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Assessing the Suitability of Kisumu County for *O. niloticus* Culture Based on Water Availability Criteria using Free GIS and SMCE Software

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Abstract

Aquaculture productivity in Kenya is lower than the level required to support major section development despite an escalated need for fish. Low fish productivity is due to the location of fish ponds without considering site suitability. Aquaculture scientists have identified specific suitability criteria namely water availability as important for fish pond location. There is therefore need to generate a water availability suitability map that can guide location of fish ponds to enable maximization of production. This study used free GIS and SMCE software to generate a water availability suitability map for O.niloticus culture in Kisumu County. The basis was evolved and regulated through classification, weighting and combination of four sub-criteria (size of watershed, amount of annual rainfall, rate of evaporation and rate of seepage). Each sub-criterion was classified into a four-level land suitability assessment scale based on FAO weighted scores, weighted by a team of experts using AHP pairwise comparison matrix and converted to a map layer. Weighted linear combination using SMCE was utilized to develop O.niloticus suitability map. Verification of results was done through comparison of fish production in various suitable sites by interviews with aquaculture farmers and fisheries officers. The findings revealed that nearly 65.5% of Kisumu County is highly suitable, 23.02% is suitable and the remaining 11.46% was not suitable for pond farming of O.niloticus.

Keywords: Amount of Rainfall, Aquaculture, Nile Tilapia, Sizes of Watershed, Rate of Evaporation, Rate of Seepage

INTRODUCTION

One of the important sources of micronutrients in human diets which also ensures a nation's food security is fish (Bhujel, 2013). There is a global, national and regional decline in the supply of fish from wild fish resources since 2009 as indicated by the FAO, and Kisumu county in Kenya is not an exception to this trend Opiyo et al, 2018; Ghozlan et al., 2018; Njiru et al., 2018; Clough et al., 2020; Obiero et al., 2019). Despite the decline of fisheries resources there is an elevated need for fish in Kenya due to high rate of population growth, increased health awareness, financial stability, promotion of fish consumption, and nutrition and diet concerns due to changes in dietary trends (Musyoka, 2016). Aquaculture within Kenya has developed substantial since 2006 and production appear to have peaked in 2014 suggesting that the enterprise has a high potential in the country (Munguti et al., 2014). In Lake Victoria region aquaculture of O*reochromis niloticus* which accounts for around 75% of farmed fish is one of the main sources of income in rural areas. Increased aquaculture production is expected to compensate for reduced capture fisheries, but it looks like aquaculture production is low, unreliable and declining (Munguti et al., 2021). Moreover, location of fishponds without consideration of site suitability based on water availability criteria is a major problems in the county.

Site suitability assessment for fish farming has evolved from the use of slow, unsustainable and unreliable manual methods to the use of fast sustainable and reliable digital techniques (Rahman et al., 2012). Timely and reliable information on the nature, extent and spatial distribution of suitable sites for aquaculture in Kisumu County based on water availability is lacking despite its being fundamental for sustainable and optimal production of aquaculture (Ssegane et al., 2012).The existing mismatch between the optimal conditions required for O. *niloticus* culture in ponds and the current location of ponds can be easily avoided through evaluation of land suitability in the county.

Sufficient rainfall determines water level in a pond which in turn favours the reproduction of fish (Abdel Rahman & Boyd, 2018). According to Ng'onga et al. (2019) annual fish yield may be predicted by the amount of rainfall. In-flow into the ponds during rainfall positively correlates with fish yield owing to the fact that it stimulates nutrient input into the pond, providing additional food for fish (Ayub, 2010). Similarly, it should be noted that earthen ponds were used for aquaculture. Because of its impact on salinization of soil in close proximity to agricultural land and drinking water sources, seepage from aquaculture ponds is one of the most serious environmental concerns encountered by shrimp farming. Seeping can be the biggest single source of water loss in a continuous water pond culture (Adhikari et al., 2017; Uzukwu. 2011). The rapid seeping rate not only causes water loss, but it also reduces pond fertility (Food and Agriculture Organization of the United Nations. 2012, Munguti, 2021, Munguti, 2014; Food and Agriculture Organization of the United Nations, 2016) and increases the quantity of lime required to maintain an alkalinity that is favourable for aquaculture on acidic soils (Munguti, 2021, Munguti, 2014; Food and Agriculture Organization of the United Nations, 2016).

Another widely discussed site suitability factor is watershed size of a fish pond (Food and Agriculture Organization of the United Nations, 2016; State Department of Fisheries, 2014; FARM AFRICA, 2016). Since aquaculture fish ponds are always superficial, the steady flow of water into the pond is important for circulation and maintenance of the dynamic ecosystem (Sipaúba-Tavares et al., 2007). The suitability of the fish pond to deliver high production successfully relay largely on its watershed. A watershed is the terrain surface of which rain and surface water fall into the pond (Miranda, 2008). Pond suitability is a reflection of its watershed, and any changes in the watershed could therefore affect the water availability in a fish pond. Location of suitable sites for fish pond based on size of watershed is therefore paramount for enhanced aquaculture.

Some aquaculture scientists (Fern et al., 2018; Brown et al., 2012; Abdel Rahman, 2018) have documented that availability of water for fish pond suitability is also affected by rates of evaporation. Water losses from the surface of a pond to the atmosphere in form of vapor (Fern et al., 2018) is referred to as evaporation. A deeper pond has a less evaporation loss per unit of water compared to a shallower pond, and represents approximately 66.2% of the total water loss from an aquaculture fish pond (Brown et al., 2012). Evaporation therefore appears to be greatest factors that may affect suitability of water availability in a fish pond hence it is important to identify sites with low evaporation for improvement in aquaculture production. The foregoing discussions demonstrate that diverse factors related to water availability determines site suitability of a fish pond. However, limited focus has been directed to these factors with regards to aquaculture production of Nile Tilapia in Kenya.

However, information with regard to how availability of water has led to selection of suitable sites for fish pond location has not been documented (Richard et al., 2017; Goepel, 2013; Goepel, 2018). Moreover, whereas Kisumu being one of the leading counties where fish is a favourite, it is ranked the sixth in Kenya in terms of number of fish ponds hence begging the question as to whether there is lack of adequate suitable sites for pond location in the area. This study was therefore set to assess the suitability of Kisumu County for *O.niloticus* culture based on water availability criteria using GIS and SMCE technologies.

Statement of the Problem

The Nile tilapia (*O. niloticus*) accounts for 75% of all fish produced in Kenyan aquaculture. Although the Economic Stimulus Program (ESP) and the Fish Farming Enterprise Productivity Program (FFEPP) implemented in 2009 and 2010 increased fish pond area from 220 ha in 2008 to 468 ha in 2010, aquaculture productivity in Kenya is not able to satisfy the escalated need for fish in the Country (Musa et al., 2012; Opiyo et al., 2018). The location of fish ponds without considering site suitability has been identified as the major cause of low aquaculture productivity in Kisumu County. This can be avoided through evaluation of land suitability for aquaculture production in the county using free GIS and SMCE technologies by considering water availability criteria which has been recommended as important for fish pond location by aquaculture scientists (Assefa and Abebe, 2018). This study therefore assessed the suitability of Kisumu County for *O.niloticus* culture based on water availability criteria using GIS and SMCE technologies. The criteria were evolved and standardized from 4 factors (size of watershed, amount of annual rainfall, rate of evaporation and rate of seepage), which were categorized into a four-level suitability scale based on weighted scores.

Main Objective

To assess the suitability of Kisumu County for *O.niloticus* culture based on water availability criteria using free GIS and SMCE technique.

Specific Objectives

1. Assess the effect of the size of watershed in the determination of suitable sites for *O.niloticus* culture in ponds.
2. Establish how the amount of annual rainfall influences the suitability of sites for *O.niloticus* culture in ponds.
3. Assess the extent to which the rate of water seepage from a fish pond affects the suitability of sites for *O.niloticus* culture in ponds.
4. Determine the effect of the rate of water evaporation from pond surfaces on the suitability of sites for *O.niloticus* culture in ponds.

MATERIALS AND METHODS

Study Site

Kisumu County is located between the longitudes $33^0$20'E and $35^0$20'E, as well as the latitudes 0^0 20' South and 0^0 50' South (Kisumu County Integrated Development Plan (KCIDP, 2018). The county is surrounded by the second biggest freshwater lake in the world, Lake Victoria, with Homa Bay County to the south, Nandi County to the north east, Vihiga County to the North West, Kericho County to the east, and Siaya County to the west. The County covers around 567 km^2 of water and 2086 km^2 land area. The area of the county, accounts for 0.36 percent of Kenya's total land area (580,367 km^2) (KCIDP, 2018).

The terrain of the county is undulating, with plain fields in the eastern half, which is a level stretch on the Rift Valley floor, and overhanging massive granite cliffs at RIAT hills (MoALF, 2017). Because of frequent floods, the eastern half of the Kano Plains has rich alluvial soils that are ideal for horticulture, fish and rice farming. The town's climate is usually warm, with temperatures ranging from 23 to 33 degrees Celsius on a monthly basis favouring the culture of *O.niloticus*. A modified equatorial climate determines the rainfall, which is distinguished by lengthy of the rain season (March to May) and short showers (September to November). The yearly rainfall ranges between 1000 and 1800 mm during the long rains and 450 and 600 mm during the short rains.

Data Set Development and Collection

Data set development and data collection in this study entailed: Criteria identification which provided water availability factors which were analyzed to reveal *O.niloticus* site suitability, collection of data in respect of each factor, creation of spatial data layers in respect of each factor. Spatial data (map) generation from shapefiles and display in QGIS and Integrated land and information system (ILWIS) software provided data which was used in spatial multi-criteria evaluation. Scores for each factor were generated during criteria standardization using a modified physical scale which has been used by FAO and other scientists (FAO, 1996; Giliba et al., 2020; Obunga et al., 2022) based on threshold value of each factor. Assignment of weight to each factor according to its importance in determination of *O. niloticus* site suitability using analytical hierarchy process (AHP) provided more data for site suitability analysis. The *O.niloticus* culture suitability map for Kisumu County was created using a spatial multi-criteria evaluation module in integrated land and water information system using the data developed and collected. Data collected during a field survey using interviews and questionnaire with fish farmers and sub-county fisheries officers was used for verification of the identified sites (Ishizaka and Labib, 2009; Ossadnik and Kaspar, 2013; Siraj et al., 2015)

Identification of Criteria

The current study used multi-criterion site suitability modeling to determine appropriate and viable aquaculture development places based on a set of limitations and criteria. Four different factors which determine water availability in fish ponds and 3 limitations were chosen according to their significance and value in aquaculture. The identification of different factors was done by a team of experts who included fisheries officers and fish farmers identified based on their qualifications, expertise and experience. The factors that influence the availability of water in a fish farm were randomly identified, chosen depending on their influences on the availability of water in aquaculture ponds and aligned to the criteria. Although many elements must be taken into account when selecting a site for *O.niloticus* culture, the most significant is the farmers' culture system. The factors chosen and used in the current analysis includes; amount of annual rainfall, size of watershed, rate of water seepage and rate of evaporation from the fish ponds (Ssegane et al., 2012). These factors have an impact on the availability of water in any fish pond and influences *O.niloticus* survival, growth, and reproduction in ponds. As a result, these factors were used to find suitable pond sites for *O.niloticus* culture based on water availability criteria. Places in the study area which cannot be used for any aquaculture were excluded using the constraint layers including wetlands, highly populated area, river and road reserves.

Scientist have diagnosed that water availability in ponds for aquaculture is determined by water inputs into and outputs from a pre-determined pond volume which is estimated using a water balance model (Ssegane et al., 2012).

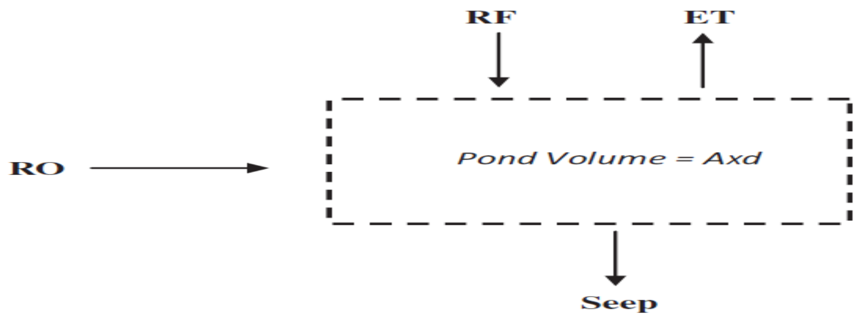

Figure 1: Water Suitability Concept Displaying Pond Inputs and Outputs.

The water balance for the pond was calculated using Equation (1)

$$\text{Model: } RO \times DA + RF \times A - ET \times A - Seep \times A = A \times d, \quad [1]$$

Where;
RO = runoff (mm); RF = rainfall (mm); DA = watershed drainage area (m2) ; A = pond surface area (m2); ET = evapotranspiration (mm); seep = seepage (mm); and d = pond depth (mm).

The needed drainage area was approximated using Equation (2)

$$DA = \frac{A\left(d + ET + Seep - RF\right)}{RO}, \quad [2]$$

Where;
DA = watershed drainage area (m^2); RO = runoff (mm); RF = rainfall (mm); A = pond surface area (m2); ET = evapotranspiration (mm); seep = seepage (mm); and d = pond depth (mm).

Data and Data Collection

Both primary and secondary datasets representing each criterion were derived using; Field observations, Semi-structured interviews, remote sensing, geographical information system (GIS) and field surveys (Table 1). Global positioning system (GPS) and shapefile data were the key data sources in this investigation.

Table 1: Data, Data Type and Method of Data Collection

Data/Information	Data type	Method of Data Collection
Criteria identification	Attribute	Semi-structured interviews, literature review and brainstorming
Identification and assignment of threshold values to each factor	Attribute	literature review
assignment of scores to each factor	Attribute	Semi-structured interviews, literature review and brainstorming
Assignment of weight to each factor	Attribute	Semi-structured interviews, literature review and brainstorming
Analog maps	Spatial data	Request from library and various Government institutions
Coordinates:	Digital data	Field surveys, borrowed from organizations, Field observations
Digital maps and shapefiles	Digital data	Digitization from existing maps and borrowed
GIS software	Software	downloaded from the internet
Database fish production from existing ponds	Database	Field surveys, borrowed from organizations which have collected the data, , borrowed from Kisumu County.

Generation of Water Availability Maps

The average annual rainfall data used during the study was obtained from meteorological department of Kisumu County in attribute form. The attribute data containing average rainfall figures for the last 10 years were converted to a rainfall shapefile in QGIS to indicate the distribution of rainfall in the county. The average values of rainfall were calculated by combining data from all meteorological stations. The rainfall distribution map for Kisumu County was generated by inserting the average annual rainfall data into Kisumu county shapefile in QGIS. A full rainfall map was created using the triangulated irregular network technique as vector data.

The data on watershed of the county was generated from the water basin shapefile of the study area. The shapefile data was borrowed from integrated livestock research institute (ILRI) and used to generate a vector map of the study area in QGIS. The watershed map was classified according to the size of the basin from the biggest to the smallest. He biggest watershed was considered highly suitable , moderate size watershed was considered moderately suitable while the smallest watershed was classified as marginally suitable.

Seepage is defined as the process of dowrnward lateral movement of water into soil from source of supply such as a fish pond. The rate of seepage depends on soil permeability, area and shape fish pond. Seepage data was estimated from the soil distribution map of the study area. The classification of seepage rates were based on the fact that different soil structure (clay, roam and sand soils) have different rates of seepage (Egna and Boyd 1997). The various soils textural classes in the county were assigned seepage rates such that areas with clay had the lowest seepage of 0.25 mm/day and those with sand were assigned the highest seepage of 25 mm/day. Areas containing other soil types were assigned appropriate seepage rates as indicated in Table 2.

Table 2: Daily Seepage Rates established from Soil Textural Class

ID	Soil texture	Seepage rates (mmday^{-1})
1	Clay loam	2.50
2	Sand clay [a]	11.25
3	Sand clay loam[a]	12.50
4	Sandy loam	13.25
5	Loamy Sand	18.75
6	Sand	25
7	Clay	0.25
8	Loam	8.00
9	Silty clay loam	6.35

The trickling rates of these textural classes were approximated based on lower limit of percent sand (seepage ≈ [% sand/100] × 25) (Source: Egna and Boyd, 1997)

The temperature of the county was estimated from the temperature map of the study area obtained from Kisumu meteorological office. The classification of evaporation rates were based on the fact that different temperatures cause different rates of evaporation from a pond surface (Ssegane et al., 2012). The rate of evaporation from a pond surface was estimated using mean monthly temperatures used in the Blaney-Criddle model:

$$ET=K_2*F$$

Where,

ET= monthly ET in (mm), K_2= A coefficient for the Blaney and Criddle method for this study the K_2 value is 1.00.

$$F=25.4*PD*\frac{1.8T_m+32}{100}$$

PD= percentage of annual daylight hours in the month

T_m= mean monthly temperature in degrees centigrade

$$F=25.4*100*\frac{1.8*23+32}{100}$$

Standardization of Each Suitability Assessment Factor

The criteria was developed and standardized in a GIS environment. The four major factors that make the water availability criteria include; size of watershed, amount of annual rainfall, rate of water seepage from a fish pond and the rate of water evaporation from the pond. Each factor was assigned threshold values ranging from the optimum, through moderately optimum to marginal and unsuitable values. Standardization was implemented to generate a common unit for measurement. This process is commonly referred to as standardization of factors, and it comprises the classification of each criterion that influence the appropriateness of fish farming in some manner.

A four-level scale was applied to each factor to display the level of suitability for all spatial assessments based on the threshold values. The degrees of suitability (1 to 0) were as follows: highly suitable (HS), moderately suitable (MS), marginally suitable and unsuitable (US) (Ishizaka and Labib, 2009). The suitability scores were created by classification of each criterion according to the availability of optimum conditions in a site and they were used to generate sub-model suitability maps (Malczewski, 1999).

The classified data in Table 3 were in different units of measurement and the maps they represent were in raster-, vector, or tabular format, further representing various spatial phenomena, these properties were accounted for in the standardization process (Richard et al., 2016). Tilapia culture suitability maps were generated based on a prediction model. The probability values were reclassified into four *O.niloticus* culture suitability classes i.e. unsuitable (0-0.2), low (0.2-0.4), “moderate” (0.4-0.6), and “high suitability areas”0.6-1(Giliba et al., 2020; Obunga et al., 2022). Table 3 presents this.

Table 3: Water Availability Categorization Based on Threshold Values for Selection of Aquaculture Suitable Sites

Availability of water characteristics				
Suitability class	Highly suitable (0.76-1)	Moderately suitable (0.26-0.5)	Marginally suitable (0.1-0.25)	Unsuitable (0)
Size of watershed	>50 m^2-36	26-35 m^2	16-25 m^2	<15 m^2
Annual rainfall	>1,200 mm-1,100	700-1099 mm	500-699 mm	< 500 mm
Rate of water seepage	<10%-20%	20 – 45%	46 – 70%	> 70%
Rate of evaporation	<10%-25%	26 – 45%	46– 65%	>70%

The most suitable areas in all maps were classified as highly suitable, assigned a suitability score of 0.61-1 and dark green colour, areas which had average suitability were classified as moderately suitable, assigned a suitability score of 0.41-0.6 and a pale green colour. Areas whose suitability for *O.niloticus* culture was below average were classified as marginally suitable, assigned a suitability score of 0.21-0.4 and a yellow colour. Areas in the county which were not suitable for *O.niloticus* were assigned a suitability score of 0-0.2 and a red colour. This method of map classification is preferred by many scientist and was applied to large number of studies (Ansari & Ghoddousi, 2018, Convertino et al., 2014, Zhang et al., 2019).

Weighting of Criteria

A team of aquaculture experts were involved in assigning weights to each criterion according to their importance in determining the suitability of the study area for *O.niloticus* culture using AHP Process in excel software. The weights were assigned using Saaty's standard rating scale (Saaty, 1977, 1980). In Saaty's standard rating scale, numbers one to nine represent different levels of importance. For example; If A and B are criteria of different importance each criterion is assigned Saaty's numbers in a matrix as follows:

1 means that the importance of criteria A is equal to that of criteria B; 3 means that criteria A is moderately more important than B; 5 means that criteria A is strongly more important than B; 7 means that criteria A has been demonstrated to be more important than B; 9 means that criteria A has been demonstrated and confirmed to be more importance than B; and 2, 4, 6 and 8 are used when there is a compromised importance between two levels (Saaty, 1977, 1980). The derived weigh assigned to each criteria is shown in Table 4.

Table 4: A Pairwise Comparison Matrix for Generating the Relative Weight

	ARA (mm)	WS m^2	RS (%)	RE (%)	DW (%)
Annual Rainfall (ARA)	1	2/5	4/5	4/5	4
Watershed size (WS)	5/2	1	3/5	4/5	5
Rate of Seepage (RS)	5/4	5/3	1	5/1	2
Rate of Evaporation (RE)	5/4	5/4	1/5	1	3

(*ARA = Annual Rainfall Amount; WS=Watershed Size; RS= Rate of Seepage; RE= Rate of Evaporation; DW=Derived Weight*).

Combination of Thematic Maps using Spatial Multi-Criteria Evaluation

The relative weights derived through pairwise comparison using AHP method and the suitability scores generated during standardization of the factors were used in SMCE module in ILWIS to generate the final overall water availability for *O.niloticus* culture suitability map based on water availability factors. The resultant vector maps in respect of each sub-criteria generated in QGIS were transferred to ILWIS software. Because multi-sensors were employed, it was necessary to geo-reference the maps into a uniform geographical reference in order to overlay the spatial database appropriately in the analysis. The GIS model was developed using a WGS 84 UTM zone 37 South coordinate system for all spatial data. The data on the above parameters was prepared for input to the GIS data base using 10x10 m pixels to minimize false accuracy in the overlaid output, which was based on a compromise between the layers and their original resolution (Ogunlade, 2020; Ssegane et al., 2012; Berg et al., 2021) .The thematic maps were used as input in the combination of various factors to produce water availability suitability map using spatial multi-criteria evaluation tools in SMCE module in ILWIS.

The suitability map was created using spatial multi-criteria evaluation technique where a criteria tree was generated, loaded with each criterion and each map or table representing the criteria and run using the tools in the SMCE module of ILWIS which are utilized the weighted linear combination method (Ssegane et al., 2012; Berg et al., 2021). This process is commonly referred to as spatial multi-criteria assessment (SMCE), and it comprises the consolidation of several aspects or criteria that influence the appropriateness of *O.niloticus* farming in some manner.

Comparison of Fish Production versus Modeled Suitability

A comparison of anticipated appropriate areas and existing *O.niloticus* productivity in the county was used to verify the model. To find 90 sites for a follow-up visit and assessment, a stratified simple random sample from different suitability zones (very appropriate, moderately suitable, and marginally suitable) was used. On-the-ground, verification is the most reliable and also the most time consuming. Such an approach is appropriate to verify individual sites after the GIS have been employed to identify the most promising sites for *O.niloticus* farming areas. The method was to compare the locations and site-related performance of current fish farming facilities to GIS-provided locations and location ratings. Observations made during site visits, as well as data from interviews and questionnaires, were used to assess performance. Because the information provided was kept confidential, the fish farming areas are referred to by letters rather than names to make comparisons easier. The goal of the verification was to see if the existing locations were compatible with the suitable sites. Local people exhibited a preference for more suitable sites based on their indigenous knowledge, which was a key assumption.

Spatial Data Analysis

The indicator map was generated in Quantum GIS (QGIS) software by loading the shape file data into the input folder in drive C followed by clicking on add vector layer in the QGIS. The resultant map was saved in the output file in drive C. Indicator maps were converted to thematic maps of the study area by being georeferenced, assigned a coordinate system and assigned a similar pixel size in integrated land and water information system (ILWIS) software. The thematic maps were used as input in the combination of various factors to produce water availability suitability map using spatial multi-criteria evaluation tools in SMCE module in ILWIS.

RESULTS

This section gives the outcome from the GIS analyses, interviews, and questionnaires.

Comparison of Criteria Weights

The factors developed by the team of experts were weighted using AHP which used pair-wise comparison matrix. The results indicate that the amount of average annual rainfall factor was assigned the largest weight (0.1224) by the team of experts in *O.niloticus* farming followed by size of watershed (0.0222). These weights demonstrate that these factors have a major contribution in determining the overall suitability of *O.niloticus* farming in the county based on water availability. The rate of water seepage (0.0068) and water evaporation (0.0145) were assigned lower weights by the team of experts and demonstrated minimal contribution to the overall suitability of *O.niloticus* farming in the county.

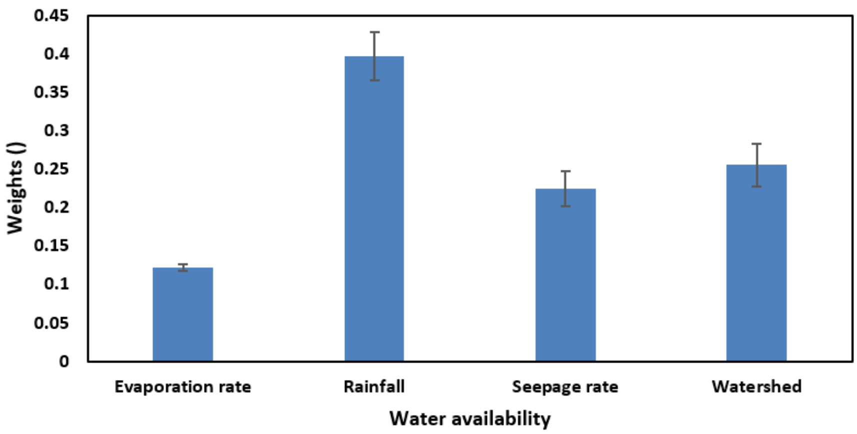

Figure 2: Comparison of the weights of factors developed by the team of experts in respect of water availability criteria.

Table 5 outlines factors which were assigned various weights by the team of experts and areas in Kisumu County assessed to be highly suitable, suitable, moderately suitable, marginally suitable and unsuitable for location of fish pond farming based on water availability criteria. The areas are also presented in the maps under each section.

Table 5: Criteria type, weight and area covered by each water availability criteria per a suitability class

Criteria	Criteria type	Criteria Weight	Suitability class, score and Area covered by each criteria per class				
			highly suitable (score= 0.61-1), colour= Dark green	Moderately suitable (score=0.41-0.60), colour= Pale green	Marginally Suitable (score=0.2-0.40) colour= Yellow	Not suitable(score=0-0.2) colour= Red	Total area
Annual rainfall	less 800 mm and more than 2000 is a cost	0.1224	1178	985	0	0	2163
Size of watershed	Less 5 km^2 is a benefit and more than 25 km^2 is a cost	0.0222	1721	389	53	0	2163
Seepage (mm/day)	>0.25 is a benefit	0.0068	1965	161	37	0	2163
Evaporation	<50% is a cost	0.0145	165	1671	25	302	2163

Area, Weight and Score for Each Suitability Criteria

Annual Rainfall Amount

Annual rainfall in Kisumu County is spatially distributed according to the modified equatorial warm climatic regions experienced in the County. Places with high average annual rainfall were found to be more suitable for *O.niloticus* farming than those with lower amount of rainfall. The county is divided into four climatic zones namely; central and lake shore, Eastern, Maseno and Kajulu with an average annual rainfall range of between 350 mm and 1,800 mm. Maseno and Kajulu areas, some parts of Kisumu East, Muhoroni and Nyakach sub-counties with an area of 1178 km^2 receives rainfall above 1200 mm per annum. Areas in Kisumu East, some parts Muhoroni and part of Nyakach covers an area of 538 km^2 and Lake Victoria and the area surrounding shores of the Lake where the central and lake shore type of climate occupies an area of 985 km^2 and receives annual rainfall, ranging from 700-1099 mm (Figure 3).

Figure 3: A Map showing the distribution of suitable sites for tilapia culture in Kisumu County based on annual rainfall distribution.

Interviews with the sub county officers revealed that most suitable areas in terms of amount of rainfall included; Kisumu west sub-county, some parts of Nyakach sub-county, Muhoroni sub-county, and Kisumu East sub-county. The areas also had the highest number of fish farmers and fish ponds in Kisumu County. Most parts of Nyando receive low rainfall.

Watershed Size

Table 5 illustrates that while a large size (more than 70 km^2) of watershed was considered a benefit, a small size (less than 2.5 km^2) was considered a cost. The table showed that 2163 km^2 of the area was suitable in terms of size of watershed for aquaculture site location. The map shows that an area of 1721 km^2 of Kisumu County was highly suitable, 389 km^2 was moderately suitable and 53 km^2 was marginally suitable for *O.niloticus* farming. The table showed that 2163 km^2 of the area was suitable in terms of size of watershed for aquaculture site location. Thus, there seems to be no risk for lack of suitability in terms of watershed size except in Nyakach. This fact was also confirmed by the fisheries officers, who saw watershed size as an important factor influencing location of fish ponds in the area. The responses from the officers were converted to a map as exhibited in Figure 4.

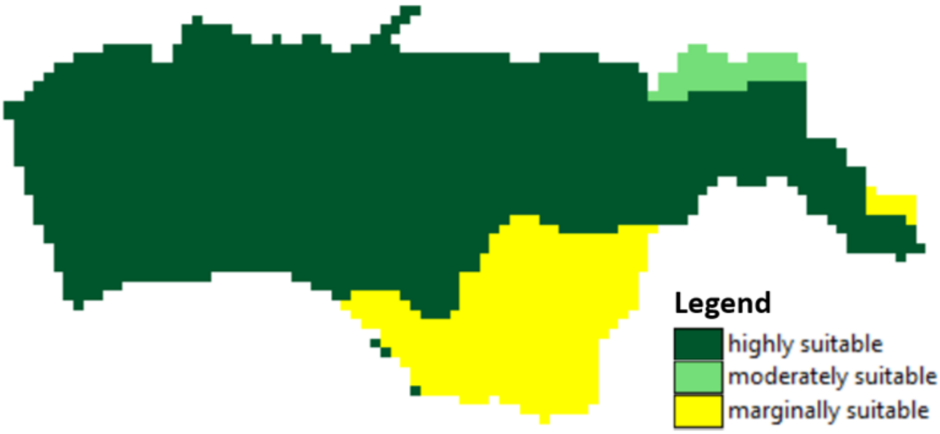

Figure 4: A Map indicating the distribution of suitable location for tilapia culture in Kisumu County based on size of watershed.

Rate of Seepage

The rate of seepage was determined by the distribution of soil structure in the county. Areas in Kisumu County with seepage rates below 0.25 mm/day occupied a total area of 1965 km^2. And was well distributed in the whole county. Those areas with seepage rates above 2.5 mm/day and below 5 mm/day covered an area of 161 km^2 and they occupy some parts of Muhoroni sub-county and Nyakach areas. Areas in most parts of Muhoroni and Nyakach sub-counties with seepage rates of between 5 mm/day and 6 mm/day occupy an area of 161 km^2. Areas with seepage rate between 6 mm/day and 7.5 mm/day covering a total area of 37 km^2. A suitability class not suitable was not recorded in this study. Figure 5 presents locations of sites according to suitability in terms of rate of seepage.

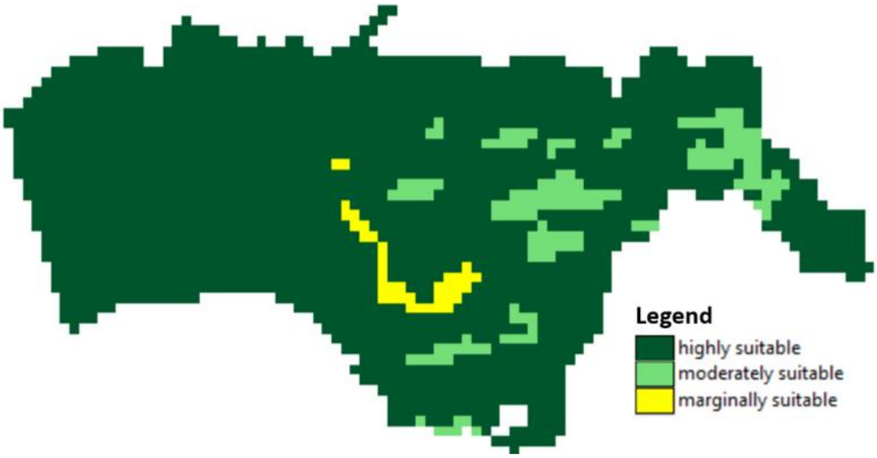

Figure 5: A Map showing the distribution of suitable sites for tilapia culture in Kisumu County based on rate of water seepage from ponds.

According to Fig. 5, most of the officers indicated that high water tables and soil typology (clay soil) are some of the factors which minimizes rate of seepage in the area hence determining suitability of aquaculture site location. Nyando, Muhoroni, and Kisumu East were some of the sub counties where rate of seepage is favourable, according to the sub county officers.

Rate of Evaporation

The rate of evaporation was determined by the temperature distribution in the county. Table 5 illustrates that evaporation of <50% is a cost. Areas in Kisumu County with evaporation rates below 50% occupied a total area of 165 km^2. These areas occupied some parts of Maseno, Kajulu and Koru. Those areas with evaporation rates above 50% and below 70% covered an area of 1671 km^2. The areas occupy most parts of Kisumu County. Evaporation rate of between 70% and 75% covered an area of 25 km^2 and occupied a small area of Nyakach. Areas with evaporation rate above 75% cover a total area of 302 km^2. The map showing the distribution of suitable sites in Kisumu County based on the rate of evaporation from ponds in presented in Figure 6.

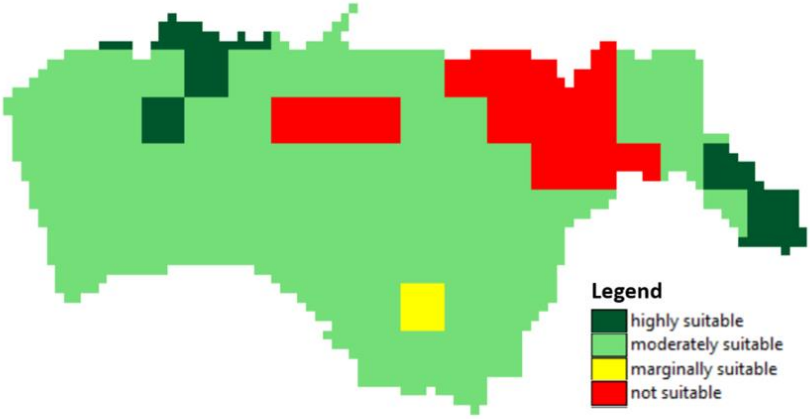

Figure 6: A Map showing the distribution of suitable sites for tilapia culture in Kisumu County based on evaporation rate of water from ponds.

Overall Water Availability Suitability Model

The spatial distribution of suitability classes in the water availability map indicates that the most suitable class which was assigned the highest suitability score of 0.6-1 and dark green colour covered an area of 1417 km^2 (65.5%) while the area covered by the moderately suitable class 498 km^2 (23.02%) and the margginally suitable class covered an area of 248 km^2 (11.46%) (Fig 7). The map showing the distribution of suitable sites in Kisumu County based on the combined water availability criteria is presented in Figure 7.

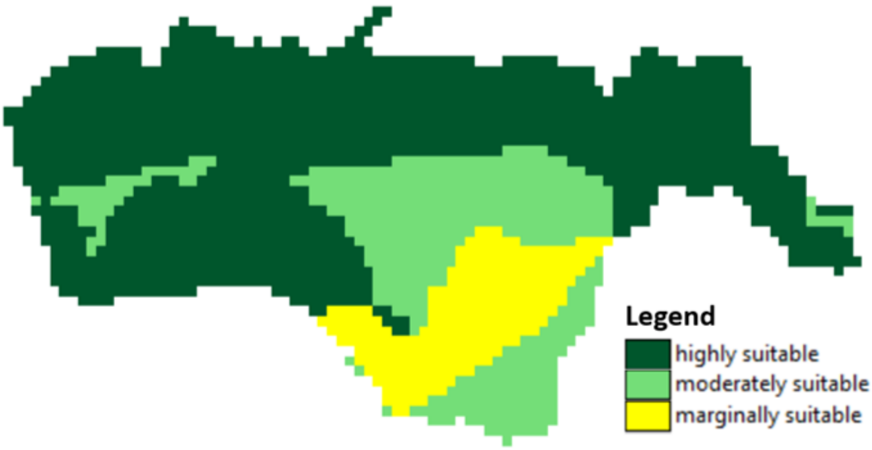

Figure 7: Water availability suitability map generated from the water availability factors.

The graph shows that the highest percentage (63.8%) of Kisumu County is highly suitable for farming O.niloticus, 23% is moderately suitable and 11.5% is marginally suitable.

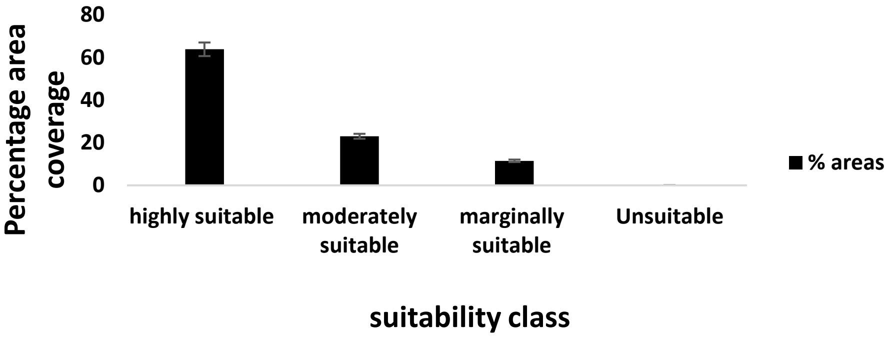

Figure 8: The percentage area covered by various suitability classes in the water availability criteria map.

Validation of Results

Among the selected 90 sites to check existing *O.niloticus* production compared to the suitability model, 25 out of 30 of the highly productive sites for *O.niloticus* farming were situated in the most suitable areas, 29 out of 30 of the moderately productive sites for *O.niloticus* farming were situated in the moderately suitable areas, and 28 out of 30 of the low productive sites for *O.niloticus* farming were situated in the marginally suitable sites respectively. These results were verified by both the fisheries officers and the farmers. As a result, 90 percent of the model output corresponded to the field verification.

DISCUSSION

The study findings indicate that there is a good potential for fish pond farming in Kisumu, although the sector and productivity is still small compared to countries in Asia, and other African countries like Egypt, Uganda, and Nigeria (Bhujel, 2013; Munguti and Ogello, 2014; Opiyo, 2018; Ghozlan, 2018; Njiru, 2018; Goepel, 2018).The study findings show that aquaculture is viable in all sub-counties of Kisumu at different levels of suitability (Table 1). The overall attitude among regional fisheries officers and local farmers to aquaculture was positive (Rahman, 2012). Coupled with the fact that over exploitation of natural fish in Lake Victoria and rising population in Kisumu city, it implies that the fish consumption is far below the recommended proportion (FARM AFRICA, 2012). With a per capita fish utilization of 8.6 kg per year and a population growth of 3% (FARM AFRICA, 2012). The additional fish production required to maintain 20180s level of fish consumption, would be some 110,000 tons in 2030. If only coming from aquaculture, this would imply a 20-fold increase of the current yield of freshwater aquaculture or fish production. With a yield of 2–4 tons of fish per ha and year in extensive pond farming (Munguti et al., 2021) this would require an additional area of 27,000–55,000 ha for pond farming.

The study found that most areas ranging from Seme sub-county, Kisumu East, through Kisumu west to some parts of Muhoroni and Nyakach covering an area of 1178 km^2 receives the highest amount of rainfall of above 1200 mm per annum. The shores of Lake Victoria, the whole of Nyando county and some parts of Nyakach occupies an area of 985 km^2 and receives moderate annual rainfall of 800 mm. There is no marginally suitable or unsuitable area in Kisumu in terms of rainfall suitability criteria in Kisumu county. This implies that in terms of amount of annual rainfall, Kisumu County is suitable for aquaculture. Suitable amount of annual rainfall as a predictor of improved production of fish pond aquaculture has been reported in Pakistan (Ayub, 2010), Australia (Meynecke et al., 2006, as well as Zambia (Ng'onga et al., 2019). Study findings also showed that 1721 km^2 of the area was highly suitable in terms of size of watershed for aquaculture site location. Thus, there seems to be no risk for lack of suitability in terms of watershed size. It is estimated that a pond will lose about an inch of water per week to evaporation. In bigger ponds up to 3 inches per week of evaporation is considered normal. Hot and dry weather can elevate evaporation another inch or two per week. There are many contributing elements that play into how much water will evaporate from your pond. Due to the fact that temperatures of Kisumu is normally high (above 26 degrees C), the sub county fisheries officers explained that this affected evaporation rate in fish ponds hence was a determining factor in aquaculture fish pond location. Rate of seepage in Kisumu County is minimal due to clay soils in the area. This reduces the cost of fish production as there is no need of using fish pond liners.

The most suitable areas for *O.niloticus* farming are those where most of the variables match with each other and have a high potential for *O.niloticus* production due to adequate water availability. Farmers from these areas can easily get high quality fish products and earn more profit than others. On the other hand, moderately suitable areas allow moderate *O.niloticus* production, although costs may be higher than the most suitable areas due to inadequate water availability.

CONCLUSION

Appropriately locating fish ponds in suitable sites could provide a potential solution to declining fish production and improved nutrition in Kenya. This study assessed the location of suitable sites for fish pond location using a combination of GIS with multi-criteria evaluation. GIS software made it possible to use large spatial data sets to analyze how a combination of criteria, related to the climate, ecology, and drainage, affected the suitability for fish pond farming in different Sub Counties in Kisumu. The importance of these criteria was decided through multi-criteria evaluations and analytical hierarchy processes, building on field interviews and questionnaires with fish farmers and fisheries officers, which provided means to include different stakeholders' knowledge in the overall GIS assessments, and also to validate the GIS spatial modelling results. The combination of GIS modeling and stakeholder consultations, building on both quantitative and qualitative data, helped to provide policy-relevant results, such as maps and compilation of stakeholder's perceptions.

Water availability sub models generated from factor maps indicates that most parts of Kisumu County are highly suitable or suitable for aquaculture except some parts of Nyakach and Muhoroni where most parts are moderately suitable. Some parts of Seme sub-county are suitable in line with the distribution of rainfall and rivers in the county. Where rainfall is high and reliable aquaculture suitability is also high. Places where evaporation and seepage are high, suitability is low compared to places where evaporation and seepage are low. Most of the areas, however, are highly suitable for aquaculture in terms of amount of annual rainfall and rate of water seepage.

References

Abdelrahman, H. A., & Boyd, C. E. (2018). Effects of mechanical aeration on evaporation rate and water temperature in aquaculture ponds. *Aquac Res*. 2018; 49:2184–2192.

Adhikari, S. Pani, K. C., & Jayasankar, P. (2017). Water gain and water loss of some freshwater aquaculture ponds at Kausalyaganga, Orissa, India.

Ansari M., & Ghoddousi A. (2018). Water availability limits brown bear distribution and the southern edge of its global change. *Ursus*, 29(1) (2019).pp.13-24.

Assefa, W. W,. & Abebe, W. B. (2018). GIS modeling of potentially suitable sites for aquaculture development in the Lake Tana basin, Northwest Ethiopia. *Agric & Food Security, 7* (72), 1 – 15.

Ayub, Z. (2010). Effect of temperature and rainfall as a component of climate change on fish and shrings catch in Pakistan. *J. Transdiscipl. Environ. Stud. 9* (1), 1–9.

Berg, H., Mulokozi, D., & Udikas, L. (2021). A GIS Assessment of the Suitability of Tilapia and Clarias Pond Farming in Tanzania. *ISPRS Int. J. Geo-Inf., 10*, 354.

Bhujel, R. C. (2013). On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Thailand. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 159–189.

Brown, T. W., Boyd, C. E., & Chappell, J. A. (2012). Approximate water and chemical budgets for an experimental, in-pond raceway system. *Journal of the World Aquaculture Society, 43*, 526–537

Clough, S., Mamo, J., Hoevenaars, K. Bardocz, T. Petersen, P., Rosendorf, P. …….. Hoinkis, J. et al (2020). Innovative Technologies to Promote Sustainable Recirculating Aquaculture in Eastern Africa—A Case Study of a Nile Tilapia (Oreochromis niloticus) Hatchery in Kisumu, Kenya. *Integrated Environmental Assessment and Management 00*, (00), 1–8.

Convertino, M. Munoz-carpena R. ,Chu-Agor M. L. Kiker, G. A., & Linkov L. (2014). Untangling drivers of species distribution: Global sensitivity and uncertainty analysis of Maven. Environmental Modelling& software, 51(2014), pp.296-309.

Egna, H. S., & Boyd, C. E. (1997). Dynamics of pond aquaculture. New York: CRC press.

FARM AFRICA. (2016). Kenya Market-Led Aquaculture Programme Strategic Environmental Assessment and Environmental Management Plan. Nairobi: FARMAFRICA, p. 112.

FARM AFRICA (2016). Report on Market Study of the Aquaculture Market in Kenya. Kenya Market-Led Aquaculture Programme (KMAP). Nairobi: FARM AFRICA :76.

Fern, A., Ponmudi, R., Ramesh, P., Vijay. S, & Ranjith. M. (2018). Control the Evaporation of Water in Lakes and Ponds. *International Journal of Engineering Research & Technology, 6* (7), 1 – 6.

FAO (1996). A Geographical Information System to Plan for Aquaculture. FAO, Fisheries Technical Paper (287).

Food and Agriculture Organization of the United Nations (FAO) (2016). Fishery and Aquaculture Country Profiles. Kenya,. Country Profile Fact Sheets. Rome, p. 42. http://www.fao.org/fishery/facp/KEN/en.

Food and Agriculture Organization of the United Nations (2010). Securing Sustainable Small-Scale Fisheries: Bringing Together Responsible Fisheries and Social Development. RAP Publication 2010/19. In: APFIC/FAO Regional Consultative Workshop. Food and Agriculture Organization of the United Nations, Bangkok, TH, pp. 1-56.

Food and Agriculture Organization of the United Nations (2012). The State of World Fisheries and Aquaculture 2012. FAO, Rome, IT.

Ghozlan, A. A, Zaki, M. M., Gaber, M. M., & Nour, A. (2018). Effect of different water sources on survival rate (%) Growth performance, feed utilization, fish yield, and economic evaluation on Nile Tilapia (*Oreochromis niloticus*) mono sex reared in earthen ponds. *Oceanography & Fisheries Open access Journal, 6* (10), 1 – 7.

Goepel, K. D. (2018). Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS). *Int. J. Anal. Hierarchy Process*, 10, 469–487.

Goepel, K. D. (2013). Implementing the Analytic Hierarchy Process as a Standard Method for Multi-Criteria Decision Making in Corporate Enterprises—A New AHP Excel Template with Multiple Inputs. 2013. Available online: https://bpmsg.com/wordpress/wpcontent/uploads/2013/06/ISAHP_2013-13.03.13.Goepel.pdf.

Ishizaka, A., & Labib, A. (2009) Analytic Hierarchy Process and Expert Choice: Benefits and Limitations, *OR Insight*, 22(4), p. 201–220.

Jayanthi, M. M., Rekha, N.P., Muralidhar, M., & Gupta, B. P. (2004). Seepage Reduction in Brackishwater Ponds with Different Materials. Eco. Env: & Cons. 10 (3): 2004; pp. (257-260).

KBNS (Kenya National Bureau of Statistics) (2019). 2019 Kenya population and Housing population census volume 1. Population by county and sub-county.

Kisumu County Integrated Development Plan (KCIDP) (2018). The County Development plan 2018 – 2022.

KMFRI (2017). Kenya's, Aquaculture Brief 2017: Status, Trends, Challenges and Future Outlook Mombasa: Kenya Marine and Fisheries Research Institute (KMFRI) 2017 p.12.

www.kmfri.co.ke/images/pdf/Kenya_Aquaculture_Brief_2017.pdf.

KNBS, Kenya National Bureau of Statistics. Economic Survey (2017). Nairobi: Kenya National Bureau of Statistics (KNBS); 2017. p. 333.

http://www.devolutionplanning.go.ke/images/hb/Economic Survey 2017.pdf.

Lake Victoria Basin Commision (2011). A Study on Aquatic Biodiversity in the Lake Victoria Basin. ACTS Press, African Centre for Technology Studies, Lake Victoria Bassin Commision, Nairobi, KE.

Malczewski, J. (1999). GIS and multi-criteria decision analysis. New York: Wiley.

Meynecke, J. O., Lee, S.Y., Duke, N.C., & Warnken, J., (2006). Effects of rainfall as a component of climate change on estuarine fish production in Queensland, Australia. Estuarine Coast. *Shelf Sci. 69,* 491–504.

Miranda L. E. (2008). Extending the Scale of Reservoir Management. *In*: M. Allen and S. Sammons (editors). Balancing fisheries management and water uses for impounded river systems. American Fisheries Society. Bethesda, Maryland USA (In press).

MoALF **(2017).** Climate Risk Profile for Kisumu County. Kenya County Climate Risk Profile Series. The Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

Munguti J, Kim J, Ogello E.O (2014). An overview of Kenyan Aquaculture, current status, challenges and opportunities for future development. Fish Aquac Sci 17(1):1–11. https://doi.org/10.5657/FAS.2014.0001.

Munguti, J. M., Obiero, K., Orina, P., Mirera, D., Kyule, D., Mwaluma, J., ……. Hagwara, A. (2021). State of aquaculture report 2021. Towards nutrition sensitive fish food production systems. Techplus media House, Nairobi. Kenya. 190pg.

Musa, S. A., Aura, C. M., Owiti, G. E., Nyonje, B. E., Orina, P. A., & Charo-Karisa, H. A. (2012). Fish farming enterprise productivity program (FFEPP) as an impetus to *Oreochromis niloticus* (L.) farming in Western Kenya: Lessons to learn. *Afr J Agric Res* 2012(7):1324–30.https://doi.org/10.5897/AJAR11.1606.

Musyoka, S., & Mutia, G. (2016). The status of fish farming development in arid and semi-arid counties of Kenya: A case study of Makueni County. *Eur J Phys Agric Sci* 4(3):28–40.

Nayak, A. K., Pant, D., Kumar, P., Mahanta, C., & Pandey, N. N. (2014). GIS-based aquaculture site suitability study using multi-criteria evaluation approach. *Indian Journal of Fisheries*, *61*(1), 108-112.

Ng'onga, M., Kalaba, F. K., Mwitwa, J., & Nyimbiri, B. (2019). The interactive effects of rainfall, temperature and water level on fish yield in Lake Bangweulu fishery, Zambia. *Journal of Thermal Biology, 84,* 45–52.

Njiru J. M., Aura, C. M., & Okechi, J. K. (2018). Cage fish culture in Lake Victoria: A boon or a disaster in waiting? *Fish Manag Ecol*. 2018;00:1-9.

Obiero, K., Meulenbroek, P., Drexler, S., Dagne, A., Akoll, P., Odong, R., Kaunda-Arara, B., & Waidbacjer, H. (2019). The contribution of fish to food and nutrition security in Eastern Africa: Emerging trends and future outlooks. Sustain 11(6):1636.

Obwanga, B, Lewo, M. R., Bolman, B. C., & van der Heijden, P. G. M. (2017). From aid to responsible trade: driving competitive aquaculture sector development in Kenya; Quick scan of robustness, reliability and resilience of the aquaculture sector. Report 2017–092 3R Kenya. Wageningen: Wageningen University & Research;. 10.18174/421667.

Ogello, E. O., & Munguti, J. (2016). Aquaculture: a promising solution for food insecurity, poverty and malnutrition in Kenya. Afr J Food, Agric Nutr Dev 2016;16:11331–50. https://doi.org/10.18697/ajfand.76.15900.

Ogunlade, S. O. (2020). Site suitability mapping for fish farming: A geospatial approach. Available at: https://www.researchgate.net/publication/343480691.

Opiyo, M. A., Marijani, E., Muendo, P., Odede, R., Leschen, W., & Charo-Karisaf, H. (2018). A review of aquaculture production and health management practices of farmed fish in Kenya. *International Journal of Veterinary Science and Medicine, 6*, 141–148.

Ossadnik, W., & Kaspar, R. (2013). Evaluation of AHP software from a management accounting perspective. *Journal of Modelling in Management,* Vol. 8 No. 3, pp. 305-319.

Patrick, A. E. S. (2016). Influence of rainfall and water level on inland fisheries production: A review. *Archives of Applied Science Research, 8* (6), 44-51.

Rahman, M. M, Mostafa Shamsuzzaman, M. D., Mahmood, S., Sarker, S., & Faruk Alam, M. D. (2012). Economics of Tilapia Culture in Watershed Pond in Bangladesh. *J Aquacult Res Dev 3* (141) doi:10.4172/2155-9546.1000141.

Richard, J. U., & Chima Ogba, C. (2016). Site selection analysis for suitable aquaculture fish pond in Andoni L.G.A. rivers state, Nigeria. International Journal of Research – Granthaalayah, 4 (3), 219-232.

Sipaúba-Tavares, L. H., Guariglia, C. S. T., & Braga, F. M. S. (2007). Effects of rainfall on water quality in six sequentially disposed fishponds with continuous water flow. *Braz. J. Biol., 67*(4), 643-649.

Siraj, S., Mikhailov, L., Keane, J. A., & Pries, T (2015). An Interactive Decision Support Tool To Estimate Priorities From Pairwise Comparison Judgments, International Transactions in Operational Research, Vol. 22, Issue 2, 217–235.

Ssegane, H., Tollner, E.W., & Veverica, K. (2012). Geospatial modeling of site suitability for pond-based tilapia and clarias farming in Uganda. *Journal of Applied Aquaculture,*

State Department of Fisheries (SDF) (2014). Fisheries Annual Statistical Bulletin Nairobi, State Department of Fisheries: p. 59.

State Department of Fisheries (SDF) (2016). Kenya Fish Farming Enterprise Productivity Capacity Assessment and Gap Analysis Report.

Uzukwu, P. U., George, O. S., & N. A. Jamabo, N. A. (2011). The Problem of Water Seepage in Aquaculture: A Preliminary Study of the Soils of Arac Fish Farm, Omuihuechi-Aluu, Rivers State, *Nigeria. Asian Journal of Agricultural Sciences* 3(2): 63-69.

Zhang, J., Jiang, F., Li, G.., Qin, W., Li, S. Gao, H, Gai, Z., Lin, Z., & Zhang, T. (2019) Maxent modelling for predicting the spatial distribution of three raptor in the Sanjiangyuan National Park, China, *Ecology and evolution,* 9(11)2019, pp.6643-6654.published by Elsevier GmbH.