Surface Catchment Development and Sustainability Evaluation for Multipurpose Water Supply for Meeting Aquaculture and Other Water Needs

Watershed & Integrated Coastal Zone Management/Study/09WIZ02AU

E.W. Tollner and Herbert Ssegane
University of Georgia,
Athens, Georgia, USA

Levi Kasisira and Peter Mulumba
Makerere University
Kampala, Uganda

ABSTRACT

Fish farming in Uganda is predominantly practiced by poor people in villages for subsistence with 80 % of the ponds about 100 m². Many of the ponds are just dug in swampy/wetland areas or micro-watershed concentrated storm runoff areas without proper planning or guidelines that take into considerations the ecological and environmental impacts. This has led to drying up of ponds and massive encroachment on wetlands and riparian buffers. Also, on the national coverage, there was no detailed map of Uganda depicting areas that are suitable for inland fish farming while accounting for the need to control encroachment on wetlands and riparian buffers. The project goal was to develop strategies to better employ water capture in Uganda by modeling for surface catchment and site evaluation in the presence of potential surface water runoff. The specific objectives included: (1) use of geographic information systems (GIS) and remote sensing (RS) to develop an aquaculture site suitability map for Uganda; (2) develop guidelines on site selection of ponds to ensure reliable water supply and sustainable ecological existence within the micro-watershed; and (3) construction of pilot pond for demonstration and future instruction purposes. The approach for the physical research began with remote sensing and GIS assessment of site suitability for Uganda with emphasis on soils, topography, climate, access to farm inputs and access to markets. Working with host country personnel, sites were identified for the preliminary screening analysis based on GIS analysis and the spreadsheet tool. Potential sites were further analyzed using infiltration or seepage pits. The major suitability study findings related to the crisp and fuzzy suitability maps developed for Uganda. For both the crisp and the fuzzy approaches, over 98 % of the land was classified as either suitable or as moderately suitable. Overall, the crisp method classified 16,322 hectares (0.09 %) as very suitable compared to zero hectares (0 %) by the fuzzy method. Simultaneously, the crisp method gave 297,344 hectares (1.96 %) as unsuitable compared to 168,592 hectares (0.96 %) by the fuzzy method. Of the 138 surveyed fish ponds that were operational, the crisp method classified 71 % as suitable while 29 % as moderately suitable while the fuzzy method classified 71.7 % as suitable while 28.3 % as moderately suitable. Key concerns regarding pond construction were side slope stabilization and levee compaction. These were extensively emphasized during the host country workshop. For the compaction, farmers expressed interest in a simple manually operated tool that can easily be transported to any site. The second challenge expressed by visited farmers was excess water during the wet months and drying up of ponds during the dry months.

INTRODUCTION

Background and Problem Definition

Agriculture is the most important sector of Uganda's economy and accounts for over 31 % of the country's export earnings, contributes 32 % to total GDP and Provides 80 % of employment (World Bank report, 2007). Because of this central and strategic role of agriculture to the national economy, it is the key to; improvement in economic performance; increased incomes; raising of living standards of households; ensuring food security and poverty eradication. A major component for development of the agricultural sector is the development and sustainable utilization of water resources. Although the country is usually considered as being well endowed with water resources (Lake Victoria, River Nile, and annual rainfall in some parts of 1600 mm – 2000 mm) the seasonal and spatial variability of rainfall patterns and stream flows cause specific problems because the country encompasses both humid and semi-arid areas. There are very wet and very dry years, but also considerable variations in the timing of the onset of seasons and the amount of rainfall. This has resulted in repeated cases of severe food shortage due to crop failure coupled with death of a significant number of livestock. One strategic approach to minimize the effects of erratic rainfall patterns on agricultural production and productivity is to integrate watershed management schemes that focus on capturing overland flow in small impoundments for multiple uses such as community water supply, aquaculture, livestock watering, and small-scale irrigation.

Some of the rural population involved in fish farming in Uganda, construct ponds by digging up areas in swampy locations and wetlands without proper siting, design, construction and management. This has led to encroachment, disruption, and destruction of natural wetlands and riparian buffers. Thus, altering and eliminating the natural functionality of wetlands and riparian buffers (which is filtration and settlement of nutrients and sediment respectively). Therefore, demonstration of proper pond siting, construction, management, and provision of guidelines in consultation with local stakeholders will provide alternatives to the above mentioned issues related to unsustainable fish farming practices. The proposed strategy for this project focused on two critical steps. The first step was the utilization of geographic information systems (GIS) and remote sensing to develop a GIS based stratification map of Uganda depicting suitable areas with respect to water availability and other metrics that influence pond based fish farming suitability. The water availability metric accounted for annual water balance, required pond volume, and average farm size. Other metrics addressed suitability related to topography, access to markets, and availability of farm inputs. The second step focused on detailed site survey and analysis for construction of pilot pond.

Purpose, Objectives, Scope: Project goals and objectives

The project goal and scope were to develop strategies to better employ water capture in Uganda by modeling for surface catchment and site evaluation in the presence of potential streams, wetlands and surface water runoff. The specific objectives included

1. Use of geographic information systems (GIS) and remote sensing (RS) to develop an aquaculture site suitability map for Uganda (*Hypothesis: Site suitability for aquaculture is significantly influenced by climate, topography, and soils*).
2. Development of guidelines on site selection for watershed and levee ponds to ensure reliable water supply and sustainable ecological existence within the micro-watershed. The information in the local guidelines does not address proper siting, design, and construction practices (*Hypothesis: Proper siting, design, construction, and maintenance of ponds are key to sustainable fish farming practices with minimal ecological and environmental impacts*).
3. Pond construction to demonstrate proper site selection (based on site suitability map), design, and construction practices that minimize encroachment on wetlands.

METHODS AND MATERIALS

Suitability metrics

Seven criteria of water requirement, water temperature, soil texture, terrain slope, potential farm gate sales, availability of farm inputs, and access to local and regional markets were analyzed for site suitability for Tilapia and Clarias farming. To enable geographic information systems (GIS) operations during the multi criterion evaluation (MCE) process, the criteria thresholds were transformed into crisp and fuzzy set values for comparison. The crisp values used the class limits based on expert knowledge while the fuzzy values allowed for a degree of membership between classes. The crisp values were based on criterion thresholds in table 1 such that values of one, two, three, and four represented not suitable (NS), moderate suitability (MS), suitable (S), and very suitable (VS) respectively. The fuzzy values (ranging from one to four) were generated by using a combination of triangular and trapezoidal membership functions.

Table 1. Summary of crisp values for each suitability group across the seven criteria

	Criterion	Criterion thresholds			
		Very Suitable	Suitable	Moderate Suitability	Not Suitable
1	Water requirement (ha – required drainage area)	< 5	5 - 20	20 - 100	> 100
2	Water Temperature (^{O}C)	28 - 32	24 - 28	20 - 24	< 20 or >32
3	Soil texture (% clay)	15 - 30	10 – 15 or 30 - 40	5 – 10 or 40 - 50	< 5 or >50
4	Slope (%)	< 2	2 - 5	5 - 15	> 15
5	Farm gate sales (people / km^2)	150 - 300	25 - 149	1 - 24	< 1or > 300
6	Access to local and regional markets (travel hours)	< 1	1 - 3	3 - 6	> 6
7	Farm inputs • Total number of poultry • Distance to feed agents (km)	> 100,000 < 30	40,000 – 100,000 30 - 50	15,000 – 40,000 50 - 100	< 15,000 > 100

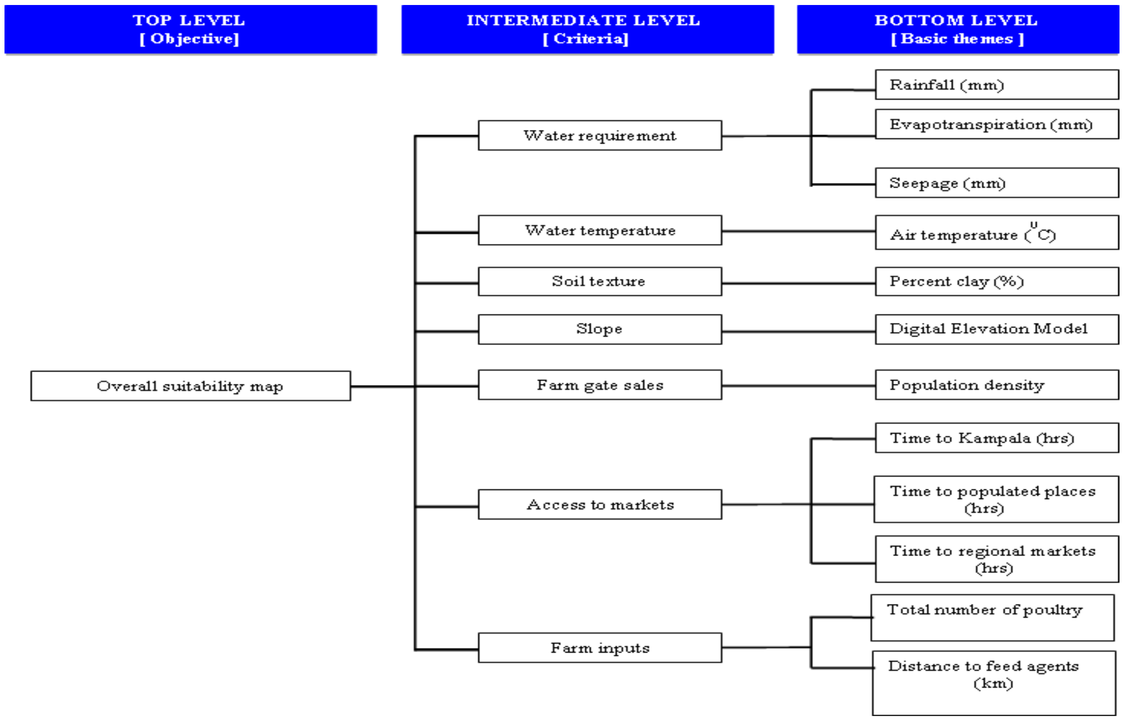

Figure 1. Flow chart of the geospatial modeling process

Data and GIS modeling

Table 1 and figure 1 depict the themes and data used to generate suitability maps for each of the seven criteria and the overall suitability. This study considered water from rainfall runoff as the primary source of water for small scale fish farming. The watershed drainage area required to provide 500 m^3 pond volume during the critical month of the year for each location was used as the metric for water requirement. The seepage values were estimated based on lower limit of seepage rates in Egna and Boyd (1997). The curve number method was used to estimate annual runoff. The curve numbers were determined using the soil hydrologic group, land use, and land cover data.

The soil hydrologic groups were estimated using soil textural classes. MATLAB® functions and scripts were developed to reclassify the soil textural classes into soil hydrologic groups. The soils textural data was extracted from the Harmonized World Series Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2008) while the landcover and landuse from the Food and Agriculture Organization (FAO) Africover multipurpose landcover database (Africover, 2002). Evapotranspiration was estimated by the Blaney – Criddle model. Annual rainfall map of Uganda was generated by interpolating (inverse distance weighing) long term average rainfall data (1961 – 1990) of various rain gauge stations in Uganda (347 stations), Kenya (706 stations), Tanzania (556 stations), Rwanda (40 stations), Sudan (171 stations), and Democratic Republic of Congo (187 stations). The rainfall gauge data was extracted from the FAO Agroclimatic database (FAO, 2010). ArcMap GIS was used to interpolate the above gauge data and to extract the Uganda annual rainfall grid.

Water temperatures were estimated using a mean monthly water temperature model by Kapetsky (1994) that relates water temperatures to air temperatures of 51 data points at the Henderson Research Station near Harare (Zimbabwe). The slope and soil texture suitability (table 1) were classified by modifying ratings by Yoo and Boyd (1993); Hossain et al. (2007); Hossain et al. (2009); and Hossain and Das (2010). Access to farm inputs was estimated using two factors. The first factor quantified the total number of poultry as an indicator of access to feeds. The total numbers of poultry were calculated at a sub-county level and the geo-referenced data were based on the Uganda National Household Survey for Agriculture and Livestock data (IGAD-LPI, 2010).

The second factor was the distance to the location of major feed agents. ArcGIS was used to compute the Euclidean distance to the major feed agents. The overall access to farm inputs was generated by computing for the maximum suitability between the two factors. This project used population density as the metric for potential farm gate sales. The same thresholds used by Kapetsky and Nath (1997); and Aguilar-Manjarrez and Nath (1998) were used. The accessibility metric used was the travel time in hours in contrast to distance because it is a more realistic metric for areas where the quality of transport network is variable (Pozzi et al., 2010). The data used were grid based GIS layers generated by the IGAD Livestock Policy Initiative. Each grid cell represented the time required to reach the nearest point of interest (Kampala or populated areas) along the least cost route (Pozzi et al., 2010).

To enable geographic information systems (GIS) operations during the multi criterion evaluation (MCE) process, the criteria thresholds were transformed into crisp (table 1) and fuzzy set values for comparison. The crisp values used the class limits based on expert knowledge (4 for VS; 3 for V; 2 for MS; and 1 for NS) while the fuzzy values allowed for a degree of membership between classes.

Design workshop and pond construction

A two day workshop was held at the host institution (Makerere University, Uganda) that brought together the major stakeholders (researchers from local institution, fish farmers, and U.S. lead advisors). The first day focused on the state of aquaculture, water availability, pond construction challenges, and use of GIS and RS in site selection. The second day focused on preliminary site assessment, in-situ measurements such as use of seepage pits, and use of spreadsheet tools for water balance and design of levee and watershed ponds. Throughout the workshop, encroachment on wetlands and riparian buffers was discouraged. A compact disc of the guidelines and design strategies was given to each participant for future reference. The workshop material emphasized: Site description (topography, photo and images showing surrounding land, climate description with monthly rainfall and evaporation values from surrounding stations, riparian zone around the pond site); Soils (texture and infiltration pit study results); Design (selected size, depth, inlet works, and outlet works); Construction (timing and photograph sequence, excavation methods, and compaction techniques); and operational plans (water quality studies, integrated fish production and riparian zone management, and riparian zone effects). The primary pond excavation, side slope and levee compaction were manually achieved. We followed recommendations that are summarized in Coche (1988) and Coche et al (1995).

RESULTS

Table 2. Summary of overall Tilapia and Clarias suitability classification by the crisp and fuzzy methods

	Crisp		Fuzzy	
	Area (hectares)	Area (%)	Area (hectares)	Area (%)
Not suitable	10,794	0.06	7,150	0.04
Moderate suitability	8,380,709	47.62	8,676,808	49.30
Suitable	9,147,925	51.98	8,914,442	50.65
Very suitable	59,203	0.34	230	0.00

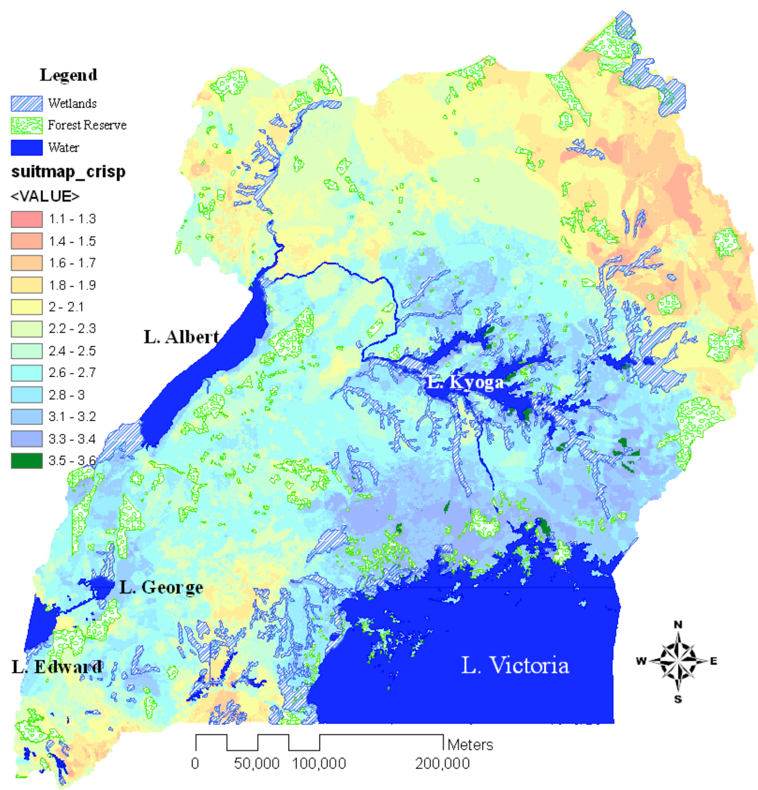

Figure 2. Tilapia and Clarias farming suitability map generated by crisp method

Figure 3: Photos of pond construction site, neighboring wetlands, and agricultural activities

CONCLUSION

There were five major outcomes of the project. These included:

1. Two suitability maps of Uganda for pond based fish farming. The first map was based on crisp classification while the second on fuzzy classification. The maps were developed using a multi criteria evaluation of seven criteria that included water requirement, water temperature, soil texture, slope gradient, potential for farm gate sales, access to local and regional markets, and availability of farm inputs. The site suitability maps designated major wetlands as protected sites that should not be considered for pond based fish farming.
2. A two day workshop was held at the host institution (Makerere University, Uganda) that brought together the major stakeholders (researchers from local institution, fish farmers, and U.S. lead advisors). The first day focused on the state of aquaculture, water availability, pond construction challenges, and use of GIS in site selection. The second day focused on use of an excel spreadsheet tool for proper design and planning for levee and watershed based pond.
3. A 60 m × 80 m pond has been constructed at the selected site for demonstration purposes and for future educational purposes and information dissemination. The site is close to an education facility Makerere University uses to retool national extension workers.
4. Visited two farmer groups in Gulu (Uganda) that work with Gulu University to support orphans through fish farming. This region of the country has been devastated with 20 years of war and with the return of peace, fish farming is one of the activities that have been embraced by the local populace. Discussions centered on possible future collaborations between Gulu University, Makerere University, and the U.S. institutions.
5. A paper has been submitted to a peer reviewed Journal of Applied Aquaculture for publication.

ACKNOWLEDGEMENT

We thank the AquaFISH CRSP for funding the project and EPA P3 for additional funding that enabled for the construction of pilot pond. We also wish to thank Dr. Nelly Isyagi, Maurice Ssebisubi, and John Walakira for the fish pond survey data.

LITERATURE CITED

Africover, 2002. Africover—Eastern Africa Module. Land cover mapping based on satellite remote sensing. Food and Agriculture Organization of the United Nations.

Aguilar-Manjarrez, J., Nath, S.S., 1998. A strategic reassessment of fish farming potential in Africa. Food and Agriculture Organization of the United Nations, Rome.

Coche, A.G. 1988. Topography for freshwater fish culture: Topological tools. UNFAO Rome IT.

Coche, A.G., J.F. Muir, and T. Laughlin. 1995. Pond construction for freshwater fish culture: Building earthen ponds. UNFAO, Rome, IT.

Egna, H.S., Boyd, C.E., 1997. Dynamics of pond aquaculture. CRC press, Boca Raton ; New York.

FAO, 2010. Food and Agriculture Organization (FAO): FAOClim-NET, Agroclimatic database management system

FAO/IIASA/ISRIC/ISS-CAS/JRC, 2008. Harmonized World Soil Database (version 1.0). In: FAO (Ed.), Rome,Italy and IIASA, Laxenburg, Austria.

Hossain, M.S., Chowdhury, S.R., Das, N.G., Rahaman, M.M., 2007. Multi-criteria evaluation approach to GIS-based land-suitability classification for tilapia farming in Bangladesh. Aquaculture International 15, 425-443.

Hossain, M.S., Chowdhury, S.R., Das, N.G., Sharifuzzaman, S.M., Sultana, A., 2009. Integration of GIS and multicriteria decision analysis for urban aquaculture development in Bangladesh. Landscape and Urban Planning 90, 119-133.

Hossain, M.S., Das, N.G., 2010. GIS-based multi-criteria evaluation to land suitability modelling for giant prawn (Macrobrachium rosenbergii) farming in Companigonj Upazila of Noakhali, Bangladesh. Computers and Electronics in Agriculture 70, 172-186.

IIGAD-LPI, 2010. InterGovernmental Authority on Development: Livestock Policy Initiative (IGAD LPI). GIS data for Uganda Food and Agriculture Organization.

Kapetsky, J.M., 1994. A strategic assessment of warm-water fish farming potential in Africa. Food and Agriculture Organization of the United Nations, Rome.

Kapetsky, J.M., Nath, S.S., 1997. A strategic assessment of the potential for freshwater fish farming in Latin America. Food and Agriculture Organization of the United Nations, Rome.

Kiker, G. A., Clark, D. J., Martinez, C. J., and Schulze, R. E. (2006). "A Java-based, object-oriented modeling system for Southern African hydrology." Transactions of the Asabe, 49(5), 1419-1433.

Moehl, J.F., Halwart, M., Brummett, R.E., 2005. Report of the FAO-Worldfish Center Workshop on small-scale aquaculture in sub-Saharan Africa : revisiting the aquaculture target group paradigm, Limbé, Cameroon, 23-26 March 2004. Food and Agricultural Organization of the United States, [Rome].

Pozzi, F., Robinson, T., Nelson, a.A., 2010. Accessibility Mapping and Rural Poverty in the Horn of Africa. IGAD Livestock Policy Initiative. Food and Agriculture Organization.

Saxton, K. E. (1982). "Spaw Model Predicts Crop Stress." Agricultural Research , 30(12), 16-16.

World Bank. (2007). Republic Of Uganda; Joint IDA-IMF Staff Advisory Note on the Poverty Reduction Strategy Paper Annual Progress Report World Bank, Washington, D.C.

Yoo, K.H., Boyd, C.E., 1993. Hydrology and water supply for pond aquaculture. Van Nostrand Reinhold, New York.