption of fish assemblage in the wild or genetic pool impact.

There is evidence of an increase in harmful organic and chemical effluents, and direct discharge of untreated waste waters in river streams appears to be widespread. Open systems exchange with the surrounding environment, transferring waste, chemicals, parasites, and disease. It also has high potentiality for fish escapes.

Health and disease monitoring and management are largely unconsidered, and there are no surveys, monitoring, diagnostic, or available guidelines on biosecurity.

Activity expansion and impacts additionally increase land and water competition that are already prone to conflict problems in the country. Open systems in public waters also commonly face conflicting interests.

This set of long-term impacting issues must be balanced with the immediate socio-economic objectives and improving productivity should promote environmentally sustainable production and extension technologies.

Besides considering physical geographical conditions, supply, demand, infrastructure, accessibility, and alternative energy (photovoltaic potential), awareness of social-cultural, ethnic, and political context and factors must guide proposed interventions. A holistic approach can result in successful and sustainable adapted proposals, targeting systems and models which can positively impact poverty, hunger, malnutrition, food security, and/or can lead to high return on investment on commercial aquaculture systems.

Closing Remarks

Closing remarks discuss assumptions and pitfalls, findings limitations, and future developments.

The exercise focuses on warm-temperate freshwater fish farming suitability modelling for African Catfish and Nile Tilapia species in Nigeria.

General Assumptions

1. All territory permits high or very high potential yields (crops/y) - number of days where temperature amplitudes are within the optimal growth range for both fish species.
2. Water availability is suitable or very suitable for most of the territory.
3. Natural and physical geography criteria are considerably more relevant to open, nonintensive integrated fish/crop farming systems.
4. Intensive systems depend on accessibility to input (feed/seed) and output markets (large urban areas).
5. Intensification can happen using closed-circulation technologies: re-circulating tanks, raceways, flow-through systems, and inland ponds, and are reliant on energy supply.

SUB-MODELS ASSUMPTIONS

1. *Accessibility infrastructure sub-model*
    a. Inland water navigation considers polygons, infrastructure network lines. Alternatively, model could use point features, lake/river ports, railway stations, and highway access.
    b. Navigable river segments have *Strahler* number[8] higher than 7.
    c. Navigation is assumed for small to medium cargo crafts.
    d. Road travel time/cost is modelled for cargo freight, tertiary and local traffic roads are not included; country road network conditions are poor[9].
2. *Demand/market sub-models*
    a. Accessibility to large regional cities (markets) - Cross border trade is not considered due to the large, growing, production consumption deficit.
    b. Urban areas - Population density above 1600 h/k² and area larger than 50 km². Accessibility calculated to major roads (polylines) intersection points with urban areas (polygons). Medium or less dense urban fabrics might not be accounted as substantial markets.
3. *Demand/Farmgate sales sub-model*:
    a. Uses population density classes does not account for purchasing or acquisitive power.
4. *Physical Geography - Soil and terrain suitability sub-model*:
    a. Soil sub-model assumes there is no substantial change in conditions since 1997 study.

[8] https://www.jayconrod.com/posts/66/the-strahler-number

[9] https://dlca.logcluster.org/display/public/DLCA/2.3+Nigeria+Road+Network

b. Soil/terrain sub-model is used for small scale extensive, semi-intensive, pond systems.

c. Slope data is used individually for intensive commercial closed systems.

5. *Inputs sub-models assumptions*:

    a. Crop – products/by-products can be used as feed or as raw materials for feed mills.

    b. Livestock - considered for organic fertilization and/or feed ingredients.

    c. PV energy - intensification potential - Other alternative sources (e.g., wind power) are not contemplated.

SUITABILITY/POTENTIAL MODELLING ASSUMPTIONS

1. *Non-intensive open farming systems*
    a. Natural and physical geography criteria weight the most on low input systems.
    b. Using 2010 poverty data assumes:
        i. Population portion exiting extreme poverty is mostly in southern states urban areas.
        ii. Spatial patterns persist - rural/urban and south/northern divides.
2. *Intensive closed Catfish farming systems:*
    a. Are limited by absent or unreliable energy distribution networks
    b. Are not dependent on soil characteristics.
    c. Have low dependency on water resources (reuse).
3. *Large Water Bodies (LWB) Intensive Tilapia farming systems:*
    a. Defining location factor is the presence of a reservoir or dam.
    b. High quality/performance feed is imported (accessibility to ports).

CONSTRAINTS

Applying protected area constraints as exclusive can be disputed. The type and level of restriction in place can also differ and socio-economic benefits can outweigh protection concerns.

Closed farming systems final location mapping constraints involve another generalization step. This is the definition of thresholds and classification (value judgement) for buffer distance to/from roads and several assumptions in IT access mobile broadband coverage maps estimation.

Automation

Part of the geoprocessing was semi-automated through the development of algorithms (python scrips), namely:

- Pre-processing, extraction and editing of vector layers (*AuxData* script).
- Computation of accessibility maps cumulative travel time/cost from ports (*TravelCostTimeSurface script*).

Scripts can be developed for other steps.

Full geoprocessing automation is not anticipated as geography impose singular criteria conjugation and specificity.

Future Developments

Methodological improvements can provide new and different criteria. Some examples are:

1. Infrastructure and accessibility dimension:
    a. Transportation infrastructures are modelled as linear phenomena instead access points and stations can be used.
    b. Road network modelling uses the same value irrespective of the considered road classes (motorway, truck, primary, secondary) or road speed limits.
    c. Accessibility to regional cities can be introduced (cross border trade).
2. Socioeconomic data
    a. Farm gate sales sub-model - population density classes can be weighted with poverty data as a measure of local population acquisitive power.
    b. Other subnational scale level data can be included (e.g. WorldFish Nigeria project survey data).
3. Production dimension:
    a. Inclusion of existing fish farms and value chain infrastructures.

4. Physical geography – Inclusion of flood areas mapping.

The modelling exercise is open and flexible, and other data dimensions and/or distinct farming systems and models can be considered. Criteria weighting is flexible and can include expert inputs and field knowledge that may lead to different outputs by using the location score (criteria weighted sum) as a *what if scenario* tool.

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ANNEX – TRAVELCOSTTIMESURFACE ALGORITHM MODEL DIAGRAM