Potential Influence of Climate Variations, Water Quality and Soil Quality on Uganda's Aquaculture

By

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ABSTRACT

Fisheries production from lakes and other natural waters in Uganda is declining, and expansion of the aquaculture sector is needed to increase aquatic protein for human consumption. The present study was conducted to improve understanding of limitations imposed on aquaculture by the environmental factors of climate, soils, and water quality in Uganda.

A total of 1,885 ponds were identified with an average pond size of about 623 m^2 in 15% of the area mapped in Uganda. Extrapolation to the entire country suggested a total of 13,946 ponds by region and 16,570 ponds by pond density calculation which was less than the number of ponds cited in the literature. Better documentation of ponds in Uganda is needed especially if extension services, aquaculture resource allocation and taxation are to be improved. Although not optimum, the temperature regime in Uganda is conducive to year-around aquaculture in most areas. Rainfall is adequate to maintain water levels in ponds throughout the year in the Central and Eastern regions. In the Northern and Western regions, it would be necessary to store water in farm reservoirs to use for maintaining water levels during the driest months. There is a tendency towards drought in Uganda, and severe droughts could cause water shortages for aquaculture.

Water quality was generally suitable in all four regions for fish production. The main water quality limitation is the need to lime ponds in some areas in all regions. Unfortunately, liming materials available in the country are of poor quality, and the agricultural limestone currently used by fish farmers is particularly low in quality. There is an urgent need to find better sources of liming materials and begin an effort to promote liming in Ugandan aquaculture. The main limitations of soils for pond sites were coarse soil texture, steep terrain in some areas, and a

widespread problem of low acidity. Of course, as in any country, each prospective pond site must be examined for its suitability. There also is cage culture in several lakes in Uganda, and Lake Victoria and Lake Albert appear to be the best lakes in which to consider expansion of cage culture operations. In summary, there does not appear to be insurmountable environmental constraints to expanding aquaculture production in Uganda. The major issues relate to selecting good sites for ponds and to finding a source of good quality liming material.

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ABBREVIATIONS

ANOVA	Analysis of Variance
DFID	Department for International Development
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographical Information System
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MFPED	Ministry of Finance, Planning and Economic Development
NAADS	National Agricultural Advisory Services
NARO	National Agricultural Research Organization
NEMA	National Environmental Management Authority
NGO	Non-Governmental Organization
SPI	Standard Precipitation Index
PMA	Plan for Modernization of Agriculture
UBOS	Uganda Bureau of Statistics
USAID	United States Agency for International Development

WMA	World Meteorological Authority

INTRODUCTION

Fisheries sector is the second largest foreign exchange earner after coffee in Uganda (MFPED 2015). The sector contributes $135 million, employs 1.2 million people and is one of the major sources of protein for the Ugandan population (MAAIF 2012). Moreover, the current high fishing pressure, illegal fishing, habitat degradation and water hyacinth have led to a decline in the fish catches.

The National Agricultural Advisory Services (2005) recorded an average annual fish supply from all lakes declining from 245,000 tonnes in 1990 to 220,000 tonnes. The National Agricultural Advisory Development (2005) also recorded a decline of annual average per capita fish consumption in Uganda from about 14 kg before 1990 to between 4 kg to 8 kg after 1990. The Uganda Bureau of Statistics (UBOS 2017) noted the maximum sustainable yield to have been exceeded as the current fish catches from Lake Victoria to be 252,000 tonnes compared to the 1993 highest yield of 330,000 tonnes. This question the sustainability of the fisheries sector especially because Lake Victoria contributes half the fish catches in Uganda.

The decline in fish catches is worsened by the high population growth currently at 3.4%. Moehl et al. (2006) considered Sub-Saharan Africa at a point where population growth and declining natural sources of fish require aquaculture to significantly contribute to fish supply. Uganda is not any different.

Aquaculture, accounts for nearly half of world's food fish production (45%) (Subasinghe et al. 2009) and is one of the fastest growing animal food sectors with its development, extension, and intensification in almost every possible region of the world. Global food fish aquaculture production has increased at an average rate of 6.2 % per year between 2000 and 2012, more than doubling from 32.4 million tonnes to 66.6 million tonnes.

Although sub-Saharan Africa has significant water and land resources, it has, to date, been only a minor player in aquaculture development for a variety of reasons (FAO 2006). Although some improvements have been noted, the situation in sub-Saharan Africa highlights economics, human demand and interest, institutional aspects, and a wide variety of other factors unrelated to the resource potential, are all contributing to this situation (Subasinghe et al. 2009). Moehl et al. (2006) relates this decline to weak management structures, low levels of investment in rural economies, and lack of economic growth.

Aquaculture in Uganda is not a new venture. Aquaculture was introduced to Uganda as a farm technology in the late 1950s (King 1993). The Uganda Game and Fisheries Department constructed Kajjansi Experimental Station, and Fisheries Extension Agents (formerly known as fish guards) were trained and posted to rural areas to educate and train farmers on pond establishment and management. The initial push for fish farming in Uganda was quite successful, with over 5,000 ponds established by smallholders throughout the country by 1959 (FAO 1984).

During the 1960s, fish farming gained popularity throughout the country, but was concentrated in only a few counties, peaking at approximately 11,000 ponds nationwide (MAAIF/DFID 1998). In addition to increased technology adoption by farmers during this period, government researchers at Kajjansi were experimenting with carp culture, tilapia hybridization, and predator control (Balarin 1985). Due to political instability, constraints on transportation for Fishery Extension Agents, and lack of access to inputs including fry, the mid-1960s would be the last period of fish culture activity in Uganda until the mid-1980s when Museveni's administration came to power (Kigeya 1995). During the 1970s and early 1980s most fishponds were abandoned. Renewed interest and investment in fish farming by the Ugandan government, donors and NGOs have led to a modest resurgence of smallholder fish farming.

Currently, fish farming in Uganda contributes up to 15,000 tonnes of fish per year (Mwanja 2005) from an estimated 20,000 ponds throughout the country with an average surface area of 500 m^2 per pond. Production is usually in the range of 5 kg to 10 kg/100 m^2 (Aganyira 2005; Mwanja 2005). Higher production is possible if proper siting, use of guidelines that take into considerations the ecological and environmental impacts, long-term availability of water supply, and, use of best aquaculture management practices are adapted.

Despite the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)'s 2010-2015 Development Strategy and Investment Plan to shift aquaculture from small-scale production for subsistence to commercial production, there are substantial constraints and

significant potentials with respect to existent ponds, climate, water quality and soil quality that are critical to the question of improvement of aquaculture.
Few studies have also been conducted on climate, water quality, and soil quality in Ugandan aquaculture. Earlier studies conducted in Uganda only took into account water temperature and soil properties that affect pond construction, e.g. Ssegane et al. (2012). The present study assessed the water quality, soil quality, and climate in Uganda and how they can be improved to increase fish production.

The main objective of the study was to determine the number and size of ponds in Uganda and determine suitability and potential role of climate, water quality of Ugandan water sources and pond soils for aquaculture. Specific objectives included:1) to determine the number, size, and distribution of ponds in Uganda, 2) to determine the climatic variations across the country and its potential influence on aquaculture production, 3) to determine water quality variations across the country and their potential influence on aquaculture production, 4) to determine soil quality in pond bottoms and their potential influence on pond aquaculture production.

The data provided a data base for the current fish ponds in the country and estimates of water budgets for rain-fed ponds and levee ponds. Hence, estimates of water inputs necessary for the farms, and recommendations on water quality, and pond bottom soil management in Ugandan aquaculture were drawn.

LITERATURE REVIEW

Pond number, size, and distribution in Uganda

The primary production unit used in fish farming in Uganda is the earthen pond (Isyagi et al. 2009). Ponds are built on land (soils). Land is a significant cost of fish farming especially when using earthen ponds. Jagger and Pender (2001) quote that the opportunity cost of land (i.e. the rental value of land in its most efficient alternative use) to likely be dependent upon three factors: how scarce land is, whether available land has high or low potential for other uses, and the extent of negative or positive environmental externalities associated with the land use.

Land scarcity is a serious factor in many areas of Uganda. Land fragmentation and decreasing farm size are common, with the average farm size being approximately 2 hectares (Jagger and Pender 2001). In addition, land will be a significant cost of fish farming if it has high potential for crop production or livestock grazing.

NEMA (1999) proposed the issue of aquaculture potential in land-constrained and/or high potential areas (where the opportunity cost of land is high) being partially addressed by establishing fishponds in wetland areas. Uganda has had a chronic problem of draining and filling wetlands for agriculture, industrial development or brick making, affecting wetland sustainability and biodiversity. The government has chosen to actively promote small-scale fish farming as a sustainable use of wetlands which have significant implications for the land poor and landless – most in need of food security and alternative income sources as a way of encouraging wetland preservation (NEMA 1999).

Studies have been carried out on the enumeration of small impoundments (ponds) including Boyd and Chaney (2012) showed the importance of ponds in improving quality of overland flow following rainfall events in Alabama. A study by Jescovitch, et al. (2016) mapped ponds on fish farms in different climate zones and continents to compare land to water surface ratios for sustainable land use in aquaculture. Structured interviews of farmers were used by Isyagi et al. (2009) to profile pond characteristics in Uganda.

Isyagi et al. (2009) noted ponds in Uganda tend to be shallow with an average water depth of less than 50 cm. Pond sizes vary from less than 100 m^2 to about 6,000 m^2 (Isyagi et al. 2009). As more farmers engage in fish farming for economic purposes, numbers and sizes of ponds being constructed per farmer has progressively increased. The national average pond area of 40 m^2 in the 1960s was about 300 m^2 in 2000 (NARO-MAAIF 2000). Government statistics however quote the average pond size in the country as being 500 m^2 (FAO 2005) but there are no available national figures for 2008/9.

Climate variation in Uganda

The world Meteorological Organization (WMO 2017) defines climate as the measurement of the mean and variability of relevant quantities of certain variables (such as temperature, precipitation, or wind) over a period of 30 years. Uganda has a tropical climate and the most important climate element is rainfall (Okoola 1998). It is a major determinant of the economy in the country.

Rainfall over Uganda exhibits large spatial and temporal variability. The spatial variation has been attributed to the existence of large-scale and local weather systems and the influence of large inland water bodies such as; Lake Victoria, Lake Kyoga, among others and the complex topography. The two main rainfall regimes experienced in Uganda are bimodal in most part of the country and unimodal in the northern region.

The bimodal regime is observed towards/near the equator with the first peak in April, for March-May (MAM) season, locally referred to as ‘long rains’ in East Africa. The second peak occurs in October, for September-November (SON) season. These seasons; MAM and SON seasons (wet seasons) coincide with the passage of the Inter Tropical Convergence Zone (ITCZ) that lags behind the overhead sun by about a month while the wet seasons are separated by two dry spells from June to August and December to February (Mutemi 2003; Okoola 1996).

Fish are poikilothermic and climate controls the suitability of an area for aquaculture at the macro-scale (extensive) level as it dictates water temperature and water quantity (Coche 1994; Kapetsky 1994; Kapetsky et al. 1997). Studies have been conducted on climate and food production in Uganda have been mainly on livestock and crop production.

Mwaura & Okoboi (2014) used ARCH model estimates to show that a variation in rainfall and temperature from the long-term mean has significant effects on crop output, while an exponential increase in rainfall has detrimental effects on crop output. Analysis of the incidence of rainfall and temperature variation from the long-term average were insignificant.

A few studies like (Aguilar-Manjarrez and Nath 1998; C. Boyd and Pine 2010; Kapetsky et al. 1997) have focused on the role of climate in aquaculture. Aguilar-Manjarrez and Nath (1998) used the rainfall and temperature data of Uganda and he reported 90% and 98% of the surface area of Uganda to be very suitable while 8% and 2% suitable for small-scale subsistence and commercial fish farming, respectively. Ssegane et al. (2012) compared the crispy and fuzzy approach using GIS where climate data was used and both approaches conferred that over 98% of the land in Uganda was classified as moderately suitable or suitable for fish farming.

Water quality in Aquaculture

Boyd (2015) defines water quality as the suitability of water for survival and growth of fish. Any physical, chemical, or biological property that influences the use of water is a water quality variable. There are literally hundreds of water quality variables, but only a few variables are of interest in aquaculture. These include: dissolved oxygen, pH, toxic metabolites like ammonia and nitrite, total alkalinity, turbidity, total hardness, and organic matter (Boyd and Tucker 1992) .

Dissolved oxygen is the most important gas in water quality because it is essential in aerobic respiration and it regulates the oxidation-reduction potential in water and sediment. The dissolved oxygen concentration is affected by salinity and temperature as it decreases with increase in salinity and temperature (Boyd 2015). The biological processes that also influence dissolved oxygen concentrations are photosynthesis by green plants and respiration by aquatic organisms.

When dissolved oxygen concentrations are low or dissolved oxygen is absent, decomposition of organic matter by anaerobic microorganisms releases many reduced substances, e.g., ammonia, nitrite, ferrous iron, hydrogen sulfide, and dissolved organic compounds, into the water. In the absence of adequate dissolved oxygen, aerobic microorganisms do not function efficiently in oxidizing these reduced substances. The combination of low dissolved oxygen concentration and high concentrations of certain reduced, toxic metabolites cause drastic, negative impacts on the structure and function of aquatic ecosystems. Boyd and Tucker (2014) state that if dissolved oxygen is kept satisfactory in aquaculture systems, other water quality problems are less likely to develop.

The pH of water is very important because hydrogen ion concentration is an important variable in nearly all the reactions related to water quality (Boyd 2015). The pH of water also is important in aquatic ecosystems, because it affects aquatic life. Gill tissue is the primary target organ of acid stress in fish (Boyd 2015).

When fish are exposed to low pH, the amount of mucus on gill surfaces increases. Excess mucus interferes with the exchange of respiratory gases and ions across the gill. Therefore, failure in blood acid-base balance resulting in respiratory stress and decreasing blood concentrations of sodium chloride. The consequential osmotic disturbance is the dominant physiologic symptoms of acid stress. Although direct pH toxicity is rare in aquaculture systems that are well sited in terms of their water supplies (Boyd and Tucker 2014), there are several conditions that can lead to fluctuation of pH outside the optimum range for fish culture in aquaculture systems that can lead to injury or death of fish. The indirect effects of pH on aqueous equilibrium of certain gases and metals are more important in aquaculture (Boyd and Tucker 2014).

Total alkalinity is an important variable for productivity. Waters with total alkalinity values of 0 to 50 mg/L usually are less productive than those with total alkalinity concentrations of 50 to 200 mg/L (Egna and Boyd 1997). Productivity tends to decrease at higher alkalinities.

Total hardness is an index of the total concentration of divalent cations in water. Although total hardness is of much less importance than total alkalinity from a biological perspective, productivity depends upon the availability of many nutrients and other favorable environmental factors (Boyd and Tucker 2014). However, calcium and magnesium, the primary hardness cations, contribute to productivity.

Specific conductance is used as an inference for total dissolved solids and salinity in aquaculture. Its major influence is mainly on the osmotic balance of the fish (Boyd 2015). When specific conductivity is above its optimum range, fish exert more energy to maintain their normal osmotic pressure hence diverted energy that would otherwise be used for growth.

Uganda is blessed with many fresh water resources that cover 18% of the country (Isyagi 2001) with the most significant hydrological feature being Lake Victoria, the second largest inland fresh water lake in the world. The quality of surface water in Uganda has been deteriorating over time during the last decades. Increasing urbanization, population growth and anthropogenic activities have resulted in significant deterioration in the quality of both surface and groundwater in many parts of the country. There are increasing incidences of surface water pollution from both domestic and industrial waste discharges, and run-off from agricultural fields.

Studies carried out in Uganda on water quality have mainly focused for drinking water. Howard et al. (2003) determined that rainfall runoff and poor sanitation contributed to microbiological contamination of shallow ground waters in Uganda. Ngabirano et al. (2017) reported temperature, pH, total dissolved solids, dissolved oxygen, salmonella, and fecal coliforms as the major contributing parameters to variations in quality of gravity flow water. Studies that focused on water quality variables and their influence in aquaculture like Ssegane et al. (2012) focused on water temperature where the majority of Uganda (61.7%) is suitable for fish growth, with isolated areas of high suitability in the Adjumani district (Northern Uganda) and suitable sites at Butiaba and Buseruka in Hoima district. The unsuitable areas for tilapia and clarias growth were in Kabale and Kisoro districts (Southwestern Uganda), where altitudes range from 1,219 m to 2,347 m and air temperatures range from 10 ˚C to 18 ˚C.

Pond bottom soil in Aquaculture

Pond bottom soils are a storehouse for many substances in pond ecosystems. Chemical and biological processes occurring in surface pond soils influence pond water quality and aquaculture (Boyd 1995). There are many soil properties, however a few have been known to play a role in aquaculture. These include; soil texture, organic matter, soil pH, soil nutrients and soil trace metals.

Soil texture is important in aquaculture especially regarding construction and hydrology. Clayey-loam soils have been preferred for fish production products rather than the heavy clay (Boyd and Tucker 2014). A 15-20% clay soil has been the recommended percentage in aquaculture. The soil pH determines the nutrient availability, microbial activity, and benthic productivity (Boyd 1995). Organic matter concentration influences the embarkment stability (high organic matter content is a negative factor), nutrient supply, and oxygen demand. Soils with organic matter more than 18% are not ideal for fish production as they tend to be poorly drained, have low pH, and low nitrogen (Egna and Boyd 1997).

Different studies have been carried out on the influence of pond bottom soil on aquaculture. and among which include; Sonnenholzner and Boyd (2000), Boyd et al. (1994), Hajek and Boyd (1994) and Banerjea (1967) which were out of Uganda and more on shrimp production.

Sonnenholzner and Boyd (2000) determined physical and chemical properties of shrimp pond soils in Ecuador. They concluded that proper use of soil and water testing could greatly improve the efficiency of liming and other soil management practices. Boyd et al. (1994)

compared chemical characteristics of bottom soils of freshwater and brackish water aquaculture ponds. They reported most pond soil chemical properties was like those of terrestrial soils, with freshwater pond soils resembling terrestrial soils from humid areas and brackish water soils being similar in many respects to soils of arid regions.

The few studies carried out in Uganda regarding pond bottom influence on aquaculture focused mainly on physical properties. Ssegane et al. (2012) showed that the majority of Uganda (49.5%) is under very suitable soil conditions (15%–30% clay) for pond sealing. Rücker (2005), also classified the average soil texture of Uganda as sandy clay loam (about 27% clay). Lower clay content (5.9%–17.4%) is in the central region and in the west, while the highest clay (52%–57.7%) content can be found in the highlands.

REFERENCES

Aganyira, K. 2005. Aquaculture: A tool for sustainable development in Uganda.: A case study of Kigoowa Catholic Women's Association in Kampala District. Master's thesis, Norwegian University of Science and Technology, Trondheim, Norway.

Aguilar-Manjarrez, J. and S. S. Nath. 1998. A strategic reassessment of fish farming potential in Africa. CIFA Technical paper 32. FAO, Rome, Italy.

Balarin, J. D. 1985. National review for aquaculture development in Africa. FAO Fish. Circ 770:18-121.

Banerjea, S. M. 1967. Water quality and soil condition of fish ponds in some states of India in relation to fish production. Indian Journal of Fisheries 14:115–144.

Boyd, C. E. 1995. Bottom Soils, Sediment, and Pond Aquaculture. Chapman and Hall, New York, USA

Boyd, C. E. (2015). Water Quality: An Introduction. Springer, New York, USA.

Boyd, C. E. and C. S.Tucker. 1992. Water Quality and Pond Soil Analyses for Aquaculture. Alabama Agricultural Experiment Station, Auburn University, USA.

Boyd, C., & Pine, H. (2010). WMO/CAgM Guide to Agricultural Meteorological Practices (GAMP) WMO n° 134.

Boyd, C. E., E. T. Margaret, M. Mahmoud and M. Kiyoshi. 1994. Chemical characteristics of bottom soils from freshwater and brackish water aquaculture ponds. Journal of the World Aquaculture Society 25:517–534.

Coche, A. G. 1994. Aquaculture development and research in sub-Saharan Africa: National Reviews. FAO, Rome, Italy.

Egna, H. S., and C. E. Boyd. 1997. Dynamics of Pond Aquaculture. CRC Press, Florida, USA.

FAO (Food and Agriculture Organization of the United Nations). 1984. Agricultural Reconstruction Project, Preparation Mission. FAO/ African Development Bank Report, 65/ 84 Af-UGA 6.

Hajek, B. F. and C. E. Boyd. 1994. Rating soil and water information for aquaculture. Aquacultural Engineering, 13:115–128.

Isyagi, A. N. (2001). Aquaculture in Uganda. *Agriculture in Uganda*, 4, 341–363.

Isyagi, N., G. Atukunda, L. Aliguma, M. Ssebisubi, J. Walakira, G. Kubiriza and E. Mbulameri. 2009. Assessment of national aquaculture policies and programmes in Uganda. Retrieved from https://www.cabdirect.org/cabdirect/abstract/20006802063.

Jagger, P. and J. Pender. 2001. Markets, marketing, and production issues for aquaculture in East Africa: the case of Uganda. Naga, the ICLARM Quarterly 24:42–51.

Jescovitch, L. N., Chaney, P. L., & Boyd, C. E. (2016). A Preliminary assessment of land-to-water surface area ratios (LWR) for sustainable land use in aquaculture. Papers in Applied Geography, 2:178–188.

Kapetsky, J. M. (1994). A strategic assessment of warm-water fish farming potential in Africa. Rome: FAO.

Kapetsky, J. M. and S. S. Nath. 1997. A strategic assessment of the potential for freshwater fish farming in Latin America. FAO, Rome, Italy.

Kigeya, J. K. 1995. Problems and prospects of fish culture among small scale farmers in Uganda: An analysis of technical, social and educational dimensions. University Microfilms International, Michigan, USA.

King, H. R. (1993). Aquaculture development and environmental issues in Africa. In Environment and Aquaculture in Developing Countries, eds. R.S.V. Pullin, H. Rosenthal and J.L. Maclean 116-124, ICLARM Conference Proceedings 31. World Fish Center, Penang, Malaysia.

MAAIF. 2012. Operationalization of the non-ATAAS component of the development strategy and investment plan (DSIP). Situation analysis report, fish production, Entebbe, Uganda.

Ministry of Finance, Planning and Economic Development MFPED. 2015. Annual budget performance report Fy 2014/15. Kampala, Uganda. Retrieved fromwww.finance.go.ug.

Moehl, J., M. Halwart and R. Brummett. 2006. Report of the FAO-WorldFish Center workshop on small-scale aquaculture in Sub-Saharan Africa: revisiting the aquaculture target group paradigm. CIFA Occasional Paper 25: I.

Mutemi, J. N. 2003. Climate anomalies over eastern Africa associated with various ENSO evolution phases. PhD thesis, University of Nairobi, Kenya.

Mwanja, W. W. 2005. National Aquaculture Sector Overview-Uganda. National Aquaculture Sector Overview Fact Sheets, 22.

Mwaura, F. M. and G. Okoboi. 2014. Climate variability and crop production in Uganda. Journal of Sustainable Development, 7: 159.

NARO/FRI (National Agriculture Research Organization/Fisheries Research Institute). 2000. Pond distribution and fry requirement statistics by region. Kajjansi, Uganda.

NEMA (National Environmental Management Authority). 1999. State of the environment report for Uganda 1998. Kampala, Uganda.

Ngabirano, H., D. Byamugisha and E. Ntambi. 2017. Temporal and spatial seasonal variations in quality of gravity flow water in Kyanamira Sub-County, Kabale District, Uganda. Journal of Water Resource and Protection 9:455-469.

Okoola, R. E. 1998. Characteristics of the ITCZ over equatorial Eastern Africa based on station rainfall records. Journal of African Meteorology Society 3:61–101.

Okoola, R. E. A. 1996. Space-time characteristics of the ITCZ over equatorial Eastern Africa during anomalous rainfall years. M.S. thesis, University of Nairobi, Kenya.

Sonnenholzner, S. and C. E. Boyd. 2000. Chemical and physical properties of shrimp pond bottom soils in Ecuador. Journal of the World Aquaculture Society 31:358–375.

Ssegane, H., E. W. Tollner, and K. Veverica. 2012. Geospatial Modeling of Site Suitability for Pond-Based Tilapia and Clarias Farming in Uganda. Journal of Applied Aquaculture 24:147–169

Subasinghe, R., D. Soto, and J. Jia. 2009. Global aquaculture and its role in sustainable development. Reviews in Aquaculture 1:2–9.

Uganda Bureau of Statistics UBOS. 2017. Report on the fisheries production. Kampala, Uganda.

WMO (World Meteorological Organization). 2017. CCl FAQs. | Retrieved December 6, 2017, from http://www.wmo.int/pages/prog/wcp/ccl/faqs.php

NUMBER, SIZE, AND DISTRIBUTION OF FISH PONDS IN UGANDA

ABSTRACT

Pond fish production is the main type of aquaculture practiced in Uganda. Increased pressures on capture fisheries in Uganda is leading to a decline in this resource, and pond aquaculture has become an alternative livelihood and source of fish supply. Little is known about the number, sizes, and distribution of ponds in the country.

The main objective of the study was to map and profile the ponds in the different regions of Uganda. This was done by dividing the country in four regions; Central, Eastern, Northern and Western. From each region, five districts were selected making a total of 20 districts which were mapped using Google Earth Pro and ArcMap.

The total number of ponds determined by satellite imagery estimated from the available resources were less than the ones cited in literature. Of all the regions, the Central had the most ponds, followed by the Eastern then Western and least Northern. The ponds were mainly distributed around the water bodies (Victoria basin) and near the borders of the districts for market strategy. However, a full mapping of the whole country is necessary to have an accurate data base of ponds.

INTRODUCTION

Uganda is Africa’s fifth largest fishing nation (Hempel 2010). The fisheries subsector in Uganda is the second largest foreign exchange earner after coffee in the country contributing USD 135 million in exports (MFPED 2015). Approximately 3% of the Gross Domestic Product (UBOS 2014) comes from the fisheries sector, and it employs about 1.2 million people (MAAIF 2012).

Although the fisheries subsector has a significant economy, declining fish stock has affected its performance due to overfishing, use of wrong fishing gear and habitat degradation (Njiru et al. 2007). Therefore, aquaculture is a promising commercial venture with ‘untapped potential’ for providing fish necessary to meet the demand, while also providing community livelihood options (Jagger and Pender 2001) given the high human population of 50-54 million by 2025 (UNDESA 2010).

Currently, fish farming in Uganda contributes up to 98,063 tonnes of fish per year and provides a livelihood to 53,000 people (FAO 2014). According to MAAIF (2012), there is an existing fish supply deficit of 180,000 tonnes, but FAO puts the deficit at 300,000 tonnes annually. This implies that there is need for production of between 400 and 600 million fingerlings annually if aquaculture is going to address the existing gap in fish supply.

The MAAIF's 2010-2017 Development Strategy and Investment Plan is to shift aquaculture from small-scale production for subsistence to commercial production (Timmers 2012). There are several programs that have been developed in the country to ensure aquaculture development among which includes National Agricultural Advisory Services (NAADS), Youth Livelihood Program (YLP) and Operation Wealth Creation (OCW) (Tapscott 2016). There are no proposed resources available to support this (Timmers 2012). Thus, a data base of the number, sizes, and distribution of ponds in the country would be useful.

Past studies showed that over 5,000 ponds were established by smallholders throughout the country by 1959 (FAO 1984), peaking at approximately 11,000 ponds nationwide (MAAIF/DFID 1998). However, during the 1970s and early 1980s most fish ponds were abandoned due to political instability. Currently there are controversies concerning the pond number, pond size and fish production. NARO/FRI (2000) estimated 7,780 fish ponds with an average surface area of 200 m^2 per pond, UBOS (2004) estimated 30,000 ponds while Mwanja (2005) estimated 20,000 ponds with an average surface area of 500 m^2 per pond. Pond sizes have been noted to vary from less than 100 m^2 to about 6,000 m^2 (Isyagi et al. 2009).

The objective of the study was to address the controversy by quantifying the number and size of ponds and show their distribution as well in the different representative districts from which the total ponds number of ponds were projected.

METHODS

The country was divided into four regions according to the administrative map (Fig. 1): Central, Eastern, Northern and Western regions. In each region, five districts were selected for pond mapping (Table 1). The selection procedure was dependent on climatic zones, known aquaculture practices and soil properties. In total, 20 districts were mapped using Google Earth Pro.

Google Earth Pro has an average resolution of 15 m x 15 m and uses Landsat imagery with a resolution of 30 m, and pan sharpens to higher resolution of 15 m. The polygon tool in Google Earth Pro was used to map ponds and obtain their pond areas and numbers as illustrated in Jescovitch et al. (2016).

Problems of cloud cover, high sun light reflection, blurred images and difficulty in accurately delineating pond images such as noted by Jescovitch et al. (2016) also were encountered in this study. Identification of ponds was hard in mountainous areas. All the imagery used to map the ponds in Google Earth was in the year of 2017.

Accuracy of pond mapping was done according to procedures outlined in (Chaney et al. 2012; Jescovitch et al. 2016). The files were then saved as KML files which were then imported into ArcMap to draw the map that showed the distribution of ponds in the different areas.

Furthermore, pond mean areas, maximum and minimum areas and pond densities of the different regions were computed.

Pond characteristics were compared using one-way ANOVA in conjunction with Tukey’s Studentized Test (HSD) to examine the differences between the regions. Pond areas (m^2) were further categorized in different size distribution (< 50, 50-700,700-1000,1000-5000, 5000-10,000 and > 10,000) to show their frequencies in the different regions (Fig 2).

The total number of ponds in the country were projected by region using each region’s pond density and by average pond density in the four regions. An assumption that mean pond density will be the same as the whole area on which calculation was made. Aguilar-Manjarrez and Nath (1998) and Ssegane et al. (2012) considered 98% of the country suitable for commercial aquaculture, this percentage was used to calculate the total pond numbers in the whole country when using the average pond density method.

RESULTS AND DISCUSSION

A total of 1,885 ponds were mapped. Central region had the highest number (676) of ponds (Table 2). The Central region was followed in order by the Western, Eastern, and Northern regions with respect to pond numbers.

Average pond area for the four regions ranged from 519 m^2 to 685 m^2 with the average pond area in the country 623 m^2. There were no significant differences in the pond areas among the different regions ($F = 1.29$, $df = 3$, $p = 0.2746$ at $\alpha = 0.005$) (Table 1). Pond areas ranged from 4.6 m^2 to 30,993 m^2 in the whole country which was higher than the upper bound (6,000 m^2) cited in the literature by NARO/FRI (2000) and Mwanja (2005). Most of the ponds were in 50-700 m^2 range in all regions with the least number of ponds in > 10,000 m^2 pond range (Fig. 2).

Pond distribution in the Central region was concentrated mainly in its northern part with much fewer ponds in the western part (Fig. 3). This could be because the western part of the Central region is hilly and pond construction would be expensive (Yoo and Boyd 1994). The Eastern region had most of its ponds near the waterbodies (L. Victoria and L. Kyoga) and near its boundaries. There were comparatively fewer ponds in its central part (Fig. 3). This could be because border areas provide access to external markets and because greater precipitation occurs near the lakes (Kizza et al. 2009). Ponds are more feasible to operate when there is dependable rainfall.

Ponds in the Northern region were distributed in the whole region apart from the northeastern corner (Fig. 3). The northeastern corner of the northern region is the Karamoja region where fish consumption is low and cattle husbandry is the main livelihood (Barber 1962). Pond distribution in the Western region was spread all over the region (Fig. 3) despite its poor topography.

Pond density results in Table 2 revealed that the Eastern region had more ponds per area followed by the Central region then Western and least was in the northern region. This could be because of high fish demand, proximity to the market, ease access to extension services, fingerlings, and fish feeds. Land fragmentation in the Central and Eastern region may have led to a greater number of ponds (Mwanja 2015).

On projection calculation of pond numbers in the whole country by region basis, a total of 13,946 ponds were estimated with the highest number in the Central region followed by the Western region then the Eastern region and last Northern region. This total was less than the number of ponds calculated by average pond density and of 98% of the country being suitable for aquaculture that is 16,570 ponds. These pond numbers were all less than the number of ponds cited in the literature by Mwanja (2005) and UBOS (2004) but was more than number of ponds cited by NARO/FRI (2000).

CONCLUSION

A total of 1,885 ponds were identified in the sampled area that is 15% in Uganda. Extrapolation of these data suggest that there were 13,946 ponds by region calculation and 16,570 ponds by average density calculation in the country, less than the numbers cited in the literature. This also is less than earlier estimates. The Central region had the highest number of ponds. This was probably because of greater market demand, ease access to fingerlings, fish feeds, extension services and funding (capital investment) in this region than in others. The average size of pond was about 623 m^2 and most ponds fell in the 50-700 m^2 size range.

Mapping of other areas should be done to obtain a complete data base of all ponds in the country. This may give the scope of pond aquaculture, help in taxation, as well show areas of improvement in terms of extension services.

REFERENCES

Aguilar-Manjarrez, J. and S. S. Nath. 1998. A strategic reassessment of fish farming potential in Africa. CIFA Technical paper 32. FAO, Rome, Italy.

Barber, J. P. 1962. The Karamoja District of Uganda: A pastoral people under Colonial rule. The Journal of African History 3:111–124.

Chaney, P. L., C. E. Boyd and E. Polioudakis. 2012. Number, size, distribution, and hydrologic role of small impoundments in Alabama. Journal of Soil and Water Conservation 67:111–121.

FAO (Food and Agriculture Organization).1984. Agricultural Reconstruction Project, Preparation Mission. FAO/ African Development Bank Report, 65/ 84 Af-UGA 6.

Jagger, P. and J. Pender. 2001. Markets, marketing, and production issues for aquaculture in East Africa: the case of Uganda. Naga, the ICLARM Quarterly 24:42–51.

Hempel, E. 2010. Value Chain Analysis in the Fisheries Sector in Africa. INFOSA and NEPAD working group.

Isyagi, N., G. Atukunda, L. Aliguma, M. Ssebisubi, J. Walakira, G. Kubiriza and E. Mbulameri. 2009. Assessment of national aquaculture policies and programmes in Uganda. Retrieved from https://www.cabdirect.org/cabdirect/abstract/20006802063.

Jescovitch, L. N., P. L. Chaney and C. E. Boyd. 2016. A preliminary assessment of land-to-water surface area ratios (LWR) for sustainable land use in aquaculture. Papers in Applied Geography 2:178–188.

Kizza, M., A. Rodhe, C.-Y. Xu, H. K. Ntale and S. Halldin. 2009. Temporal rainfall variability in the Lake Victoria Basin in East Africa during the twentieth century. Theoretical and Applied Climatology 98:119–135.

MAAIF (Ministry of Agriculture, Animal Industries, and Fisheries) and DFID (Department for International Development).1998. Small-scale fish farming for food security and income generation – Project Memorandum, Kampala, Uganda.

MAAIF. 2012. Operationalization of the non-ATAAS component of the development strategy and investment plan (DSIP), situation analysis report, fish production. Entebbe, Uganda.

Ministry of Finance, Planning and Economic Development MFPED. 2015. Annual budget performance report Fy 2014/15. Kampala, Uganda. Retrieved fromwww.finance.go.ug.

Mwanja, M., J. Rutaisire, C. Ondhoro, R. Ddungu, and C. Aruho. 2015. Current fish hatchery practises in Uganda: The potential for future investment. International Journal of Fisheries Aquatic Studies 2:224-232.

Mwanja, W. W. 2005. National Aquaculture Sector Overview-Uganda. National Aquaculture Sector Overview Fact Sheets, 22.

NARO/FRI (National Agriculture Research Organization/Fisheries Research Institute). 2000. Pond distribution and fry requirement statistics by region. Kajjansi, Uganda.

NARO/Ministry of Agriculture Animal Industry and Fisheries Fish Farming Project. 2002. Baseline survey, regional data tables. Uganda: National Agricultural Research Organization (NARO) and Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF), Uganda.

Njiru, M., P. Nzungi, A. Getabu, E. Wakwabi, A. Othina, T. Jembe and S. Wekesa. 2007. Are fisheries management, measures in Lake Victoria successful? The case of Nile perch and Nile tilapia fishery. African Journal of Ecology 45:315–323.

Ssegane, H., E. W. Tollner, and K. Veverica. 2012. Geospatial Modeling of Site Suitability for Pond-Based Tilapia and Clarias Farming in Uganda. Journal of Applied Aquaculture 24:147–169.

Tapscott, R. 2016. Where the wild things are not: crime preventers and the 2016 Ugandan elections. Journal of Eastern African Studies 10:693–712.

Timmers, B. 2012. Impacts of climate change and variability on fish value chains in Uganda. Retrieved on September 28, 2017, from http://www.worldfishcenter.org/resource_centre/WF_3139.pdf

UBOS. 2004. Report on the agricultural module, piggy-backed onto the population and housing census (PHC), 2002: household based agricultural activities crop, livestock, and poultry characteristics. Kampala, Uganda.

United Nations Secretariat (UNDESA). 2010. Population Division of the Department of Economic and Social Affairs. World Population Prospects: The 2010 Revision, http://esa.un.org/unpd/wpp/index.htm Accessed on January 14, 2017.

Yoo, K. H. and C. E. Boyd. 1994. Hydrology and Water Supply for Pond Aquaculture. Chapman and Hall, New York, USA.

Table 1: Districts in the different regions of Uganda that were mapped and their soil properties

Region	District	FAO Soil classification
Central	Mukono	Acric ferralsols
	Mpigi	Luxic ferralsols
	Masaka	Luxic ferralsols
	Luwero	Acric ferralsols/ Petric plinthosols
	Kiboga	Acric ferralsols/ Petric plinthosols
Eastern	Jinja	Nitosols
	Tororo	Petric plinthosols
	Soroti	Petric plinthosols
	Katakwi	Arenosols
	Kapchorwa	Nitosols
Northern	Lira	Petric plinthosols
	Gulu	Acric ferralsols
	Adjumani	Leptsols/vertisols
	Kitgum	Eutric legosols / vertisols/ leptsols/lixic ferralsol
	Kotido	Gleysols/ Eutric legosols / vertisols/ leptsols/lixic ferralsol
Western	Masindi	Acric ferralsols/ Petric plinthosols
	Hoima	Vertisols
	Kabarole	Leptic/skeletic andosols
	Bushenyi	Acric ferralsols
	Kabale	Luvisols/ Acric ferralsols

Table 2: Number, mean pond area size and pond density of the different regions

Region	Area (km^2)	No. of ponds	Mean Pond Area (m^2)	Density (no. of ponds / km^2)	Estimates of no. of ponds on Extrapolation
Central	61,403.2	676	641.0 ± 57.66^a (4.6 – 30993.0)	0.09	5,526
Eastern	39,478.8	384	519.3 ± 30.09^a (43.8 – 3943.0)	0.10	3,948
Northern	85,391.7	340	685.9 ± 82.45^a (26.0 – 18240.0)	0.02	1,708
Western	55,276.6	485	647.4 ± 43.99^a (20.0 – 9820.0)	0.05	2,764
Average			623	0.07	
Total by region	241,550.3	1,885			13,946
Total by average density					16,570

*similar letter 'a' means no significant difference at α =0.05

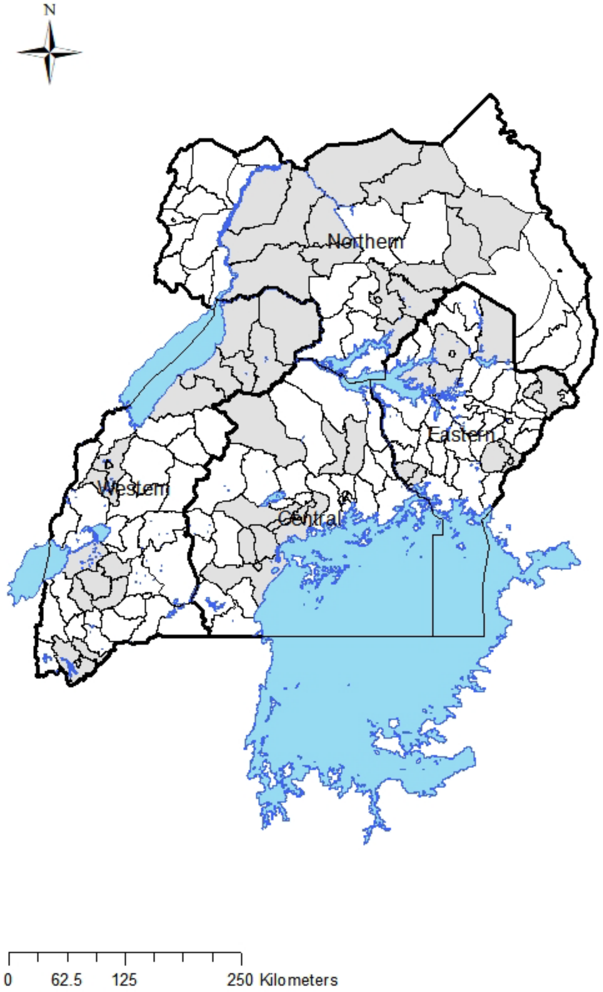


Figure 1: Mapped districts (in gray) in the different regions in Uganda

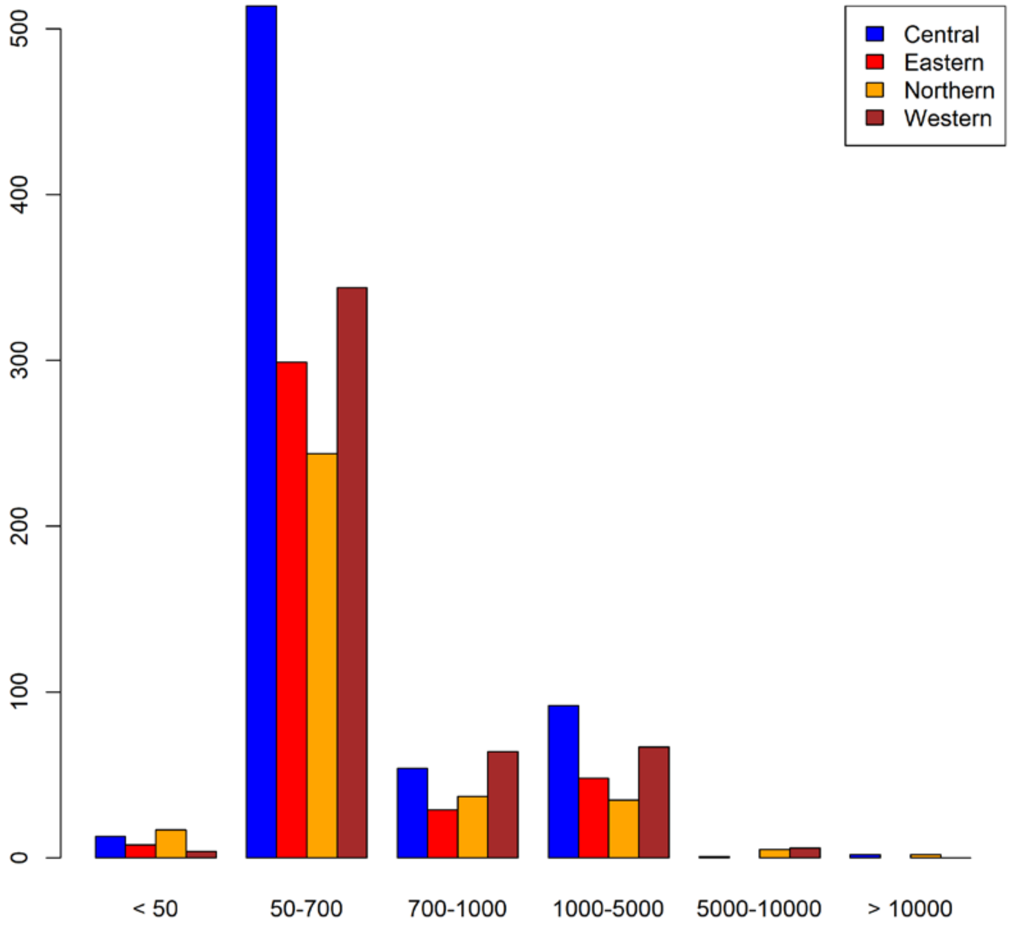


Figure 2: Frequency of ponds in the different area size (m^2) in the different regions

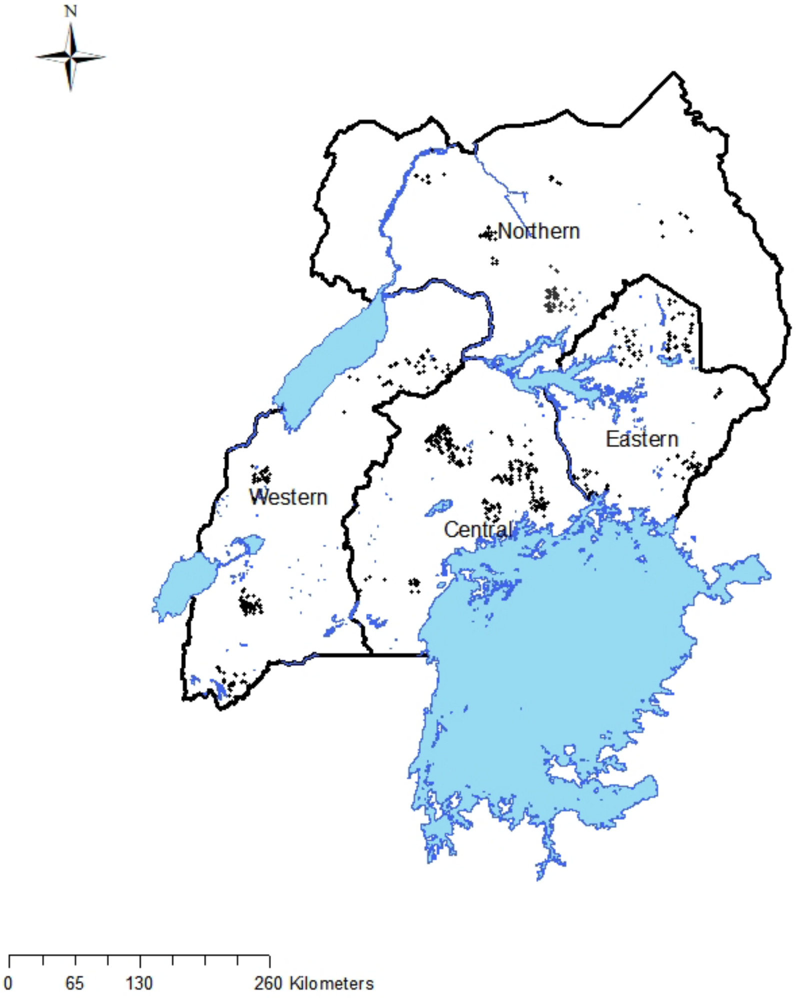


Figure 3: Ponds mapped in the different districts in Uganda

POTENTIAL INFLUENCE OF CLIMATE ON UGANDAN AQUACULTURE

ABSTRACT

Climate defines the viability of an area for aquaculture at the macro-scale (extensive) level as it dictates water temperature and water quantity in a location that in turn affects fish productivity. Temperature and rainfall data from 1980 to 2016 were analyzed and compared among the different regions of Uganda (Central, Eastern, Northern, and Western) using the Seasonal Mann Kendall Times Series and the 12-month Standard Precipitation Index (SPI). These data were used in the computation of monthly water requirements of the different regions.

A positive upward trend showed increased aquaculture production was observed for all regions except the Eastern region (p = 0.4222, tau b = 0.027). The 12-month SPI showed all regions having near normal SPI (-0.99 to 0.99) but with the Central region having highest SPI and the western region with the lowest SPI. The Central region had the lowest monthly water requirement compared to other regions which was attributed to lower temperatures and low evaporation rates in the region compared to others.

Overall, potential climate effects on aquaculture are not a major issue in the country if climate smart strategies are adopted. That is; water harvesting during the rainy seasons for use in drier periods and planning of the fish production cycle so that the period of water deficit coincides with fish harvest or pond preparation.

INTRODUCTION

The World Meteorological Organization (WMO 2017) defines climate as the measurement of the mean and variability of relevant quantities of certain variables (such as temperature, precipitation, or wind) over a period of 30 years or more. Climate defines the viability of an area for aquaculture at the macro-scale (extensive) level as it dictates water temperature and water quantity in a location (Coche 1994; Kapetsky et al. 1997) which in turn affects fish productivity (Kapetsky 2000).

Fish are poikilothermic with each species having a specific temperature range, outside the temperature range or near temperature limits causes poor growth, reproduction complications and increases sensitivity to parasite and disease infestation (Boyd and Pine 2010). However, extended periods with the temperatures outside the optimal range for a species will result in this species being suitable for aquaculture at a location.

Boyd (2005) states that aquaculture depends on a constant supply of water with the total volume of water used for aquaculture per unit production greater than for agricultural crops. All fresh water sources have been noted to depend on precipitation (Kapetsky 2000). Yoo and Boyd (1994) expressed the importance of precipitation excess and deficit in fisheries and aquaculture. Nicholson (2014) puts Uganda among the countries with frequent occurrence of drought and plagued with floods which have devasting effects on livelihoods especially if they occur in the same year (Nicholson 2015).

Droughts, floods, landslides, windstorms, and hailstorms also have been reported to contribute well over 70% of the natural disasters, destroying annually an average of 800,000 hectares of crops, and making economic losses in excess of $ 33 million (UNESCO 2006). Such events could also have negative impacts on pond fish culture as well.

Unusual precipitation excess can lead to high runoff that increases pond turbidity which in turn lowers primary production, smothers benthic organisms and fish eggs, and lowers salinity which can be detrimental for shrimp culture (Boyd and Pine 2010). Precipitation deficit leads to excessive decrease in pond water levels that causes crowding, destructs spawning areas and benthic food availability, favors growth of pond weeds, and increases concentration of dissolved substances (Yoo and Boyd 1994).

Even though Uganda has a tropical climate, fluctuations in the minimum, maximum temperatures and rainfall patterns can affect fish production. The way climate fluctuates yearly above or below a long-term average value is called climate variability (WMO 2017). For the case of Uganda, climate variability is mainly the result of remote forcing by El Niño Southern Oscillation (ENSO) near the equatorial Pacific Ocean where fluctuations of sea surface typically causing temperatures to alternate every few years between a warming phase (El Niño) and cooling periods (La Niña), with a neutral phase in between (Phillips and McIntyre 2000).

Local geographical factors like Lake Victoria and mountains ranges in Uganda also affect climate. The country's orientation, intensity of the Inter Tropical Convergence Zone (ITCZ), sub-tropical anticyclones, Indian ocean cyclones, monsoonal winds, sea-surface temperatures and jet streams all shape Uganda's climate (Nicholson 2017; Ogallo 1989).

Aquaculture in Uganda depends on rainfall, streams, and wells for water during production in outdoor ponds (Isyagi et al. 2009; Boyd and Pine 2010). These water sources are all climate vulnerable. The vulnerability of these water resources is aggravated with increased population growth and fragmented land use in the country.

Many studies have been carried out on climate variability on agriculture. Phillips and McIntyre (2000) and Timmers (2012) focused on livestock and crops and less work was on aquaculture. Vianny et al. (2015) and Musinguzi et al. (2016) discussed climate variability effects on the fisheries sector but focused mainly on capture fisheries. Those that focused on aquaculture, like Szumiec (1983), and Kapetsky (2000), did not address the practical use of climate variability in aquaculture. The review by Boyd and Pine (2010) focused on the practical use of climate information in aquaculture, but it was generalized. It did not focus on a specific area, but rather provided a general assessment of climate and aquaculture production. Therefore, the present study focused on the practical use of climate variability information in the planning of aquaculture production cycles in Uganda, which could be adopted in other nearby developing tropical nations

The objectives of this study were to 1) compare temperature regimes and rainfall patterns among different regions of Uganda, 2) determine temperature variations from long term mean, 3) compute precipitation deficits and surplus and 4) draw monthly aquaculture water requirement and required pond inflows for the different regions of Uganda.

This was achieved by analyzing temperature data (minimum and maximum) from 1980 to 2016 for descriptive statistics as well as using seasonal Mann Kendall and Sen’s slope, and computed mean potential evapotranspiration data for the different regions. The rainfall data of 1980 to 2016 was analyzed using 12-month standard precipitation index and the seepage rate was obtained from 3 ponds in the different regions over a 3-day period without rain. The results provided information necessary to calculate farm water requirements as fish farming is a water-intensive endeavor (Yoo and Boyd 1994) and can advance with proper timing of production cycle.

METHODS

The study was carried out in Uganda which is centered at 1.3733° N, 32.2903° E in East Africa. The country has a tropical climate, with air temperature ranging from 16 ^{o} C to 30 ^{o} C. The average altitude of the country is 1,100 m above sea level excluding the mountain ranges. The national average precipitation is 1,000 mm rainfall per annum. The wetter places of the country along the equator have a soil water surplus year-round. The two main rainfall regimes experienced in Uganda are bimodal in most part of the country and unimodal in the northern region. The bimodal regime is observed towards/near the equator with the first peak in April, for March-May (MAM) season, locally referred to as ‘long rains’ in East Africa. The second peak occurs in October, for September-November (SON) season. These seasons; MAM and SON seasons (wet seasons) are separated by two dry spells from June to August and December to February (Mutemi 2003; Okoola 1996).

The country was divided into four regions for this study; western region, central region, eastern region, and northern region using the administrative map of Uganda (Fig 3, TUBS 2012).The central and western region have a bimodal rainfall while northern region has unimodal rainfall and eastern region has intermediate rainfall (Ogallo 1988; Phillips and McIntyre 2000).

Climate data consisting of precipitation and air temperature were obtained from the Uganda National Meteorological Authority for the years 1980 to 2016. Climate data were collected for the Gulu station to represent the northern region, Jinja station for the central region, Soroti for the eastern region and Mbarara for the western region. These districts were selected because they are known to give a better representation of Ugandan climate (Komutunga 2005). Means, minimum and maximum of temperatures, annual rainfall totals and evapotranspiration were computed and compared among the different regions using ANOVA test using SAS (9.4 version).

The Seasonal Mann Kendall time series was used to test the monotonic trend in the temperature data. The presence of seasonality implies that the data have different distributions for different seasons (in this case months of the year). The Seasonal Mann Kendall test is a nonparametric (distribution-free) method proposed by Hirsch et al. (1982) for use with 12 months. It can be used when there are missing data and data that has less than one or more limits of detection (LD).

The null hypothesis was that there is no monotonic trend over time while the alternative hypothesis was that for one or more months there is an upward or downward monotonic trend over time. Sen’s slope was used to give the strength of the trend.

Nile tilapia and African catfish are the main aquaculture species in the country (Isyagi et al. 2009; Rutaisire 2007). Mean temperatures were further compared to the optimum range of African catfish and Nile tilapia of 26 - 32 ^{o}C (Isyagi et al. 2009). Deviations from the long-term mean were also computed to visualize how temperature fluctuates over the years and these were standardized to allow comparison among the regions (Fathauer 2011).

Monthly rainfall totals were summed for each year to obtain annual rainfall totals, and later used in calculating standardized precipitation index (SPI) as precipitation deficit and excess is more important than precipitation alone in aquaculture (Boyd 1998; Yoo and Boyd 1994). The SPI was also noted to be more suitable for monitoring rainfall patterns especially droughts than other indices (Hayes et al. 1999; Ntale and Gan 2003).

The SPI was designed to quantify the precipitation deficit for multiple timescales, which reflect the impact of drought on the availability of the different water resources, characterizing both wet and dry years. Since it is standardized, it allows comparisons between different locations (McKee et al. 1993). The 12-month SPI reflects long-term precipitation patterns and is tied to stream flows, reservoir levels, and even groundwater levels at longer timescales (WMO 2012). The SPI of the different regions were further compared.

Evapotranspiration was computed using Blaney-Criddle model adopted from Ssegane, et al. (2012) as shown below;

Potential Evapotranspiration = p [(0.46 x mean temperature + 8)], where p depends on the month and the latitude of a location and a value of $p = 0.27$ was deemed appropriate for all months for Uganda because it lies at the equator. Mean temperature was calculated by the usual method of taking the mean of the maximum and minimum temperatures in the region.

Water budgets for the different regions were then determined by subtracting the outflows (evapotranspiration and seepage) from the inflows (precipitation) (Aguilar-Manjarrez and Nath 1998). This draws possible production cycles for the different regions as shown below;

Water requirement (WR) = [(Mean monthly precipitation x 1.1) – (Monthly potential evapotranspiration x 1.3) – Mean Seepage], where the factor 1.1 was to compensate the amount of rain that drain into the pond through the pond dikes, the factor 1.3 was to compensate for higher evaporation from free surfaces for small open ponds, and a seepage of 80 mm/month was used for all regions.

Furthermore, estimated monthly required inflows in liters per minute per acre farm were calculated with assumptions adopted from Yoo and Boyd (1994, pg 135).

RESULTS AND DISCUSSION

Mean temperature and mean annual rainfall were higher for the Northern and Eastern region than the Central and Western region (Table 3). This was in agreement with a study done by Phillips and McIntyre (2000). Higher mean rainfall for the Eastern region can be attributed to Lakes Victoria and Kyoga and mountain Elgon’s influence (Sun et al. 2015). Higher mean annual rainfall in the Northern region can be attributed to the hilly peaks of Ngeta, Moru, and Kilak which enhance precipitation in the region from orographic lifting, especially when there is a surge of the moist Congo air mass converging with the prevailing synoptic easterlies during July-August (Basalirwa 1995).

There were significant differences between the mean temperature ($F= 836.06$, $p < 0.0001$, $df = 3$, at $p = 0.05$) and mean annual rainfall ($F = 41.66$, $p < 0.0001$, $df = 3$, at $p = 0.05$) among the regions (Table 3). The post-hoc multiple comparison test by Tukey’s Studentized range (HSD) showed mean temperatures were different among regions and mean annual rainfall was also different among regions apart from that of Eastern and Central region which were similar (Table 3). This was in line with data reported by Nicholson (2017) where he classified Central and Eastern regions in the equatorial rainfall region.

Linkages between temperature and optimum temperature range for catfish and tilapia showed that all regions had mean temperature below the optimum range of 26 ^{o} C to 32 ^{o} C

(Azaza, et al. 2010) apart from the Eastern region over the years (Fig 4). Although the temperatures were out of the optimum range for the culture of African catfish and Nile tilapia, they were within the range for optimum feeding by these species, which has a lower limit of 20 ^{o} C (Azaza et al. 2010; Isyagi et al. 2009) apart for the Western region (Fig. 4). The lower temperature in the Western region possibly could allow culture of cool-water fish species such as trout in some areas.

Seasonal Mann Kendall output showed a positive increasing trend among the regions apart from the Eastern region (Table 4). This implies increasing temperatures in those regions which will favor aquaculture production in future. The strength of the slope was weak for the regions that had the trend as the temperature varied between 0.002 ^{o} C/yr. for the Eastern region to 0.058 ^{o} C/yr. for the Northern region (Table 4).

Deviations from the long-term mean (Fig. 5) showed that there were high temperature fluctuations in the Western regions than other regions over the years. However, the fluctuations were within 6 ^{o} C for all regions which was noted to be suitable for young fish but not larger fish (Azaza et al. 2010). Furthermore, Szumiec (1983) observed that a difference of 1 ^{o} C from the seasonal mean temperature to correspond to a difference of 1000 kg/ha in carp production which indicates a decreased performance for production facilities.

The 12-month SPI showed a rainfall deficit in the Northern and Western Region but are classified as near normal (-0.99 to 0.99) according to McKee et al. (1993) (Table 4). Eastern region and Central region also were near normal although Central region had the highest SPI

(Table 4). The classifications were made according to McKee et al. (1993). The negative SPI values in the Northern and Western region indicate the need for strategies for storing water during their rainy seasons for use in the dry season. Over the years, all regions generally fell within -1.5 to 1.5 SPI that is between moderately dry to moderately wet (Fig. 6). There were more flood events than drought events over the years in all regions. The climatic events coincided with the years noted as severe to extreme floods/drought (Ogwang et al. 2012). The frequency of flood events was more pronounced in the Eastern region (that is every five years) than other regions. This could be due to the influence of Lakes Victoria and Kyoga and Mountain Elgon coupled with the El-Nino.

Mean evaporation was higher in the Northern region followed by the Central and least in the western, and there were missing data for the Eastern region (Table 5). Average potential evapotranspiration was highest for the Eastern region, followed by the Northern region then the Central region and least was the Western region (Table 5). However, the evaporation rates were all categorized as low (Yoo and Boyd 1994; Aguilar-Manjarrez and Nath 1998).

The Central region had the least water requirement compared to other regions (Fig 7) which was in line with the mean SPI results. This could be the result of the lower potential evapotranspiration and mean temperatures in the Central region compared to other regions. Therefore, a year-round production cycle is possible in the Central region that would allow for stocking ponds at different times. However, it may be optimal when pond preparation is in

December-February where pond bottom soils dry out and fertilizer application can be made in the dry season without nutrient leaching problems.

The Eastern and Western regions had a similar possible production cycle where pond preparation or fish harvest could be in June-July or December-February. This is advantageous as pond refilling would be easier during the rainy season that follows and it also presents a competitive market and high profit margin as other poultry products are less available in the local markets during dry season (Ssebisubi et al. 2012).

In the north, a single production cycle is possible with pond preparation in March and fish harvest in December unless water harvesting is done to store water for use during the dry months. Fish harvest in December would be advantageous to the Northern region as fish is a delicacy sought at this time of the year (Jagger and Pender 2001). Harvest during the holiday and vacation season will increase prices for farmers.

The monthly required inflows for levee ponds showed that all regions required water during December-February period which is the longest dry season other than in the Western region where July is the driest month (Table 6). However, the Western and the Northern region had the highest water requirements of the four regions. The results corresponded with studies conducted by Orlove et al. (2010) and Funk (2012).

The high-water requirement in the Western region can be attributed to the lee shadow effect caused by the Rwenzori mountain hence, winds warm up, descending in the region and suppressing precipitation (Basalirwa 1995; Orlove 2010). The high-water requirement in the northern region can be attributed to the region’s unimodal rainfall pattern, thus most part of the year, it is dry. The northern region is also far away from the influence of the moisture transport from Lake Victoria resulting in drier climate. Furthermore, the northern region is generally a plateau which does not significantly disrupt moist winds hence moderate rains. This coupled with the drought events that have occurred yearly since 2008, and especially during July-August when the Northern region is expected to get most rains (Nicholson 2015).

Overall, the water requirement in all regions was within 2000 to 1 mm which was classified as moderately suitable for ponds by Aguilar-Manjarrez and Nath (1998).

Considering all factors, the Central region had the most favorable climate for aquaculture production. Nevertheless, all regions are suitable for aquaculture production provided water harvesting strategies are adopted for storing water during the dry periods.

CONCLUSIONS

The temperature was sometimes out of the optimum range in all regions, but the temperature range nonetheless would allow fish production. The Central region was considered most favorable among all regions for fish production. However, all areas were noted to be suitable for fish culture, provided water harvesting techniques were employed during the dry period.

Overall, potential climate effects on aquaculture is not that significant in the country if the right strategies are adopted that is; water harvesting during the drier periods and planning of the fish production cycle so as period of water deficit coincide with fish harvest or pond preparation.

The effective use of climate forecasts in aquaculture will depend on the success of extension workers and non-government organizations in sensitizing farmers on the implications of climate on fish production. Also, critical to the success of the implementation of the fish culture climate smart strategies will be the timely provision to farmers of inputs, such as fertilizers and fish fingerlings by the non-government organizations and the government.

REFERENCES

Aguilar-Manjarrez, J. and S. S. Nath. 1998. A strategic reassessment of fish farming potential in Africa. CIFA Technical paper 32. FAO, Rome, Italy.

Azaza, M. S., M. Legendre, M. M. Kraiem and E. Baras, 2010. Size-dependent effects of daily thermal fluctuations on the growth and size heterogeneity of Nile tilapia Oreochromis niloticus. Journal of Fish Biology 76:669–683.

Basalirwa, C. P. K. 1995. Delineation of Uganda into climatological rainfall zones using the method of principal component analysis. International Journal of Climatology 15:1161–1177.

Coche, A. G. 1994. Aquaculture development and research in sub-Saharan Africa: National Reviews. FAO, Rome, Italy.

Fathauer, T. 2011. A glimpse into a changing climate: New 1981–2010 climate normals take effect. Weatherwise 64: 34–36.

Funk, C., J. Rowland, G. Eilerts, L. White, T. E. Martin and J. L. Maron. 2012. A climate trend analysis of Uganda. US Geological Survey Fact Sheet 3062.

Hayes, M. J., M. D. Svoboda, D. A. Wilhite and O. V. Vanyarkho.1999. Monitoring the 1996 drought using the standardized precipitation index. Bulletin of the American Meteorological Society 80:429–438.

Helgi, G., M. Ssebisubi and K. Ögmundur. 2012. The value chain of farmed African catfish in Uganda. Proceedings of the Sixteenth Biennial Conference of the International Institute of Fisheries Economics and Trade, July 16-20, Dar es Salaam, Tanzania.

Hirsch, R. M., J. R. Slack and R. A. Smith.1982. Techniques of trend analysis for monthly water quality data. Water Resources Research 18:107–121.

Isyagi, N., G. Atukunda, L. Aliguma, M. Ssebisubi, J. Walakira, G. Kubiriza and E. Mbulameri. 2009. Assessment of national aquaculture policies and programmes in Uganda. Retrieved from https://www.cabdirect.org/cabdirect/abstract/20006802063.

Jagger, P. and J. Pender. 2001. Markets, marketing, and production issues for aquaculture in East Africa: the case of Uganda. Naga, the ICLARM Quarterly 24:42–51.

Kapetsky, J. M. 2000. Present applications and future needs of meteorological and climatological data in inland fisheries and aquaculture. Agricultural and Forest Meteorology 103:109–117.

Kapetsky, J. M. and S. S. Nath. 1997. A strategic assessment of the potential for freshwater fish farming in Latin America. FAO, Rome, Italy.

Komutunga, T. E. 2005. Optimum cropping calendar derived for rain-fed agriculture in Uganda using rainfall data. PhD thesis. University of Nairobi, Nairobi, Kenya

McKee, T. B., N. J. Doesken, and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology17:179–183

Musinguzi, L., J. Efitre, K. Odongkara, R. Ogutu-Ohwayo, F. Muyodi, V. Natugonza, M. Olokotum, S. Namboowa and S. Naigaga. 2016. Fishers' perceptions of climate change impacts on their livelihoods and adaptation strategies in environmental change hotspots: a case of Lake Wamala. Uganda. Environment, Development and Sustainability 18:1255–1273.

Natungoza, V., R. Ogutu-Ohwayo, J. Efitre, F. Muyodi, D. Mbabazi, M. Olukotum, S. Naigaga and S. Namboowa. 2015. The responses of Nile tilapia Oreochromis niloticus (Linnaeus, 1758) in Lake Wamala (Uganda) to changing climatic conditions. Lakes & Reservoirs: Research and Management 20:101–119.

Nicholson Sharon E. 2015. An analysis of recent rainfall conditions in eastern Africa. International Journal of Climatology 36:526–532.

Nicholson, S. E. 2014. A detailed look at the recent drought situation in the Greater Horn of Africa. Journal of Arid Environments 103:71–79.

Nicholson, S. E. 2017. Climate and climatic variability of rainfall over eastern Africa. Reviews of Geophysics 55: 590-635.

Ntale, H. K. and T. Y. Gan. 2003. Drought indices and their application to East Africa. International Journal of Climatology 23:1335–1357.

Ogallo, L. J. 1988. Relationships between seasonal rainfall in East Africa and the Southern Oscillation. Journal of Climatology 8:31–43.

Ogwang, B. A., T. Guirong and C. Haishan. 2012. Diagnosis of September-November drought and the associated circulation anomalies over Uganda. Pakistan Journal of Meteorology 9:11-24.

Orlove, B., C. Roncoli, M. Kabugo and A. Majugu. 2010. Indigenous climate knowledge in southern Uganda: the multiple components of a dynamic regional system. Climatic Change 100: 243-265.

Phillips, J. and B. McIntyre. 2000. ENSO and interannual rainfall variability in Uganda: implications for agricultural management. International Journal of Climatology 20:171–182.

Rutaisire, J. 2007. FAO Fisheries and Aquaculture Department - Study and analysis of feeds and fertilizers for sustainable aquaculture development. Retrieved September 28, 2017, from http://www.fao.org/docrep/011/a1444e/a1444e00.htm

Ssegane, H., E. W. Tollner, and K. Veverica. 2012. Geospatial Modeling of Site Suitability for Pond-Based Tilapia and Clarias Farming in Uganda. Journal of Applied Aquaculture 24:147–169.

Szumiec, M. A. 1983. Meteorology in the service of limnology and aquaculture. Polish Archives of Hydrobiology, Fish Culture Experimental Station-Golysz, Chybie

Timmers, B. 2012. Impacts of climate change and variability on fish value chains in Uganda Retrieved September 28, 2017, from http://www.worldfishcenter.org/resource_centre/WF_3139.pdf

TUBS. 2012. Deutsch: Karte der politischen Gliederung von XY (siehe Dateiname). Retrieved from https://commons.wikimedia.org/wiki/File:Uganda,_administrative_divisions_-_Nmbrs_-_colored.svg#metadata

WMO. 2012. Standardized precipitation index user guide.: World Meteorological Organization, Geneva, Switzerland.

WMO. 2017. CCI FAQs | WMO. Retrieved December 6, 2017, from http://www.wmo.int/pages/prog/wcp/ccl/faqs.php.

Yoo, K. H. and C. E. Boyd. 1994. Hydrology and Water Supply for Pond Aquaculture. Chapman and Hall, New York, USA.

Table 3: Mean temperature, maximum, minimum temperatures, and annual mean rainfall for years 1980 to 2016 in the different regions. Means are tested for difference by Tukey's Studentized Range (HSD) test; homogeneity of variances was tested by F-statistic. Means indicated by the same letter in a column do not differ (P-value = 0.05) according to HSD test.

Region	Central	Eastern	Northern	Western
Mean Temperature (^{o}C)	22.66^{a}	24.94^{b}	24.07^{c}	21.09^{d}
Minimum Temperature (^{o}C)	17.80	22.60	19.90	19.30
Maximum Temperature (^{o}C)	28.90	34.70	28.30	26.20
Annual mean Rainfall (mm)	1248.0 ± 284.39^{a}	1335.7 ± 210.28^{a}	1476.0 ± 174.30^{b}	921.5 ± 203.16^{c}

Table 4: Seasonal Mann Kendall output and Mean SPI for the different regions

Region	Central	Eastern	Northern	Western
Tau b	0.244	0.027	0.595	0.468
P-value	> 0.0001	0.4222	> 0.0001	> 0.0001
Sen’s slope	0.015	0.002	0.058	0.038
Risk (%)	0.01	43.97	0.01	0.05
Mean SPI	0.1225	0.0000	-0.0003	-0.0005

Table 5: Mean Evaporation and mean Evapotranspiration for the different regions

Region	Central	Eastern	Northern	Western
Mean Evaporation (mm/ year)	139	-	168	120.8
Calculated potential Evapotranspiration (mm/month)	151.2 ± 4.17	160.0 ± 4.86	156.6 ± 4.80	145.3 ± 3.94

Table 6: Monthly water requirement (inflows) in liters per minute (gpm)/ acre for levee ponds

Region	Northern	Central	Western	Eastern
Jan	5.91	3.22	0.00	3.48
Feb	5.34	4.09	0.00	3.14
Mar	0.08	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00
Jun	0.00	3.44	0.00	0.00
Jul	0.00	3.41	0.72	0.00
Aug	0.00	0.30	0.00	0.00
Sep	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.00
Dec	3.82	1.17	0.00	2.57

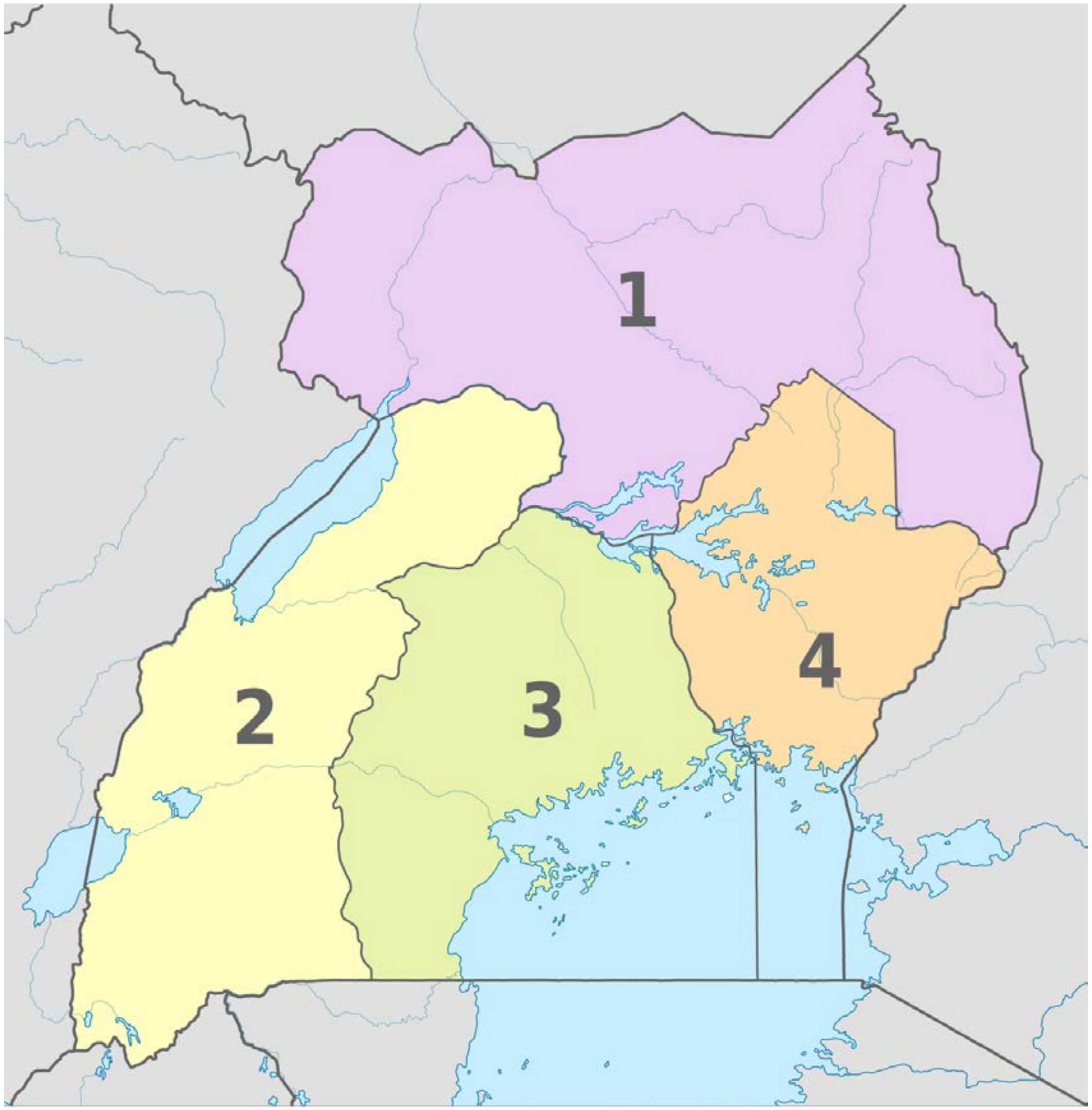
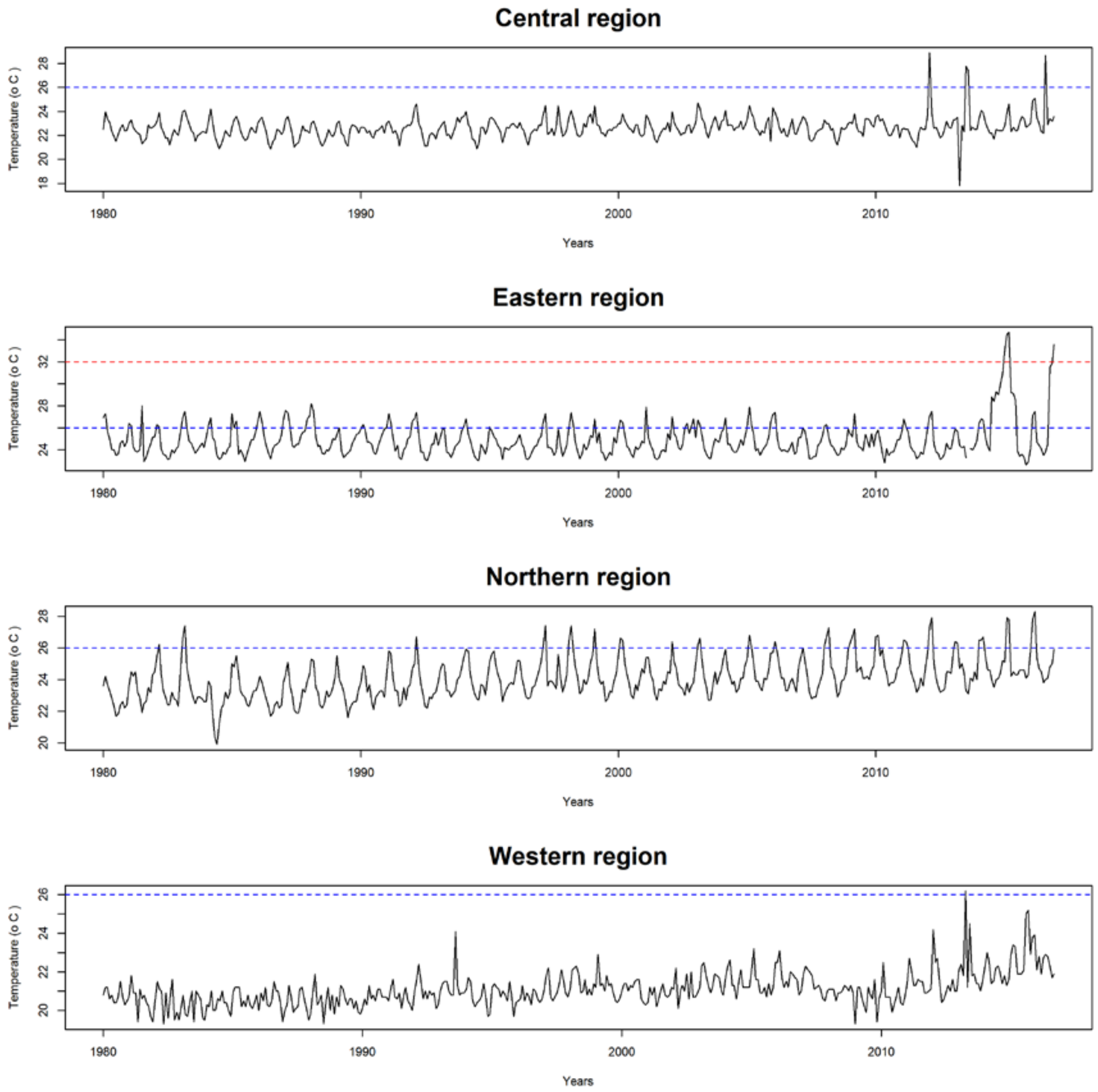


Figure 4: Administrative map of Uganda showing Northern region (1), Western region (2), Central region (3) and Eastern region (4) (TUBS, 2012)


Central region

Eastern region

Northern region

Western region

Figure 5: Mean Temperature for different regions for period 1980-2016 and how they relate with the optimum temperature range for culture of Nile tilapia and African catfish (26- 32 ^{0}C)

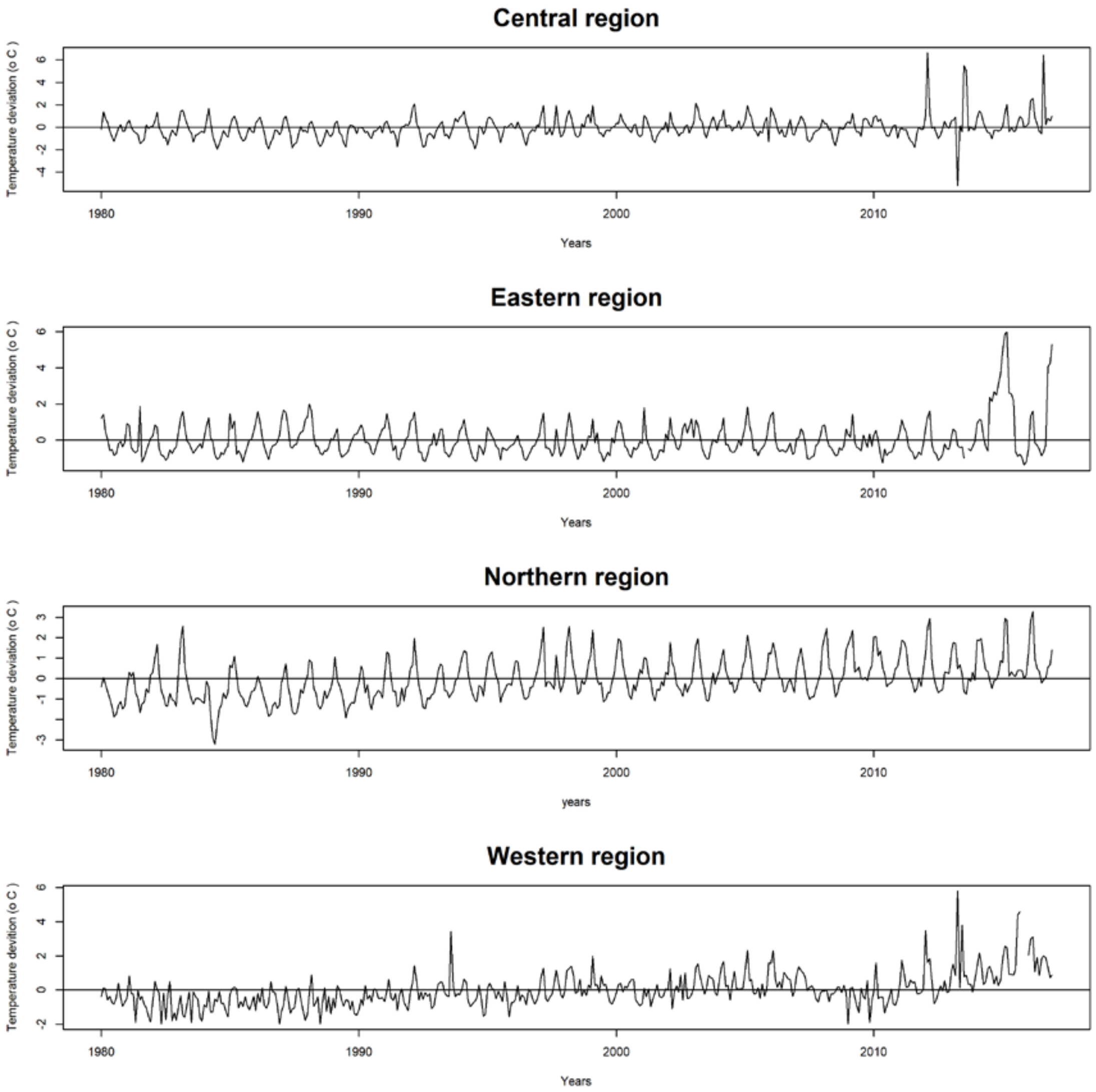


Figure 6: Temperature deviations from the long term mean for the different regions for a period 1980-2016

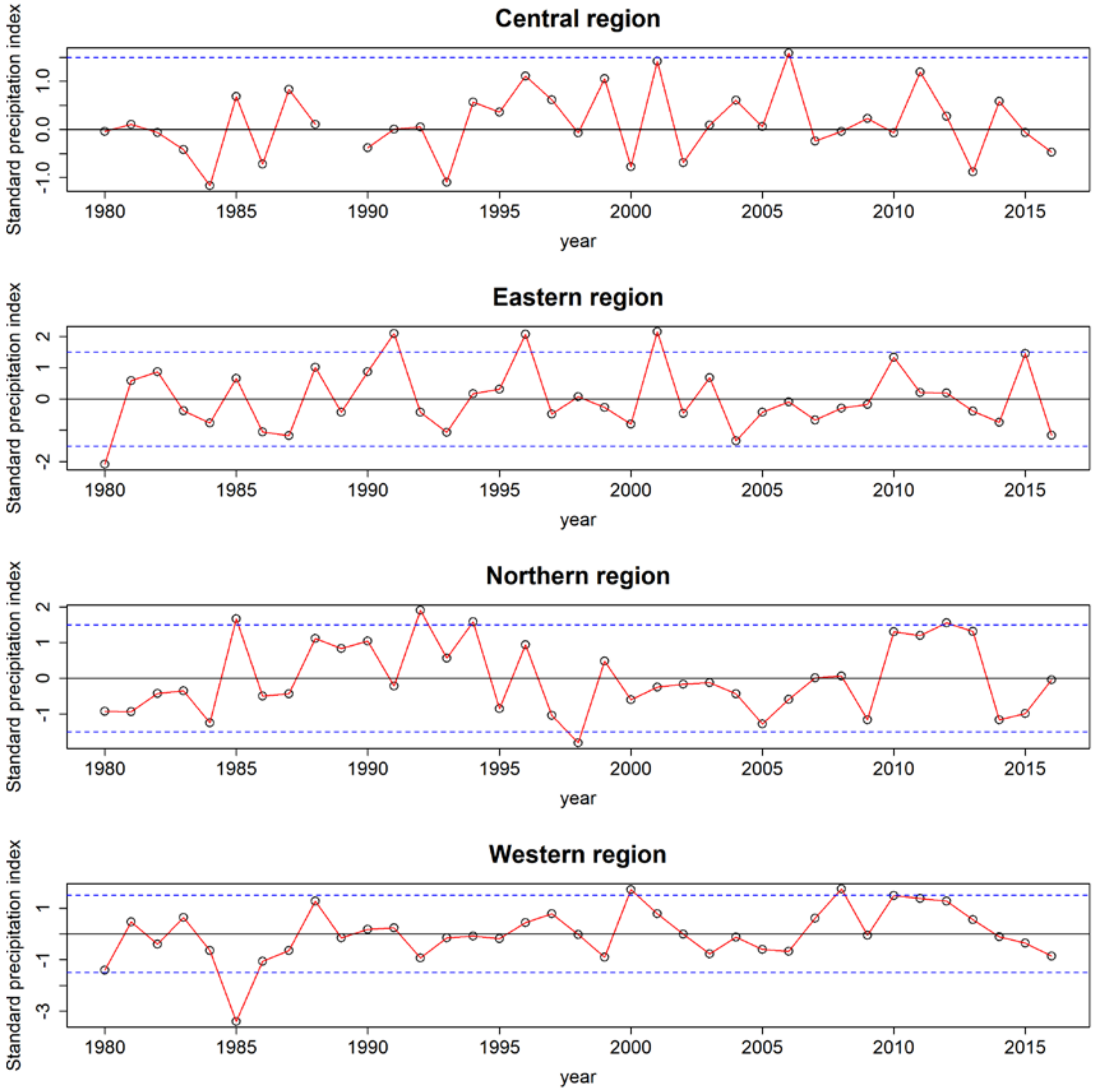


Figure 7: 12-month Standard precipitation index for the different regions for a period of 1980- 2016

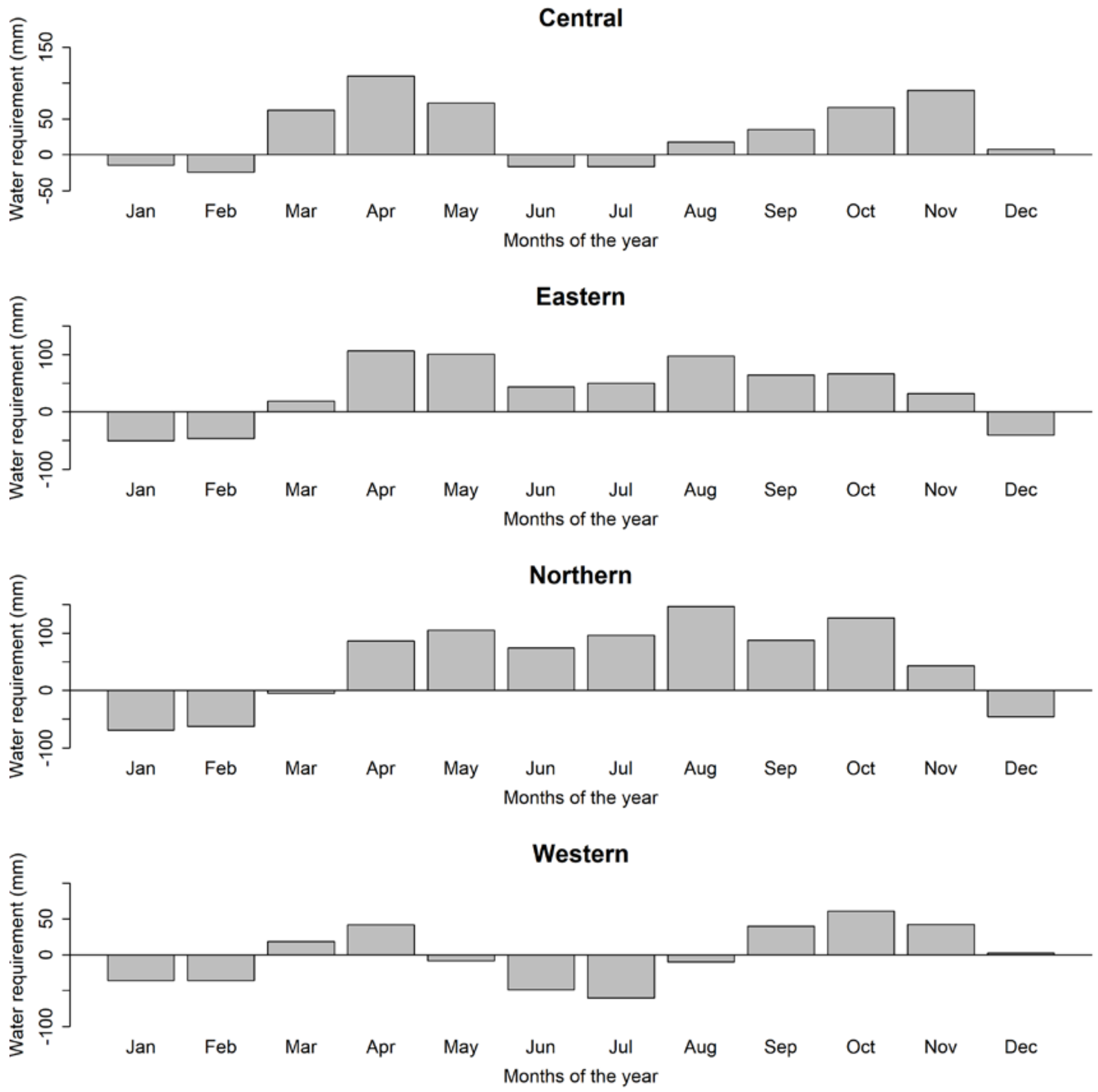


Figure 8: Monthly water requirement for rainfed ponds the different regions

SUITABILITY OF BASIC WATER QUALITY CONDITIONS FOR AQUACULTURE IN UGANDA

ABSTRACT

In Uganda, aquaculture is a promising commercial venture with untapped potential to provide fish for food as well as an alternative livelihood. However, little attention has been given to water quality as a way of improving aquaculture production in Uganda. The main objective of this study was to assess the suitability of the quality of Ugandan water sources for Nile tilapia and African catfish farming.

Water samples were collected from pond water sources in 20 districts in four regions (Central. Eastern, Northern, and Western parts of Uganda) which were representative of the different climatic zones in Uganda and the major lakes of the country. Water samples were collected and analyzed for specific conductivity, total hardness, calcium hardness, pH, total alkalinity, dissolved oxygen, turbidity, and trace metals, and compared by one-way ANOVA with post-hoc multiple comparison- Tukey's test.

The pH was high (> 9) in more than half of the pond water sources in the Eastern region. Waters with pH consistently above 8.5 or 9.0 are not suitable for aquaculture. Total hardness and calcium hardness were usually within the optimum range of 50-150 mg/l, total alkalinity was also within optimum range of 50-150 mg/l apart from the central region.

Nevertheless, some water had less than 30 mg/l total alkalinity and pH of less than 6.5, therefore these waters should be treated with liming material. Overall, the Eastern region was most suitable for pond culture of fish and Lakes Victoria and Albert were more suitable for fish culture in cages as compared to other lakes.

INTRODUCTION

Water quality in aquaculture focuses on the suitability of water for survival and growth of fish (Boyd 1982). Schmittou et al. (1998) cited water quality as one of the key parameters that determine the levels of production and success in aquaculture. Application of water-quality management allows greater production per unit of pond area or culture system volume (Teichert-Coddington et al. 1997).

Uganda is blessed with about 16% of its total land area being covered by open water and wetlands (Nsubuga et al. 2014). This is supporting 1.2 million people in Uganda employed in fishing (directly or indirectly) and contributing 12% to national GDP (Isyagi et al. 2009).

However, with the current high fishing pressure, illegal fishing, habitat degradation and widespread infestation of water hyacinth in the waterbodies, fish catches have been declining. This is further coupled with the high population growth rate (3.3%) (United Nations, Department of Economic and Social Affairs, Population Division, 2018) which questions the sustainability of fisheries sector in country. This leaves the fate of Uganda’s fisheries to aquaculture which should move from an extensive level to intense to commercial level.

Water quality of the different water sources should be accessed for their suitability for aquaculture as fish live in water and we are what we eat (Anthelme 1826). Most studies in Uganda have focused on water suitability for human consumption (Haruna et al. 2005), water quality effects on capture fisheries in lakes. A few studies that focused on aquaculture were conducted on market and fish consumption (Jagger and Pender 2001), fish value chain (Helgi et al. 2012), fish diseases (Mugimba et al., 2018), and fish food safety (Bagumire et al. 2009). Fewer studies have focused on water quality in aquaculture, and those that did only included water temperature as a factor on suitability of fish farming in Uganda (Ssegane et al. 2012).

This study included other basic water quality parameters that are likely to affect fish production be in ponds or in cages installed in lakes. Water quality parameters (both physical and chemical) that were measured included; water depth, pH, dissolved oxygen, specific conductivity, Secchi depth, total alkalinity, total hardness, major ions, and trace metals. However, dissolved oxygen, secchi depth and water depth were measured only for the lakes.

These water quality parameters were analyzed as they are paramount to site and species selection, hatcheries operation and grow-out facilities. They are also the root determinant of dissolved oxygen concentration, toxic gas production, primary productivity and bioavailability of trace metals minerals in ponds (Boyd and Tucker 1998; 2014).

The water pH is negative logarithm of hydrogen ion activity (Boyd and Tucker 2014). Although direct pH effects are less common in aquaculture as farm sites and water supplies to ponds are checked so as they are within optimum range, the practice is rarely adopted in Uganda. Furthermore, the indirect effects of pH through the production cycle are profound especially in nutrient availability and toxicity of certain gases and metals.

Specific conductivity is an index of mineralization and measure the water's ability to conduct an electric current (Boyd 2014). Specific conductivity can be used as a surrogate for salinity and total dissolved solids concentrations of water and also an early indicator of change in water system (Talling 2009). The main concern in aquaculture is its effect on osmotic pressure, that is, if out of range, fish exert more energy to maintain osmotic balance and less is available for growth (Boyd and Tucker 2014).

Total alkalinity is the measure of titratable bases with bicarbonates and carbonates being more abundant than other anions in natural waters. It is the buffering capacity of water and if total alkalinity is within optimum range, pH fluctuations in the pond are minimized. It also contributes to the supply of inorganic carbon for photosynthesis (Boyd and Tucker 2014).

Total hardness is the measure of divalent ions and mostly calcium and magnesium ions are measured as they are more abundant than other divalent ions (Boyd 2015). Total hardness is important in aquaculture especially during production cycle as it helps in buffering of pH rise. This is by precipitating the carbonates when aquatic plants use bicarbonate as a carbon source when pH is above 8.3 and carbon dioxide is not present. The calcium hardness however, is important in mollusks especially in skeleton formation.

The water quality parameters were analyzed on water samples drawn from pond water sources in different regions of the country as categorized by the administrative map (TUBS 2012) (Central, Eastern, Northern and Western) and the major lakes of the country. This was to assess the suitability status of water quality for the culture of African catfish and Nile tilapia and provide best management practices where needed to increase aquaculture production in the country.

METHODS

Water samples were collected from pond water sources and from the five major lakes in Uganda (Victoria, Albert, Edward, George, and Kyoga)

Pond sampling

Water samples were collected from water sources from a total of 20 districts in four regions (Central. Eastern, Northern, and Western parts of Uganda) which were representative of the different climatic and soil properties in Uganda. This sampling was conducted from April to June 2017.

Different water sources were sampled as shown in Table 7, however, where the pond water source was runoff, water was collected from the pond. One liter of water was collected from each water source to conduct total alkalinity, total hardness, and calcium hardness in the laboratory. A 700 ml of water sample was also collected in another bottle which was preserved by a drop of nitric acid to run the trace element analysis on it in the laboratory.

Specific conductivity and pH were measured *in situ* using Hach Hq40d portable pH, conductivity, dissolved oxygen meter and SmarTROLL Multiparameter. The time was noted when pH analyses were taken.

Lake sampling

Lakes were sampled between 7:00 am to 1:00 pm before changes in the diel patterns of some water quality variables of the lakes. Areas where there is little to no human pollution were sampled and two points were selected for Victoria, Albert, and Kyoga while one point was sampled for Edward and George. This is because the latter were smaller lakes.

Depth, secchi depth, dissolved oxygen, total dissolved solids, pH, salinity, and temperature were measured *in situ* using SmarTROLL Multiparameter. One liter of subsurface water was collected and taken to the laboratory to analyze total alkalinity, total hardness, and calcium hardness.

Laboratory and Statistical analyses

Total alkalinity was analyzed by titration with standard sulfuric acid to the methyl orange endpoint, total hardness was by EDTA titration to the eriochrome black endpoint and calcium hardness was by EDTA titration by murexide endpoint (Boyd & Tucker 1992). Trace metals were determined simultaneously by Inductively Coupled Plasma (ICP) Atomic Emission Spectrometry using a Varian Vista-MPX Radial Spectrometer in the Auburn soil testing laboratory.

Total alkalinity, total hardness and calcium hardness results were analyzed using R version (3.3.3) to develop into graphics and perform chi square test among the different regions.

SAS version 9.4 was used to perform the ANOVA test on the results of total alkalinity, total hardness, and calcium hardness concentrations in the different regions.

Statistical tests could not be conducted on trace metals as it was in range form. Trace metal concentrations were compared to the recommended ranges outlined in Boyd and Tucker (1998; 2014) with consideration of total hardness in the different regions.

Water quality parameters measured for lake water samples were used to assess their suitability for cage culture with reference to Secchi depth, subsurface-mid surface dissolved oxygen profile, water depth, the long axis of the bay, distance to obvious source of pollution, connection of the bay to the open water of the lake and the current between the bay and the lake as illustrated in Boyd (2004, USAID/FISH PROJECT). All the water quality parameters were compared to the recommended optimum ranges for Nile tilapia and African catfish (Table 8).

RESULTS AND DISCUSSION

Pond mean concentrations of the different water quality parameters all showed that were within optimum ranges for Nile tilapia and African catfish. The exceptions were in the Central region for total alkalinity and in the Eastern region for pH (Table 9). However, the ranges of each water quality parameter measured were wide.

The Northern region had the highest total hardness, total alkalinity, and the greatest specific conductivity as compared to other regions. The high concentrations of specific conductivity, total alkalinity, and total hardness in the Northern region agree with studies done by Boyd and Tucker (2014) in which moderate to high concentrations of total alkalinity and total hardness were positively correlated with increasing specific conductivity. The Northern region also is drier than other regions; hence, more evaporation occurs, leading to concentration of ions in water (higher specific conductivity).

Comparisons among the different regions by a chi square test (Table 9) showed that all regions were independent of each other as p-value was less than $\alpha = 0.05$, df = 3 at 95% confidence interval. Mean concentrations for all water quality parameters analyzed were statistically significantly other than for the calcium hardness ($p = 0.0828$, $\alpha = 0.005$, df = 3) as determined by ANOVA (Table 5).

Further comparison with the Tukeys' test revealed that the regions had pH measures that were statistically significantly different from each other. For other water quality parameters, the

Northern region was statistically different from all other regions other than the Eastern region (Table 9). Similarities between the Northern region and the Eastern region could be because of similar geological conditions, land uses, and pond management practices.

Pond frequency distribution for water quality variables (Fig. 8) showed that most pond water sources had total hardness concentration out of the optimum range for Nile tilapia and African catfish. The Eastern region had most of its water sources within range as compared to other regions while the Northern region had most water sources with hard water.

Pond frequency distribution for specific conductivity (Fig. 9) showed that most water sources were within optimum range for the Eastern region. For other regions, however, the specific conductivity concentrations were within the tolerable range as freshwater species are found to tolerate up to 5,000 µS/cm (Boyd and Tucker, 2014).

Total alkalinity pond frequency distribution (Fig. 10) showed that most water sources for all regions were below the optimum range except the Eastern region. The Central region had lower total alkalinity concentrations when compared to other regions. Pond frequency distribution for pH (Fig 11) showed that regions other than the Eastern region had water sources within the optimum pH range. This observation agrees with studies done by Boyd and Tucker (2014), where ponds with total alkalinity below 50 mg/L usually had pH between 6 to 8 in the morning.

Higher pH values in the water sources in the Eastern region despite their high total alkalinity could be attributed to excessive photosynthesis by water plants in the ponds as reported to occur in ponds in other parts of the world (Boyd and Tucker 2014). Most of the water sources in the Eastern region were measured in ponds, and the time of sampling which was done in the early afternoon, at the time of day when pond pH is greatest.

Pond trace metal analysis revealed that concentration of most trace metals was within optimal limits for fish culture. The exceptions were aluminum and iron (Table 10) which sometimes were greater in concentration than the normal concentrations listed for freshwater pond in Boyd and Tucker (2012) and Boyd (2015) . This also agreed with studies which showed elevated concentrations of iron and aluminum in ground waters of Uganda (UNESCO 2006). The elevated concentrations of iron and aluminum in the pond water sources could be the result of corrosion of the borehole casings, seepage of the sewage waste and natural weathering of the aquifer matrix which is high in iron and aluminum.

Frequency analysis of iron concentrations showed that regions other than the Western region had at least 50% of most water sources in the optimal range. This was contrary to the study done on drinking water in Western region by Ngabirano et al. (2017) which showed that most of the water sources analyzed had their iron concentrations within optimal range. For the aluminum concentration, the Northern and Western regions at least 50% of their water sources were in optimum range contrary to Central and Eastern region (Table 11). Higher occurrence of high aluminum and iron concentrations in the Central and the Eastern regions compared to the Western and the Northern regions could be attributed to the seepage of sewage waste in the Central and Eastern regions, as they have more industries compared to other regions.

Lake results showed that all water quality parameters of concern in aquaculture (Table 12) were in optimal range for cage culture. However, the low calcium hardness < 20 mg/l in Lake Victoria can be compensated by calcium in the artificial feed given to the fish. Further analysis of site suitability using Boyd's method (2004 USAID/FISH PROJECT) showed Lakes George and Kyoga were poor sites for fish cage culture, Lake Edward had its siting as fair with Lakes Victoria and Albert having suitable site characteristics (Table 13).

CONCLUSION

Pond mean concentration of the different water quality parameters showed that they were within optimum range for African and catfish culture, but frequency farm analysis showed otherwise with a high percentage of water sources in all regions being outside of optimal ranges in total alkalinity and pH. There is, therefore, a need to analyze water sources from all sites and make applications of agricultural lime to ponds as necessary to increase the pH and total alkalinity and favor greater fish production.

The Eastern region had better water sources for fish farming compared to others. Lake results revealed Lakes Victoria and Albert were most suitable sites for cage culture compared to other lakes. Further studies are needed where nutrient analysis (nitrogen and phosphorus concentrations) is included to give a better overview of water quality in Uganda.

REFERENCES

Anthelme, B. S. 1826. Physiologie du goût, ou Méditations de gastronomie transcendante. Paris: A. Sautelet.

Bagumire, A., E. C. D. Todd, C. Muyanja and G. W. Nasinyama. 2009. National food safety control systems in Sub-Saharan Africa: Does Uganda's aquaculture control system meet international requirements? Food Policy 34: 458–467.

Boyd, C. E. 1982. Water Quality Management for Pond Fish Culture. Elsevier, Amsterdam, Netherlands.

Boyd, C. E. 2015. Water Quality: An Introduction. Springer, New York, USA.

Boyd, C. E. and C. S. Tucker. 1998. Pond Aquaculture Water Quality Management. Kluwer, Massachusetts, USA.

Boyd, C. E. and C. S. Tucker. 2014. Handbook for Aquaculture Water Quality. Craftmaster Printers, Alabama, USA.

Haruna, R., F. Ejobi and E. K. Kabagambe. 2005. The quality of water from protected springs in Katwe and Kisenyi parishes, Kampala City, Uganda. African Health Sciences 5:14–20.

Helgi, G., M. Ssebisubi and K. Ögmundur. 2012. The value chain of farmed African catfish in Uganda. Proceedings of the Sixteenth Biennial Conference of the International Institute of Fisheries Economics and Trade, July 16-20, Dar es Salaam, Tanzania.

Isyagi, N., G. Atukunda, L. Aliguma, M. Ssebisubi, J. Walakira, G. Kubiriza and E. Mbulameri. 2009. Assessment of national aquaculture policies and programmes in Uganda. Retrieved from https://www.cabdirect.org/cabdirect/abstract/20006802063.

Jagger, P. and J. Pender. 2001. Markets, marketing, and production issues for aquaculture in East Africa: the case of Uganda. Naga, the ICLARM Quarterly 24:42–51.

Mugimba, K. K., A. A. Chengula, S. Wamala, E. D. Mwega, C. J. Kasanga, D. K Byarugaba and H. M. Munang'andu. 2018. Detection of tilapia lake virus (TiLV) infection by PCR in farmed and wild Nile tilapia (Oreochromis niloticus) from Lake Victoria. Journal of Fish Diseases 41: 1181-1189.

Ngabirano, H., D. Byamugisha and E. Ntambi. 2017. Temporal and spatial seasonal variations in quality of gravity flow water in Kyanamira Sub-County, Kabale District, Uganda. Journal of Water Resource and Protection 9:455-469.

Nsubuga, F. N. W., E. N. Namutebi and M. Ssenfuma. 2014. Water resources of Uganda: An assessment and review. Journal of Water Resource and Protection 6:1297–1315.

Schmittou, H. R., Z. Jian and M. C. Cremer 1998. Principles and practices of 80: 20 pond fish farming. American Soybean Association, Missouri, USA.

Ssegane, H., E. W. Tollner, and K. Veverica. 2012. Geospatial Modeling of Site Suitability for Pond-Based Tilapia and Clarias Farming in Uganda. Journal of Applied Aquaculture 24:147–169.

Talling, J. f. 2009. Electrical conductance — a versatile guide in freshwater science. Freshwater Reviews 2:65–78.

Teichert-Coddington, D. R., T. J. Popma and L. L. Lovshin. 1997. Attributes of Tropical Pond-Cultured fish. CRC Press, Florida, USA.

United Nations, Department of Economic and Social Affairs, Population Division. 2018. Uganda population (2018) - Worldometers. Retrieved March 7, 2018, from http://www.worldometers.info/world-population/uganda-population/

Table 7: Frequency of different pond water sources sampled in different regions

Water source	Central	Eastern	Northern	Western
well	11	12	11	7
river	2	-	-	-
reservoir	3	1	9	8
underground	7	10	3	4
runoff	-	2	1	2
swamp	2	1	2	-
stream	5	4	4	9

Table 8: Water quality parameters and their optimal range for aquaculture production according to Boyd & Tucker, (2014).

Water quality parameter	Optimal range
Total hardness (mg/l)	50 - 150
Total alkalinity (mg/l)	50 - 150
pH	6.5 - 9
Specific conductivity (µS/cm)	150 - 500

Table 9: Mean concentrations of the different water quality parameters and their standard errors of water samples from pond water sources. Means were tested for independence using Chi Square test. Means indicted by * were all different from each other (P-value = 0.05). Means are tested for difference by Tukey's Studentized Range (HSD) test; homogeneity of variances was tested by F-statistic. Means indicated by the same letter in a column do not differ (P-value = 0.05) according to HSD test.

Water parameter	Region			
	Central	Eastern	Northern	Western
Total hardness (mg/l)	50.3±11.40^{a*}	89.0±16.62^{b*}	102.7±22.49^{b*}	66.0±13.35^{a*}
	(6.3-258.6)	(21.5-502.9)	(12.7-533.8)	(5.5-332.3)
Calcium hardness (mg/l)	20.9±4.97^{a*}	43.3±5.94^{a*}	34.0±5.86^{a*}	31.1±7.38^{a*}
	(0.0-109.0)	(8.1-133.6)	(3.2-114.2)	(0.0-140.0)
Total alkalinity (mg/l)	43.2±8.99^{a*}	80±9.16^{ab*}	106±20.72^{b*}	55.5±12.95^{a*}
	(6.0-69.8)	(7.9-238.1)	(13.7-441.1)	(6.4-329.3)
Specific conductivity (µS/cm)	174.7±29.16^{a*}	298.2±46.89^{ab*}	351.1±71.70^{b*}	157.6±19.52^{a*}
	(38.4-557)	(79.0-469.0)	(53.3-1377.5)	(25.9-383.9)
pH	7.3±0.20^{a*}	9.8±0.34^{b*}	8.3±0.24^{c*}	7.0±0.19^{a*}
	(5.9-10.6)	(7.0-13.0)	(5.2-13.0)	(5.3-9.4)

Table 10: Range of concentration of different water trace metals analyzed in the different regions

Element (mg/l)	Central	Eastern	Northern	Western
Al	< 0.1- 6.3	< 0.1 – 3.0	< 0.1 – 6.0	< 0.1 – 2.5
As	< 0.1	< 0.1	< 0.1	< 0.1
B	< 0.1	< 0.1 – 0.3	< 0.1	< 0.1
Ba	< 0.1- 2.2	< 0.1 – 3.1	0.1 – 1.9	< 0.1 – 3.7
Ca	1.6 – 45.5	8.9 – 117.0	4.7 – 141.0	1.9 – 103.0
Cd	< 0.1	< 0.1	< 0.1	< 0.1
Cr	< 0.1	< 0.1	< 0.1	< 0.1
Cu	< 0.1	< 0.1	< 0.1	< 0.1 – 0.7
Fe	< 0.1 – 16.7	< 0.1 – 8.2	< 0.1 – 6.5	< 0.1 – 11.9
K	0.4 – 10.0	0.9 – 43.6	0.9 – 26.8	0.3 – 9.0
Mg	0.7 – 58.2	4.0 – 104.0	2.3 – 80.0	1.2 – 43.7
Mn	< 0.1 – 2.3	< 0.1 – 2.2	< 0.1 – 1.2	< 0.1 – 1.5
Na	8.3 – 52.9	12.8 – 77.5	7.7 – 136.0	8.9 – 68.3
Ni	< 0.1	< 0.1	< 0.1	< 0.1
P	< 0.1 – 1.7	< 0.1 – 2.0	< 0.1 – 1.2	< 0.1 – 2.2
Pb	< 0.1	< 0.1	< 0.1	< 0.1
Zn	< 0.1 – 0.2	< 0.1	< 0.1	< 0.1

Table 11: Percentage distribution of pond water sources in terms of iron and aluminum concentrations in the different regions

Trace metal	Condition	Central	Eastern	Northern	Western
Iron (%)	Optimal	53.3	66.7	70	36.7
	Non-optimal	46.7	33.3	30	63.3
Aluminum (%)	Optimal	40	40	53	70
	Non-optimal	60	60	47	30

Table 12: Mean concentrations of the different water quality parameters measured in the different lakes

	Lake				
Water Parameter	Victoria	Albert	Edward	George	Kyoga
Depth (m)	10.80	20.90	13.70	1.60	2.70
Secchi depth (m)	2.90	1.90	1.40	0.30	1.20
Temperature (^{0}C)	25.50 ± 0.03	27.90 ± 0.04	26.40 ± 0.06	27.20 ± 0.11	28.10 ± 0.18
Total dissolved solids (mg/l)	0.06 ± 0.00	0.42 ± 0.00	0.58 ± 0.00	0.32 ± 0.03	0.16 ± 0.01
Salinity (PSU)	0.05 ± 0.00	0.31 ± 0.00	0.44 ± 0.00	0.24 ± 0.02	0.12 ± 0.01
Dissolved oxygen (mg/l)	6.64 ± 0.14	5.31 ± 0.08	5.41 ± 0.40	2.77 ± 1.50	2.76 ± 0.56
Specific conductivity (µS/cm)	97.70 ± 0.06	640.80 ± 2.20	886.40 ± 2.16	485.40 ± 48.77	252.60 ± 17.80
pH	8.40 ± 0.05	8.80 ± 0.07	9.30 ± 0.06	7.90 ± 0.50	7.40 ± 0.16
Total alkalinity (mg/l)	38.65 ± 0.11	265.52 ± 2.78	382.01 ± 0.08	102.36 ± 1.07	43.58 ± 2.04
Total hardness (mg/l)	24.16 ± 0.74	140.32 ± 1.06	215.22 ± 0.08	86.72 ± 1.00	28.06 ± 1.27
Calcium hardness (mg/l)	5.49 ± 1.66	22.36 ± 1.36	26.49 ± 0.05	39.46 ± 0.04	8.92 ± 2.29

Table 13: Rating of different water bodies for cage suitability with reference to small to medium sized facilities by Boyd

Lake/ Water parameter	Victoria	Albert	Edward	George	Kyoga
Water depth	3	3	3	1	1
Secchi depth	3	2	2	1	2
Dissolved oxygen profile	3	2	2	1	1
Long axis to the bay	3	3	2	1	2
Current between the bay and the lake	3	3	2	1	2
Connection of the bay to open water of the lake	3	2	1	1	1
Distance to obvious source of pollution	3	3	2	1	1
Total score	21	18	14	7	10

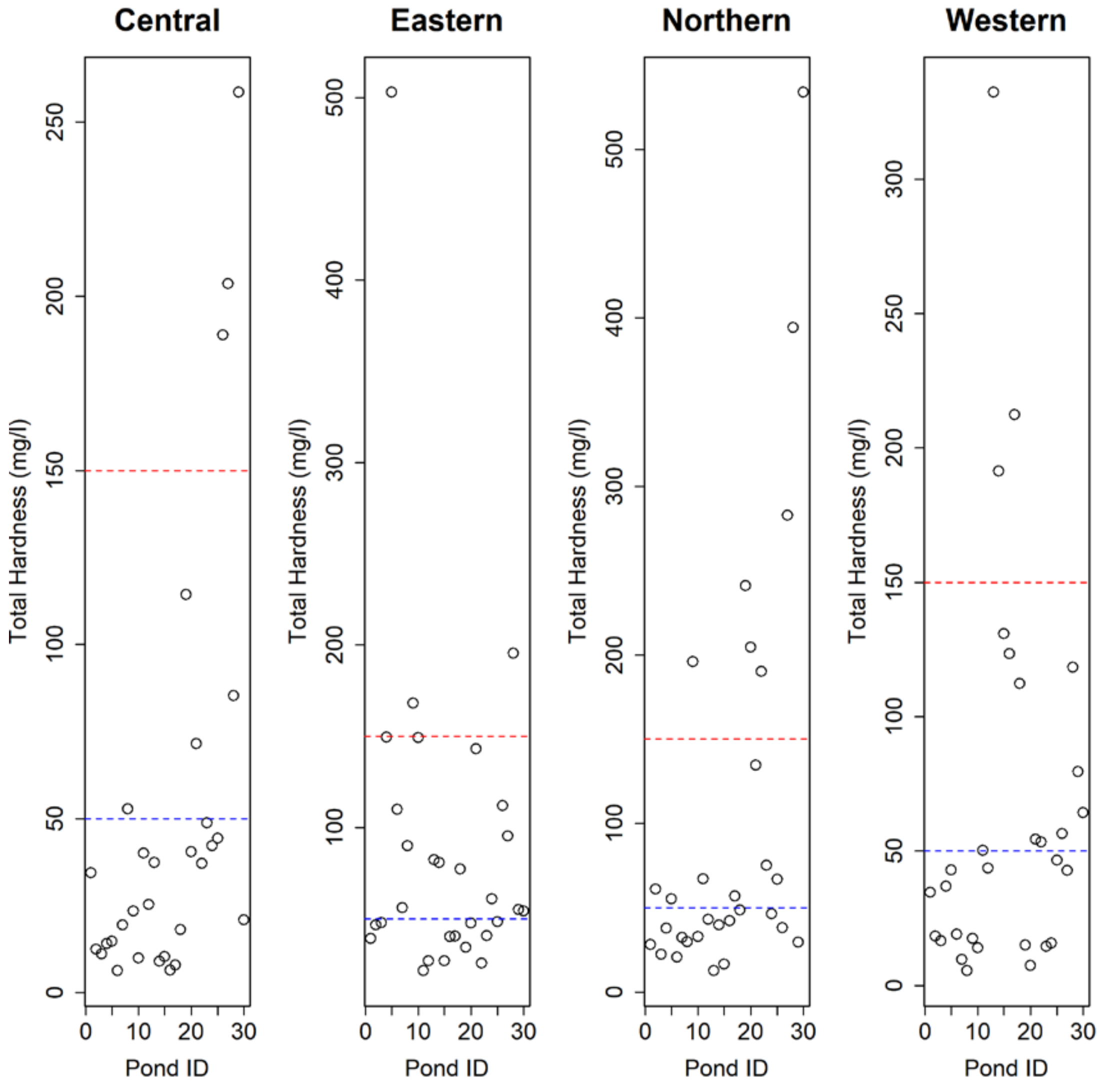


Figure 9: Frequency distribution of different pond water sources for total hardness concentration

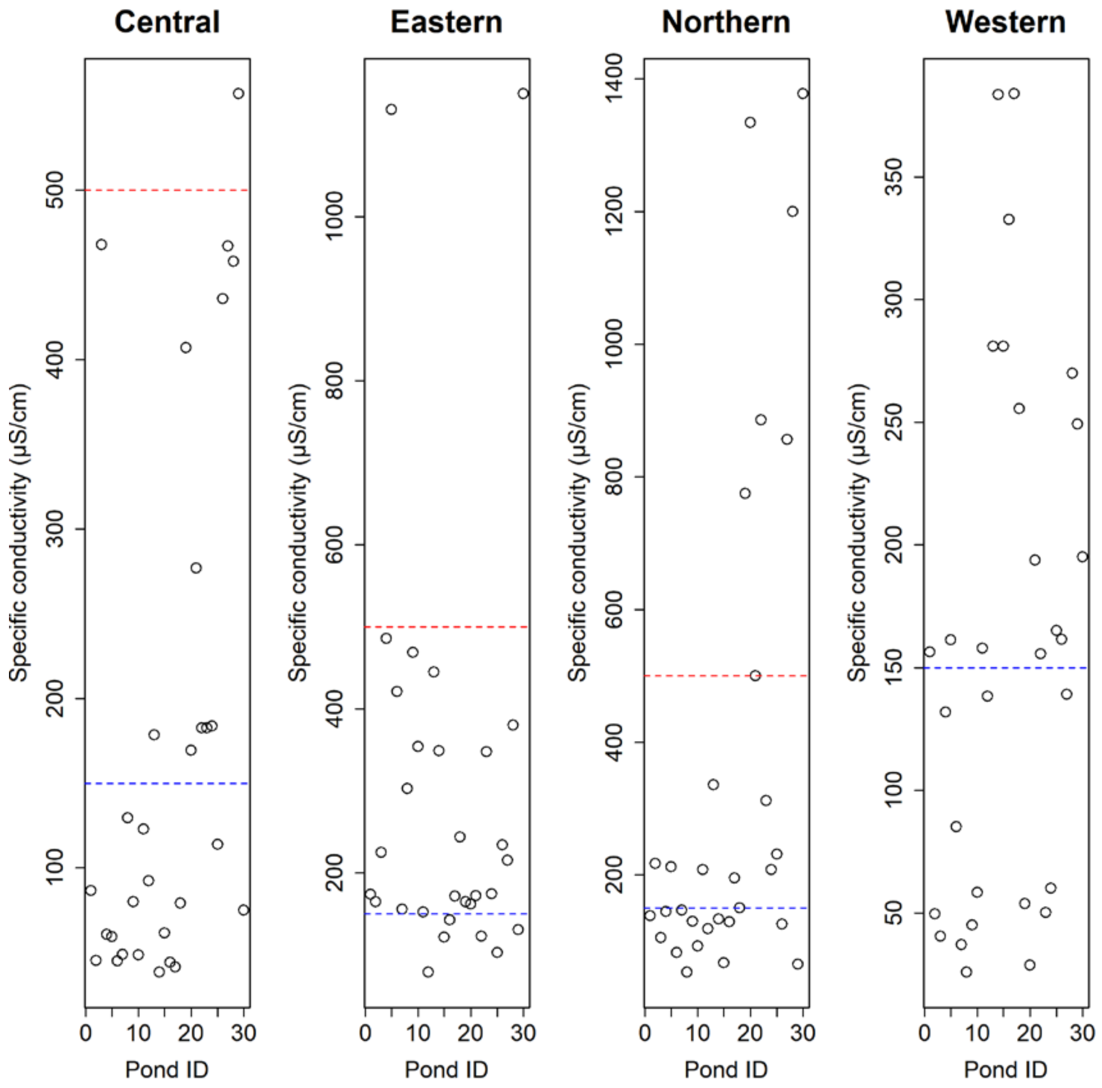


Figure 10: Frequency distribution of different pond water sources for specific conductivity concentration

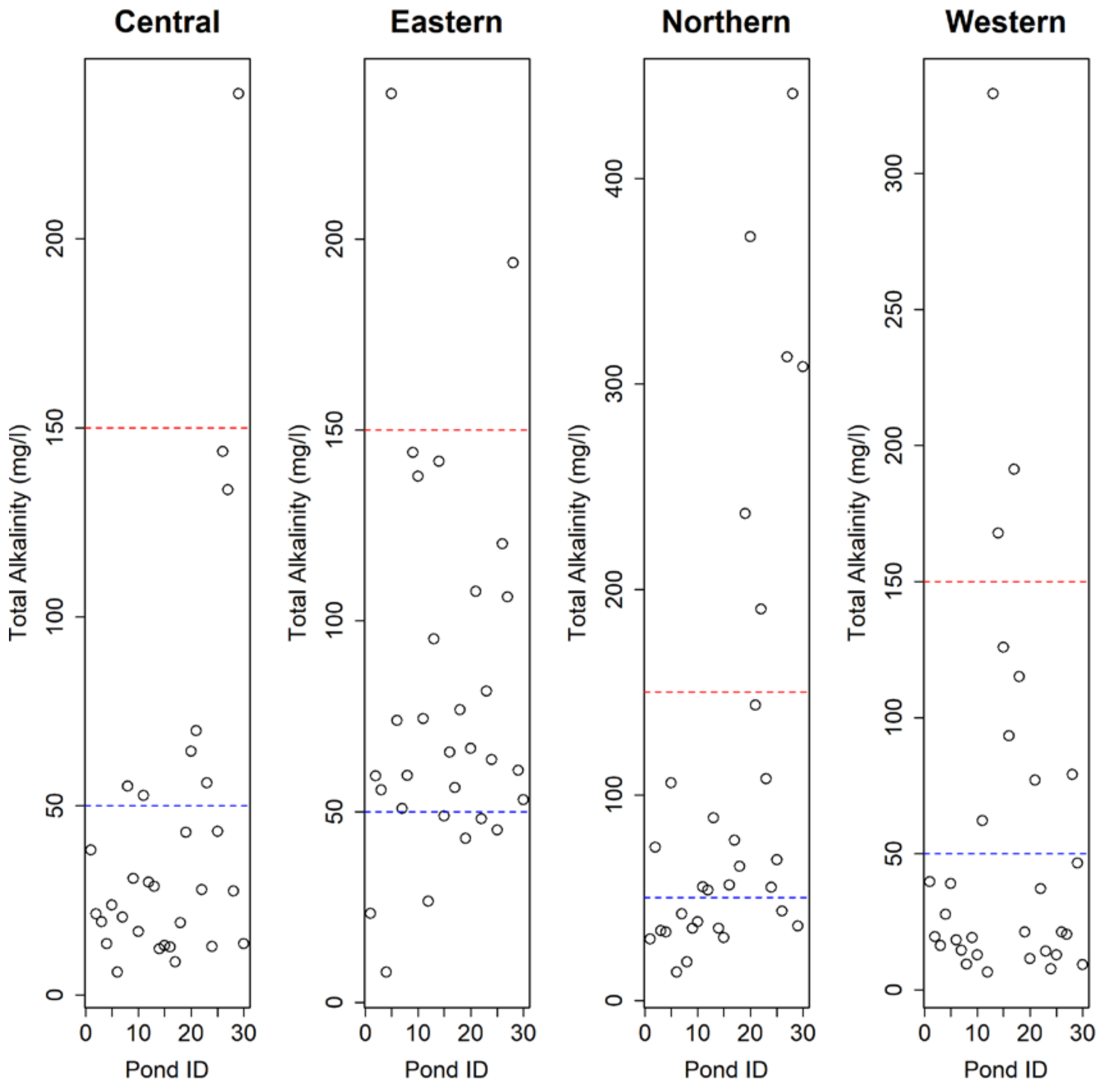


Figure 11: Frequency distribution of different pond water sources for total alkalinity concentration

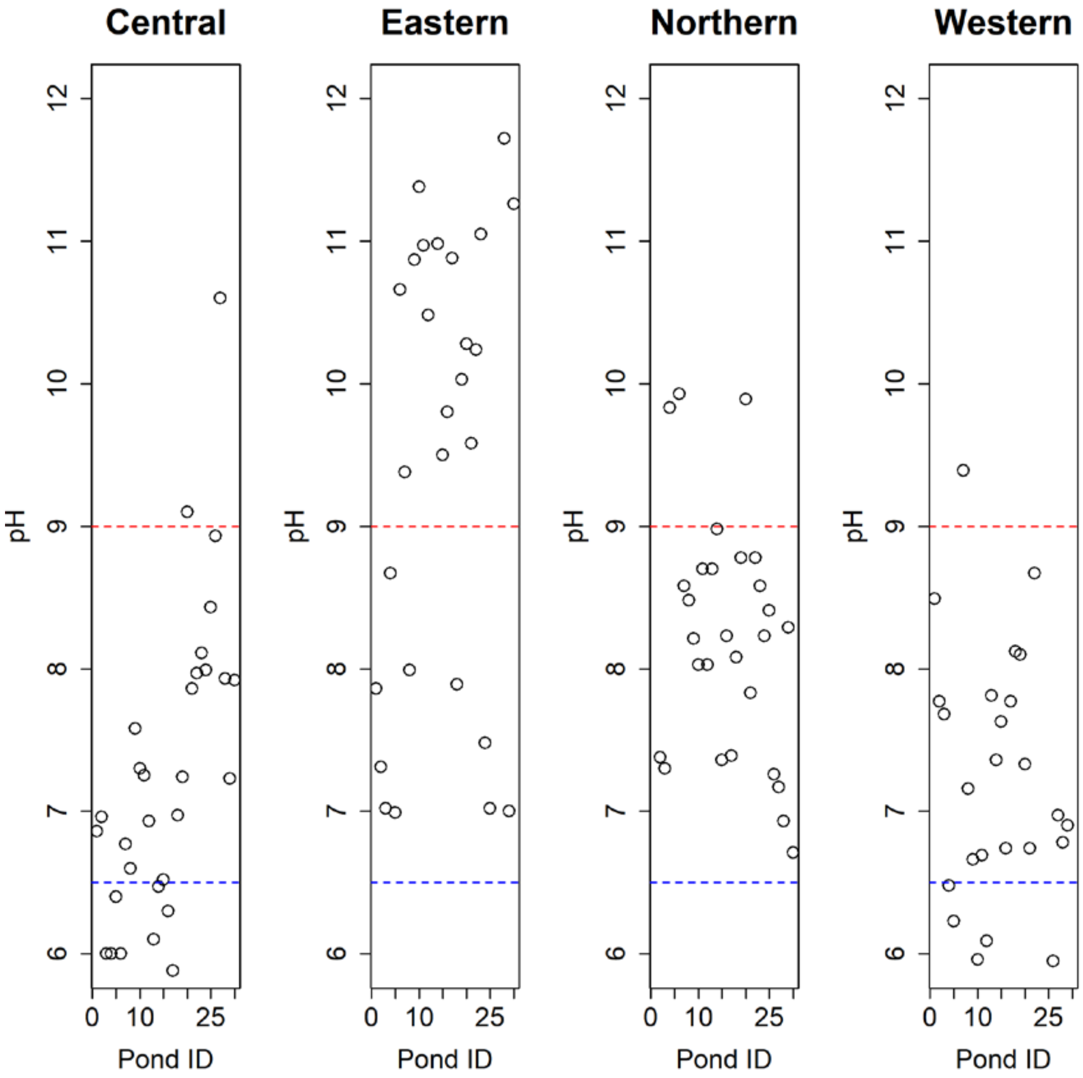


Figure 12: Frequency distribution of different pond water sources for pH concentration

ASSESSMENT OF SOIL QUALITY LIMITATIONS FOR AQUACULTURE IN UGANDA

ABSTRACT

There are strong interactions between soil and water that influence water quality in ponds and affects fish production. However, more attention has been given to water quality than to soil quality as a factor limiting fish production in ponds. Studies that attempted to address soil quality in Uganda only focused on site suitability factors related to pond construction such as soil texture and soil terrain.

The recent study included both physical and chemical characteristics of soil that could influence aquaculture production. To address the potential effects of soil quality in pond aquaculture, Uganda was divided in four regions (Central, Eastern, Northern and Western) using the Administrative map of the country. In the four regions, five districts were selected for sampling using the World Reference Base for Soil Resources which provides general description of the different soil properties in Uganda. The Soil samples were analyzed for soil texture, soil pH, total carbon, total nitrogen, organic matter, and trace elements.

Soil pH was out of the optimal range for some locations in all regions, but other soil quality parameters were within optimal apart from the elevated organic matter concentration in the Western and the Central region. The study further, analyzed the effectiveness of liming materials and their application liming rates. Liming materials available in Uganda were not competent of good quality as compared to calcium carbonate reference as their neutralizing value

were all ≤ 50. Therefore, to improve fish production, pond bottom treatment like pond drying should be observed.

INTRODUCTION

Soil quality in traditional agriculture comprises the different chemical, physical, and biological properties which interact to produce healthy and nutritious crops (SSSA 1984). Parr et al. (1992) defines soil quality as the capability of soil to produce safe and nutritious crops in a sustainable manner over a long term and to enhance human and animal health without impairing the natural resource base or the environment. In aquaculture, there are also strong effects and interactions among soil characteristics, water quality and fish production in ponds (Egna and Boyd 1997). Thus, pond bottom soil quality also is important in aquaculture just as in traditional agriculture.

Boyd (1990; 1992) noted that pond soils affect water quality and many water quality problems in ponds stem from pond soils. For example, acidic soils can cause low pH and total alkalinity in ponds, soils with high oxygen demand can result in low dissolved oxygen concentrations in ponds (Boyd et al. 1994). Pond bottom soils also influence concentrations of nutrients in the water and serve as a biological recycling center for organic residues that settle to the bottom (Ray and Chien 1992). Therefore, the bottom soil is considered a chemical laboratory in any pond culture system (Felix 1998), which affects balance of an aquaculture system and consequently in the growth and survival of cultured animals (Banerjea 1967; Boyd 1992).

More attention has been given to water quality than to soil condition as a factor limiting fish production in ponds (Egna and Boyd 1997), but several studies have addressed the pond bottom soil influence on aquaculture among which include (Boyd et al. 1994; Munsiri et al. 1995; Sonnenholzner and Boyd 2000; Das et al. 2002; Kamal et al. 2017). However, none of these studies were carried out in Uganda or nearby tropical countries to which Uganda can be related.

In Uganda, previous soil studies focused on soil fertility and its constraint to crop production (Mwanjalolo et al. 2015; Rukundo et al. 2016), policy options for reducing soil nutrient depletion in relation to crop production (Nkonya et al. 2005) and land ownership and its relation to credit access (Roth et al.1994). A few studies such as Ssegane et al. (2012) have mentioned the role of pond bottom soils in Ugandan pond aquaculture. These studies focused on the physical characteristics of soil like soil texture and slope which are important for selecting sites and constructing ponds, and chemical characteristics were not included. Soil textural classification does not consider the minerology of the clay fraction, and it is applicable to mineral soils but not organic soils (Egna and Boyd 1997). Furthermore, a high clay content alone does not guarantee low permeability and seepage in ponds (Coche 1985).

The present study measured soil texture, but it focused on chemical characteristics of soil to include soil pH, organic matter, total carbon, total nitrogen, saturated hydraulic conductivity, and trace metals. These soil characteristics were selected as they have been known to play a role in aquaculture (Boyd and Tucker 2014). Furthermore, the liming materials used in Uganda were analyzed for their quality as it affects their ability to raise pond pH and alkalinity.

Soil texture refers to the size distribution of mineral particles that comprise the soil with the most reactive fraction being clay (Egna and Boyd 1997). Most concern to the aquaculturalists has been the clay content because of its importance in pond construction and seepage control from ponds.

Soil pH is the measure of the acidity or basicity of the soil. Watershed and bottom soils with low soil pH typically result in low water alkalinity concentrations (Boyd et al. 1994). Soil pH also is needed in calculating liming requirement for ponds (Boyd and Tucker 2014).

Essington (2004) defines soil organic matter as the unrecognizable remains of organic materials that occur in the soil system. Soil organic matter is about half soil organic carbon (Boyd and Tucker 2014). Organic matter in soil contributes to cation exchange capacity, chelates trace metals, provides food for benthic organisms in ponds and releases inorganic nutrients upon decomposition (Egna and Boyd 1997; Essington 2004).

Soils with high organic matter concentrations (>18%) are not suitable for aquaculture and can lead to anaerobic conditions at the water-soil interface in which toxic reduced substances result from microbial metabolism (Egna and Boyd 1997) while low organic matter (0.5 %) leads to low productivity of benthos in ponds (Banerjea 1967; Boyd 1992). There also is need to know how soil organic matter and organic carbon concentrations are altered by uneaten feed and culture activities, hence soil properties (Kamal et al. 2017).

Concentrations of total ammonia nitrogen and nitrate needed by aquatic plants in ponds are greatly influenced by microbial decomposition, nitrification, and denitrification in pond bottoms (Egna and Boyd 1997).

Saturated hydraulic conductivity was defined by Hillel (2008) as the ratio of the flow rate (flux) to the potential hydraulic gradient. Oosterbaan and Nijland (1986) defined saturated hydraulic conductivity as the constant of proportionality in the Darcy's Law equation. Saturated hydraulic conductivity is affected by soil structure as well as by texture, being greater if the soil is highly porous or aggregated than if it is tightly compacted and dense (Hillel 2008).

Other factors affecting water movement in soil include; soil temperature, microbial activity and ion exchange process (Hillel 2008; Oosterbaan and Nijland 1986). Measurements of saturated hydraulic conductivity are paramount as they could be used for calculating seeping rates of the soil, hence the pond water budget.

No significant relationship have been drawn among the soil microelements and aquaculture production (Kamal et al. 2017), but trace metal toxicity concentrations in pond soils have in a few instances had negative impacts on aquaculture production (Boyd and Tucker 2014).

The soil quality parameters were analyzed on soil samples drawn from ponds in different regions of the country as categorized by the administrative map (TUBS 2012) (Central, Eastern, Northern and Western). This was to assess the possible influence of soil properties on the culture of African catfish and Nile tilapia in the country.

METHODS

Soil samples were collected from the four regions (Central, Eastern, Northern and Western). In each region, five districts were selected for sampling by aid of the World Reference Base for Soil Resources of Ugandan soils which outlines representative soil properties in the different areas of the country. A soil sample was collected from each of six fish farms in each district making a total of 120 soil samples.

Soil samples were collected from one pond on each fish farm which reported by the farmers, to have the most culture problems. The soil sample was comprised of soil taken from five areas within the pond and combined to make a composite sample. The soil sample was then placed in a zip lock bag for transport to the laboratory and dried at 60 ^{o} C in the oven. Soil samples were not kept more than 3 days before drying them. Liming materials used by the farmers also were collected (400 g) and paced in a zip-lock bag for analysis in the laboratory.

The dried soil samples were shipped to the Soil, Forage and Water Testing Laboratory at Auburn University for analyses. The soils were analyzed for soil texture, soil pH, buffer pH, trace metals, total nitrogen, total carbon, and organic matter. Saturated hydraulic conductivity was calculated.

Soil texture was determined using Hydrometer Method (Bouyoucos 1962). Soil pH was analyzed using 1:1 soil to distilled water and buffer pH was 1:1 soil to p-nitrophenol buffer (8.0) which were then ran using LabFit AS-3000 Dual pH analyzer calibrated with buffer 7 and buffer 4.

Total nitrogen, total carbon, and organic matter were determined using Elementar Vario Macro CN Analyzer (Kristen 1979) while saturated hydraulic conductivity was calculated using an online link (http://hydrology1.nmsu.edu/teaching/soil456/soilwater.html) that uses the percentage of sand and clay in a soil sample.

Soil trace metals were determined by inductively Coupled Plasma (ICP) Atomic Emission Spectrometry using a Varian Vista-MPX Radial Spectrometer (Odom and Koné 1997).

Soil pH, total nitrogen, total carbon, organic matter, and saturated hydraulic conductivity results were analyzed using R Version (3.3.3) to put into descriptive statistics. A chi test was performed to test the independence among different regions. SAS Version 9.4 was used to perform the ANOVA test if one of the means of the different soil quality parameters is equal to the other.

Statistical tests could not be conducted on trace metals as it was in range form. Trace metal concentrations were compared to the recommended ranges outlined in Boyd and Tucker (2014). All the water quality tests were compared to the recommended optimum ranges for soils for the culture of Nile tilapia and African catfish (Table 14).

Soil pH and buffer pH results were used to determine the lime requirement (Boyd and Tucker 2014). However, for the soil samples whose soil pH was less than or equal to 4.6, lime requirement was determined by K-bicarbonate method (Han et al. 2014). The lime requirement was given both at a kilogram per hectare and kilogram per pond area basis with consideration of average pond area of 500 m^2.

The different liming materials obtained were analyzed for neutralizing value, fineness value, effective fineness value and effective price as outlined in Boyd and Tucker (2014) and Han et al. (2014). The best liming material was used to calculate the liming rates for ponds.

RESULTS AND DISCUSSION

Most of the farms in the different regions had a sandy clay loam soils except for the Western region which had a sandy loam soil (Table 15). This was in line with a study conducted by Rücker (2005). Although, in aquaculture clay loam soils are preferred (Boyd and Tucker 2014) which were mostly seen in farms in Western region, sandy clay loam soils are acceptable.

The mean soil pH for the different regions were all below the optimum range (Table 16) with the Central region having the lowest average soil pH. The soil pH values in all regions were similar to those previously observed in Bogor (Indonesia) by McNabb et al. (1990) who noted ponds with low pH had low fish production. The percentage soil total nitrogen was optimal for all regions while the percentage total carbon and soil organic matter were with in optimum range for all regions apart from the Western region where the soil quality variables were high. The saturated hydraulic conductivity was higher for the western region compared to other regions (Table 16). The high saturated hydraulic conductivity in the western region is due to the high organic matter in the ponds (Hillel 2008; Oosterbaan and Nijland 1986) and indicated high seepage rates in those soils.

However, there are factors other than the hydraulic conductivity of soil that affect seepage rate. During pond construction, soils are compacted to reduce seepage, and organic matter produced in ponds and added to ponds in manure during aquaculture production tends to fill the interstitial spaces among soils to lessen seepage (Yoo and Boyd 1994). Thus, soil hydraulic conductivity should only be viewed as potential seepage, and soils that have a high potential for seepage should be given special attention for thorough compaction during construction. Of course, with improper construction, a pond constructed on soil with low hydraulic conductivity may seep badly.

A chi square test (Table 16) showed that all regions were independent of each other as p-value was less than $\alpha = 0.05$, df = 3 at 95% confidence interval. The ANOVA output revealed that all the mean concentrations for all soil quality parameters were statistically significant among all the regions (Table 15). Tukey's test (Table 16) showed soil pH and calculated seepage of the Central and the Western region to be statistically different from that of Eastern and Northern regions. For other soil quality parameters, the Western region was statistically different from other regions.

Frequency distribution of soil pH showed that most ponds had a soil pH out of range with the Central and the Western regions having the highest number of ponds with a pH less than 6.5 (Fig. 12). However, none of the soil samples from all regions had a soil pH above the highest recommended soil pH for fish culture.

In most of the ponds, the percentage total carbon content was within the optimal range especially the Central and the Northern regions (Fig. 13). However, the Western region had most of the ponds that were sampled with a high carbon content percentage above the recommended level. This could be to poor soil management practices like high fertilization rates by the manure (Egna and Boyd 1997).

Frequency distribution of the organic matter content in soil samples in the different regions revealed similar trends as the frequency distribution of the percentage soil total carbon with the Northern region having most of it soil samples within the optimal range and the Western region having most of its farms with elevated organic matter content (Fig. 14).

All trace metal concentrations were within the optimal range apart from the copper concentrations where some soil samples were above 2 mg/kg which is the maximum safe concentration for copper in sediment according to Abdul-Wahab and Jupp (2009) (Table 17). However, this reference refers to copper in subtidal, estuarine marine environments and unlikely applies well to aquaculture pond soils. Nevertheless, the Northern and Eastern regions had several soil samples with copper concentration higher than the recommended range reported for estuarine sediment. Copper concentrations above 2 mg/kg in pond soils are fairly common and apparently of no concern (Boyd and Tucker 1998).

Liming requirement results inferred from the soil pH and buffer pH showed that the Central region had the highest number of ponds (> 80%) that required liming and the Northern region the least number of ponds that required liming (60%) (Fig. 15). However, a different trend was shown with the lime requirement of the ponds that required liming with ponds in the Western region having a higher liming requirement 2970 ± 414.42 kg/ha or 743 ± 103.61 kg/pond area (500 m^2) (Table 18). Nevertheless, the Northern region still had the least lime requirement as many of soils there contain limestone.

The neutralizing value and fineness rating are used to assess the quality of agricultural limestone, but only the neutralizing value is used for burnt and hydrated lime as lime is more soluble than agricultural limestone (Boyd and Tucker 2014). Data in Table 19 reveal that the ENV or effective neutralizing value [(NV % × FV %) ÷ 100] of the four available liming products obtained in Uganda ranged from 8.9 to 51.8%. According to Table 19, the agricultural limestone products would be very inefficient for use in ponds, because a huge quantity that would be necessary. The best choice seems to be the Neel Kanth hydrated lime, but it cannot be applied at over 200 kg/ha per application in ponds with fish, because lime can raise pH above the level tolerated by fish (Boyd and Tucker 2014). As a result, liming would have to be done to the pond bottoms between crops and 2 to 3 weeks allowed for the pH to fall after refilling ponds and before stocking fish.

The quality of liming material, and especially of agricultural limestone, in the market in Uganda were extremely substandard. The availability of good quality liming material appears to be a serious limitation to improving pond management in Uganda. Many ponds in the country need to be limed, but the quality of the available products for liming is poor. The cost of agricultural limestone – despite its low quality – is high and if quality is considered, the cost of all the liming materials is outrageous as compared to the costs of these materials in other countries with substantial aquaculture sectors.

The government or private agricultural vendors in Uganda could possibly import liming materials from other countries. It also seems that an effort to improve the quality of the domestic products could be initiated, and possibly there are better liming products which were not located during the present study. Nevertheless, there seems to be good reason to conduct further investigation into this issue.

Liming rates for the best liming material (Neel Kanth hydrated lime class A) were very high for all regions (Table 20). Liming rates followed a similar trend as lime requirement with the Western region having a higher liming rate, followed by the Central region, then the Northern region, and least for the Eastern region.

CONCLUSION

All regions had soil pH below the optimum range for fish culture; hence, liming will be required to increase production, especially since most farmers do not apply fish feed. The Northern region generally had the best soil for pond bottoms and the Western region had the most soils with limitations for use as pond soils. All liming materials were of low quality as indicated by low neutralizing value of agricultural limestone and large particle size distribution in agricultural limestone. All liming materials were incompetent as per the reference of calcium carbonate (NV $\leq$ 50) leading to higher application rates. Of all, the liming materials, the Neel Kanth hydrated lime class A was the best.

However, there were no major setbacks with the pond soils in Uganda apart from the western region. Most of the problems stemmed from pond management, pond siting and little knowledge of farmers on pond bottom treatments. Therefore, rising awareness is needed among the farmers to improve soil productivity hence fish production.

REFERENCES

Abdul-Wahab, S. A. and B. P. Jupp. 2009. Levels of heavy metals in subtidal sediments in the vicinity of thermal power/desalination plants: a case study. Desalination 244: 261–282.

Banerjea, S. M. 1967. Water quality and soil condition of fish ponds in some states of India in relation to fish production. Indian Journal of Fisheries 14:115–144.

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analyses of soils. Agronomy Journal 54:464–465.

Boyd, C. E. 1990. Water Quality in Ponds for Aquaculture. Alabama Agricultural Experiment Station, Alabama, USA.

Boyd, C. E. 1992. Shrimp pond bottom soil and sediment management. In Proceedings of the special session on shrimp farming (pp. 166–181). World Aquaculture Society, Louisiana, USA.

Boyd, C. E. and C. S. Tucker. 1998. Pond Aquaculture Water Quality Management. Kluwer, Massachusetts, USA.

Boyd, C. E. and C. S. Tucker. 2014. Handbook for Aquaculture Water Quality. Craftmaster Printers, Alabama, USA

Boyd, C. E., E. T. Margaret, M. Mahmoud and M. Kiyoshi. 1994. Chemical characteristics of bottom soils from freshwater and brackish water aquaculture ponds. Journal of the World Aquaculture Society 25:517–534.

Coche, A. G. 1994. Aquaculture development and research in sub-Saharan Africa: National Reviews. FAO, Rome, Italy

Das, B., Y. S. Ahmed Khan, K. T. Osman, P. Das and M. N. Amin. 2002. Physico-chemical changes in acid sulfate soil during semi intensive culture of Penaeus monodon fabricius, in cleared mangrove areas of The Chakaria Sundarbans, Bangladesh. Journal of Shellfish Research 21: 267–272.

Egna, H. S., and C. E. Boyd. 1997. Dynamics of Pond Aquaculture. CRC Press, Florida, USA.

Essington, M. E. 2004. Soil and Water Chemistry: An Integrative Approach. CRC Press, Florida, USA.

Han, Y., C. E. Boyd and R. Viriyatum. 2014. A bicarbonate titration method for lime requirement to neutralize exchangeable acidity of pond bottom soils. Aquaculture 434: 282–287.

Hillel, D. 2008. Soil-water dynamics. In Soil in the Environment (pp. 91–101). San Diego: Academic Press. https://doi.org/10.1016/B978-0-12-348536-6.50012-5

Kamal, A. H. M., O. Hishamuddin and C. E Boyd. 2017. Physical and chemical characteristics of soil from tiger shrimp aquaculture ponds at Malacca, Malaysia. Journal of Applied Aquaculture, 30:47–62.

McNabb, C. D., T. R. Batterson, B. J. Premo, C. F. Knud-Hansen, H. M. Eidman, C. K Lin, Jaiyen, J. E. Hanson and Chuenpagdee, R. 1990. Managing fertilizers for fish yield in tropical ponds in Asia. In Proceedings of the Second Asian Fisheries Forum (pp. 17–22). Asian Fisheries Society, Manila, Philippines.

Munsiri, P., C. E. Boyd and B. F. Hajek.1995. Physical and chemical characteristics of bottom soil profiles in ponds at Auburn, Alabama, USA and a proposed system for describing pond soil horizons. Journal of the World Aquaculture Society 26:346–377.

Mwanjalolo Jackson-Gilbert, M., M. T. Makooma, K. P. C. Rao, B. Musana, F. Bernard, B. Leblanc, J. Mkangya, K. Muke, K. Rick, K.C. Luswata, and N. Josephine. 2015. Soil Fertility in relation to Landscape Position and Land Use/Cover Types: A Case Study of the Lake Kivu Pilot Learning Site. Advances in Agriculture 2015:1-8.

Nkonya, E., J. Pender, C. Kaizzi, K. Edward and S. Mugarura. 2005. Policy Options for Increasing Crop Productivity and Reducing Soil Nutrient Depletion and Poverty in Uganda. International Food Policy Research Institute, Washington, USA.

Odom, J. W., and M. B. Koné. 1997. Elemental analysis procedures used by the Auburn University Department of Agronomy and Soils. Auburn University Agricultural Experiment Station, Alabama, USA.

Oosterbaan, R. J. and H. J. Nijland. 1986. Determining the saturated hydraulic conductivity. In: H.P.Ritzema (Ed.), Drainage Principles and Applications. International Institute for Land Reclamation and Improvement (IILRI), Wageningen, Netherlands.

Parr, J. F., R. I. Papendick, S. B.Hornick and R. E. Meyer. 1992. Soil quality: attributes and relationship to alternative and sustainable agriculture. American Journal of Alternative Agriculture, 7: 5-11.

Ray, W.-M. and Y.H. Chien. 1992. Effects of stocking density and aged sediment on tiger prawn, Penaeus monodon, nursery system. Aquaculture, 104:231–248.

Roth, M., J. Cochrane and W. Kisamba-Mugerwa, 1994. Tenure security, credit use, and farm investment in the Rujumbura pilot land registration scheme, Uganda. In Searching for Land Tenure Security in Africa (169–198). The World Bank, Washington, USA

Rukundo, D., P. Nganzi, K. Sneyers, N. Herold and N. Duivenbooden. 2016. Towards Nutrient Cycle Optimization through Synergies with Sustainable Land Management Stakeholders in Pilot Zones of the Fertile Grounds Initiative in Uganda. FGI Report U01, Alterra Wageningen UR, Wageningen, Netherlands.

Sonnenholzner, S., & Boyd, C. E. 2000. Chemical and physical properties of shrimp pond bottom soils in Ecuador. Journal of the World Aquaculture Society 31:358–375.

Ssegane, H., E. W. Tollner, and K. Veverica. 2012. Geospatial Modeling of Site Suitability for Pond-Based Tilapia and Clarias Farming in Uganda. Journal of Applied Aquaculture 24:147–169.

Yoo, K. H. and C. E. Boyd. 1994. Hydrology and Water Supply for Pond Aquaculture. Chapman and Hall, New York, USA.

Table 14: Soil chemical parameters and their optimal range for aquaculture production according to Boyd & Tucker, (2014).

Soil parameters	Optimum range
Soil pH	6.5 – 8.5
Total Carbon (%)	0.5 – 2.5%
Organic matter (%)	1 - 3%

Table 15: Frequency distribution of soil textural classes of soil samples from different regions and their content

Soil Textural Class	Central	Eastern	Northern	Western
Sandy loam	9	6	3	11
Sandy clay loam	18	14	20	6
Sandy clay	1	6	3	1
Clay	1	-	2	2
Clay Loam	-	4	2	9
Loam	1	-	-	1
Sand (%)	67.4 ± 14.80 (47.5 – 85.0)	63.0 ± 15.08 (32.5 – 85.0)	65.3 ± 12.73 (33.1 – 82.5)	63.3 ± 17.51 (31.9 – 85.0)
Clay (%)	24.5 ± 7.81 (0.0 – 43.1)	27.8 ± 9.28 (13.8 – 46.9)	29.4 ± 9.92 (16.3 – 55.0)	24.6 ± 9.61 (0.0 – 32.5)
Silt (%)	8.1 ± 9.49 (15.0 – 50.0)	9.2 ± 9.00 (0.0 – 30.0)	5.4 ± 5.31 (0.0 – 18.8)	12.2 ± 9.98 (15.0 – 50.0)

Table 16: Mean concentrations of the different soil quality parameters in the different regions. Means were tested for independence using Chi Square test. Means indicted by * were all different from each other (P-value = 0.05). Means are tested for difference by Tukey's Studentized Range (HSD) test; homogeneity of variances was tested by F-statistic. Means indicated by the same letter in a column do not differ (P-value = 0.05) according to HSD test.

Soil parameter	Region			
	Central	Eastern	Northern	Western
Soil pH	$5.3\pm0.11^{a*}$ (4.3-6.6)	$6.3\pm0.16^{b*}$ (4.7-7.8)	$6.4\pm0.19^{b*}$ (4.5-8.3)	$5.5\pm0.14^{a*}$ (4.6-7.4)
% Total Nitrogen	$0.1\pm0.01^{a*}$ (0.0-0.2)	$0.2\pm0.02^{a*}$ (0.0-0.5)	$0.1\pm0.01^{a*}$ (0.0-0.3)	$0.5\pm0.10^{b*}$ (0.0-2.1)
% Total Carbon	$1.2\pm0.13^{a*}$ (0.2-2.4)	$1.7\pm0.21^{a*}$ (0.4-4.5)	$1.2\pm0.11^{a*}$ (0.1-3.0)	$6.4\pm1.38^{b*}$ (0.5-30.5)
% Organic matter	$2.1\pm0.23^{a*}$ (0.4-4.2)	$2.9\pm0.37^{a*}$ (0.6-7.7)	$2.0\pm0.18^{a*}$ (0.2-5.2)	$10.9\pm2.38^{b*}$ (0.9-52.5)
Saturated hydraulic conductivity (cm/hr)	$0.6\pm0.07^{a*}$ (0.2-1.3)	$0.5\pm0.08^{a*}$ (0.2-1.6)	$0.4\pm0.05^{ab*}$ (0.1-1.1)	$0.8\pm0.13^{b*}$ (0.1-1.3)

Table 17: Trace metal concentration ranges in the soil samples taken from the different regions

Element (mg/kg)	Central	Eastern	Northern	Western
Al	18.0 – 295.0	19.0 – 350.0	39.0 – 903.0	3.0 – 1153.0
As	< 0.1	< 0.1	< 0.1	< 0.1
B	0.3 – 1.7	0.3 – 2.3	0.3 – 2.7	0.4 – 2.1
Ba	1.4 – 11.2	2.0 – 10.4	0.8 – 7.4	1.2 – 13.0
Ca	104.0 – 1930.0	311.0 – 3299.0	527.0 – 3161.0	457.0 – 3146.0
Cd	< 0.1	< 0.1	< 0.1	< 0.1
Cr	< 0.1	< 0.1	< 0.1	< 0.1
Cu	0.7 – 3.7	0.2 – 11.5	0.3 – 11.5	0.0 – 4.8
Fe	51.0 – 470.0	6.0 – 415.0	7.0 – 847.0	3.0 – 591.0
K	18.0 – 136.0	26.0 – 160.0	18.0 – 209.0	26.0 – 126.0
Mg	40.0 – 596.0	100.0 – 715.0	112.0 – 667.0	123.0 – 1132.0
Mn	10.0 – 279.0	3.0 – 295.0	8.0 – 225.0	4.0 – 336.0
Na	38.0 – 184.0	45.0 – 192.0	55.0 – 298.0	40.0 – 324.0
Ni	< 0.1	< 0.1	< 0.1	< 0.1
P	< 0.1 – 22.0	< 0.1 – 62.0	< 0.1 – 26.0	< 0.1 – 372.0
Pb	< 0.1	< 0.1	< 0.1	< 0.1
Zn	0.6 – 16.5	0.5 – 7.4	0.7 – 14.0	0.2 – 16.0

Table 18: Liming requirement in the different regions

Liming requirement	Central	Eastern	Northern	Western
Lime requirement (kg/ha)	1420 ± 259.79 (91 – 4086)	749 ± 151.44 (126 – 1512)	829 ± 274.42 (91 – 3528)	2970 ± 414.42 (272– 5400)
Lime requirement (per average pond)	355 ± 64.95 (23 – 1022)	187 ± 37.86 (32 – 378)	207 ± 68.60 (23 – 882)	743 ± 103.61 (68 – 1350)

Table 19: Liming materials with their liming properties and prices

Type of liming material	Neutralizing value (NV) (%)	Fineness value (FV) (%)	Effective neutralizing value (ENV) (%)	Price ($/ton)	Price ($/ton of effective lime)
Grey lime	22.0	46.1	10.1	302	2980
Neel kanth hydrated lime class A	51.8		51.8	504	973
Stock feed agricultural lime	35.6	25.0	8.9	252	2833
Tororo hydrated lime	38.7		38.7	302	780

Table 20: Liming rates for the different regions using Neel kanth hydrated lime class A

Region	Central	Eastern	Northern	Western
Liming rate (kg/ha)	2741	1446	1600	5734
Lime rate (kg/ pond area)	685	362	400	1433

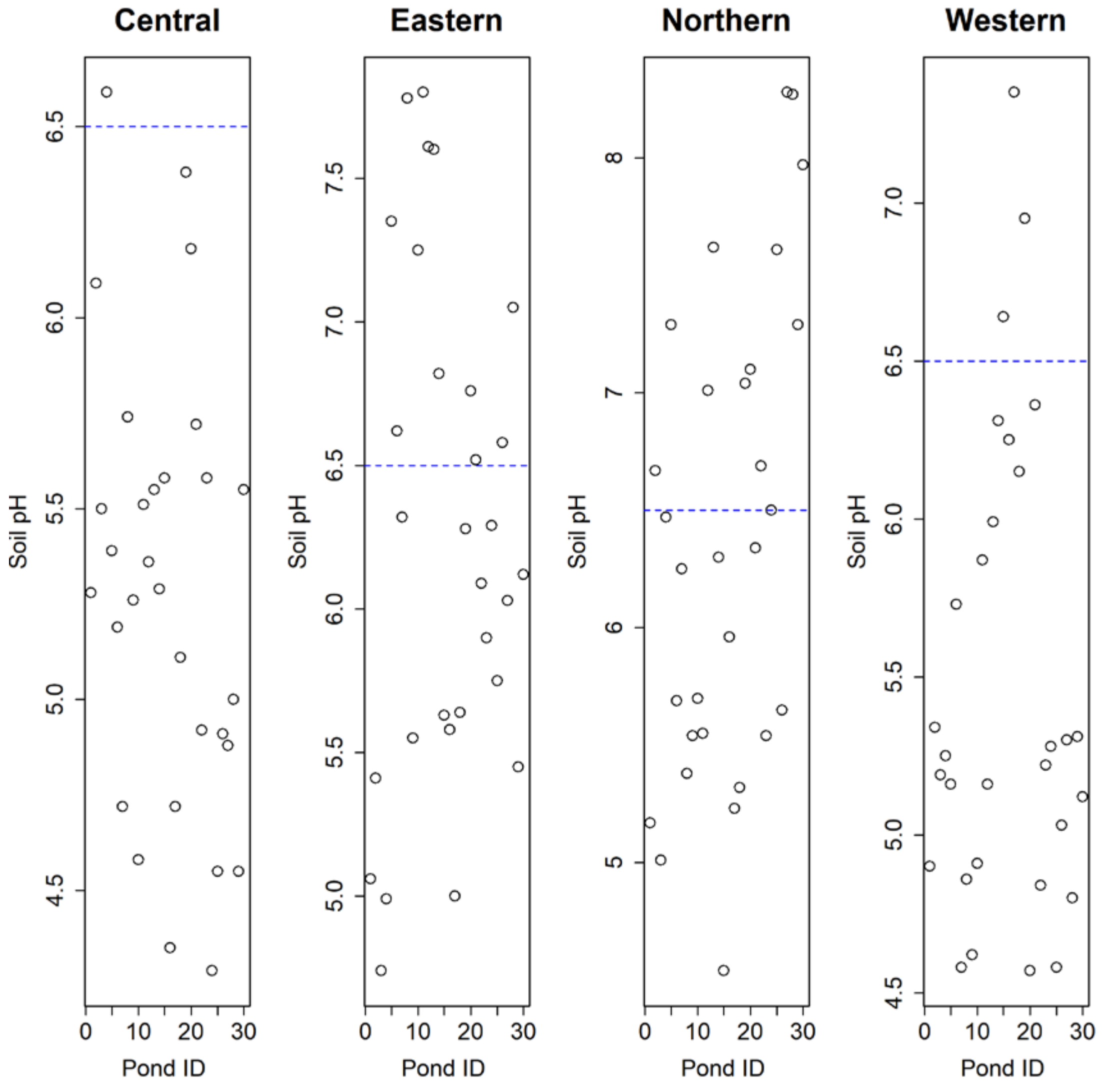


Figure 13: Frequency distribution of soil samples for soil pH in different regions

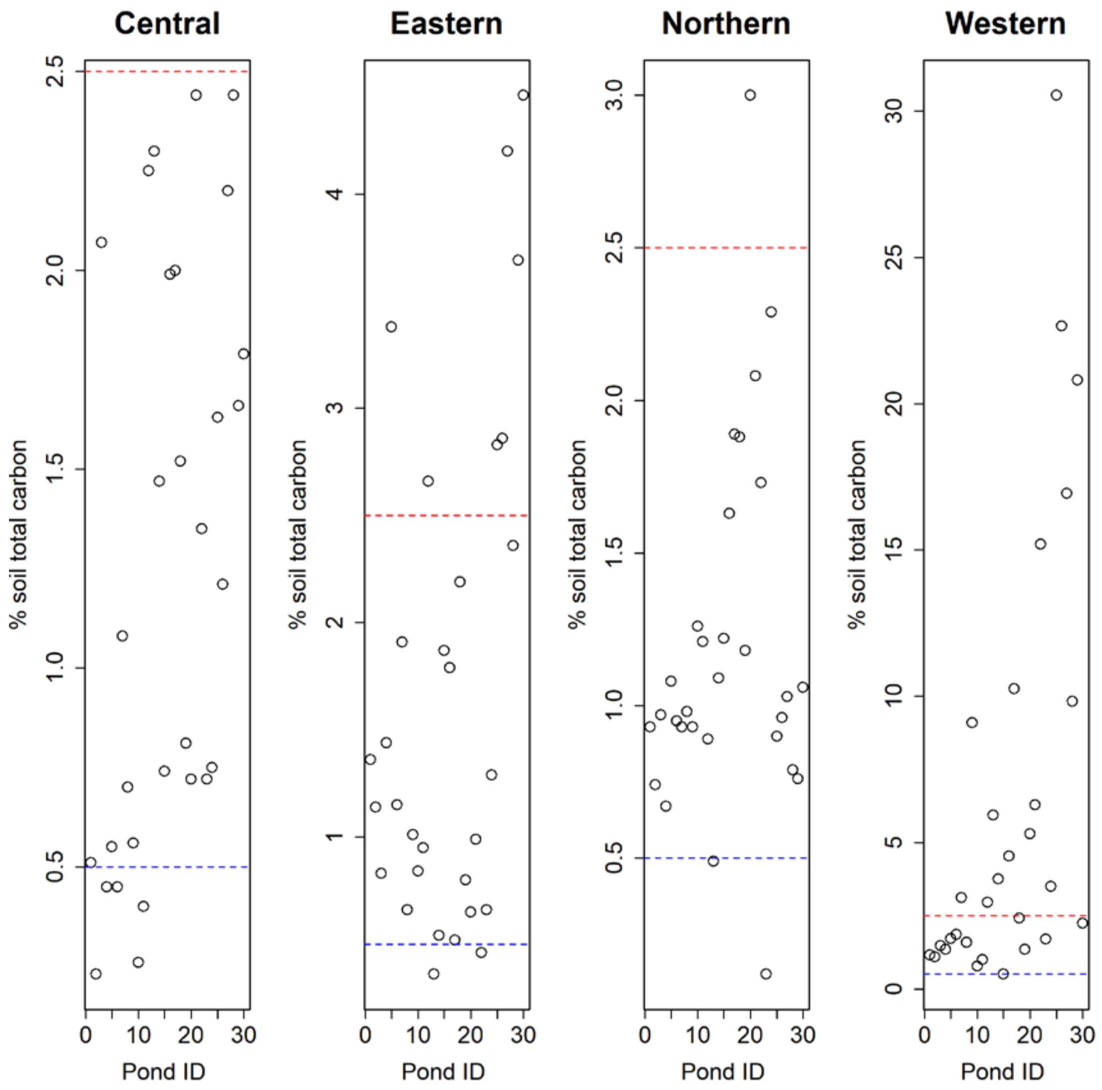


Figure 14: Frequency distribution of soil samples for total organic carbon in different regions

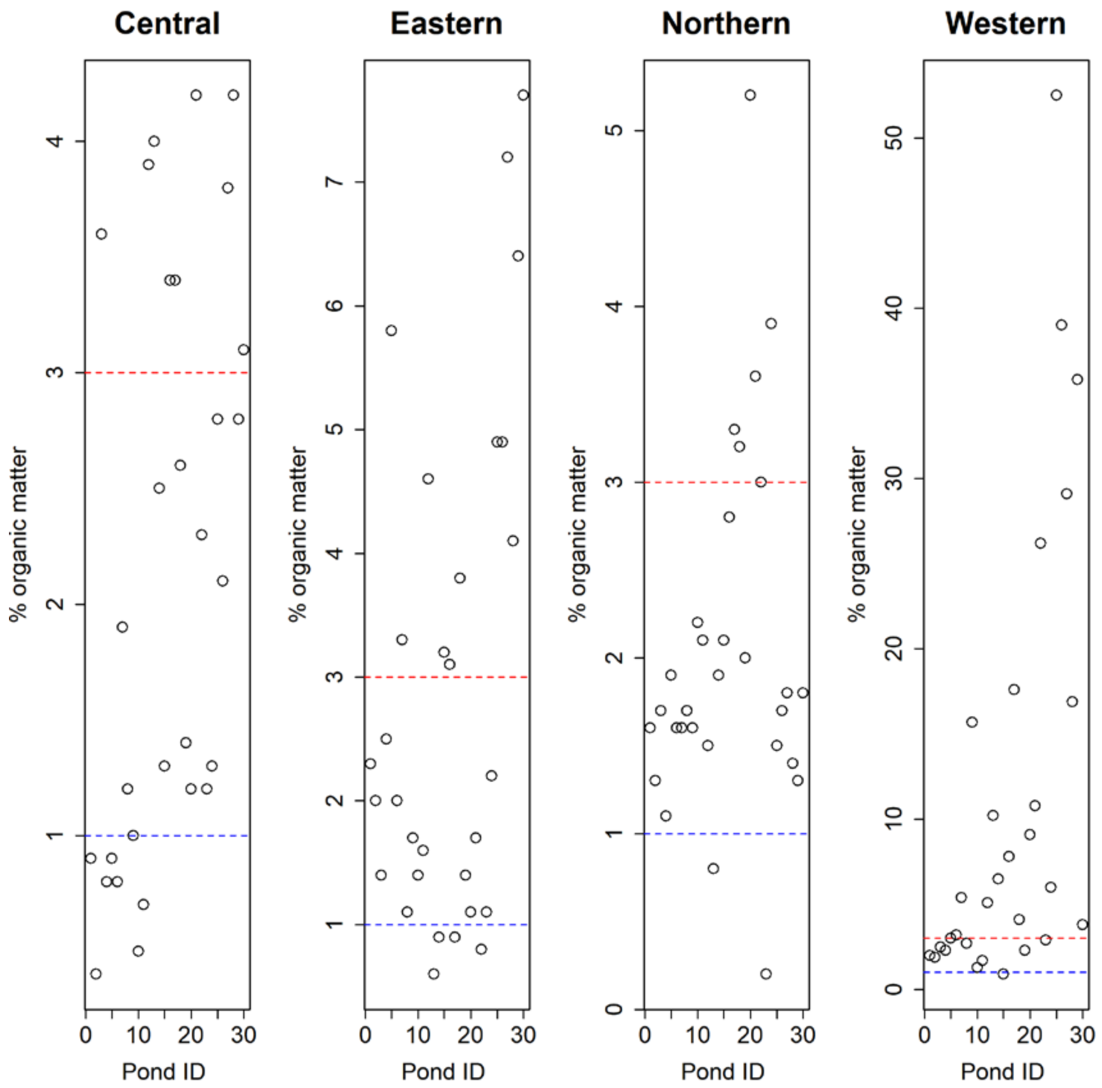


Figure 15: Frequency distribution of soil samples for organic matter in different regions

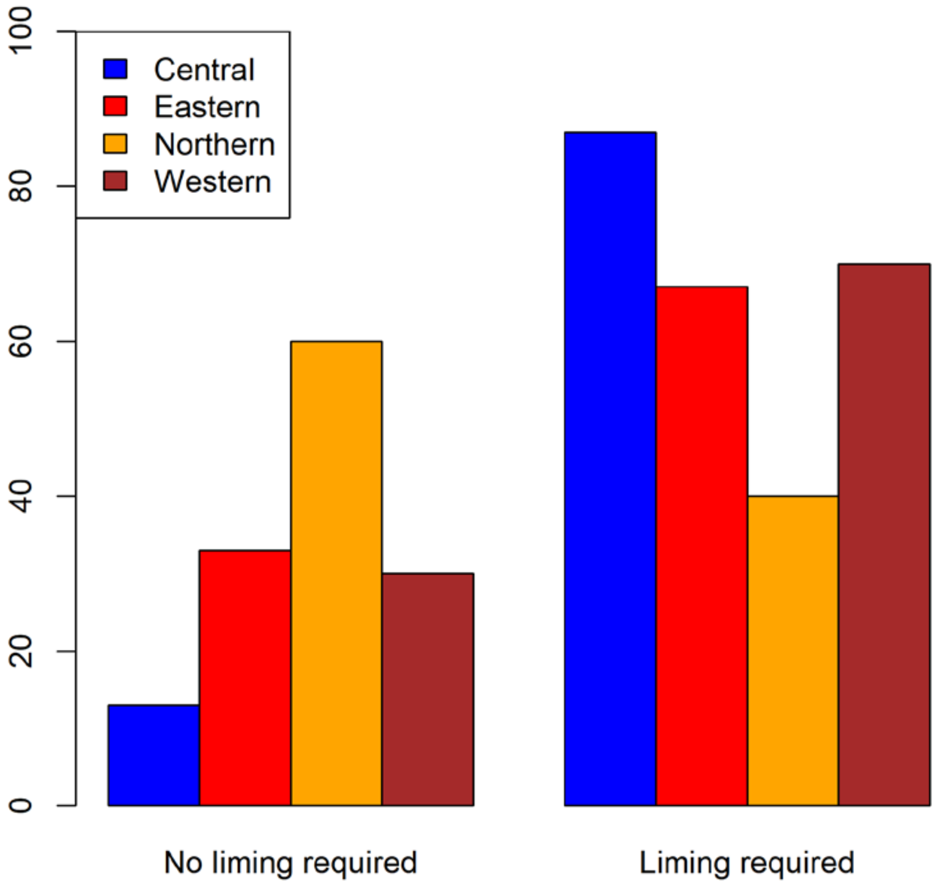


Figure 16: Percentage frequency of the ponds that needed liming and those that did not in the different regions

WATER QUALITY AND POND BOTTOM MANAGEMENT RECOMMENDATION FOR TILAPIA AND AFRICAN CATFISH CULTURE IN UGANDA

APPENDIX

A list of water quality management procedures for use in pond culture of tilapia and African catfish are provided below;

Tilapia

1. The water source for the pond such as a well or stream or water from the pond that is filled by runoff should be analyzed. The minimum analysis would include: pH, total alkalinity, and electric conductivity. A complete analysis including trace elements would be desirable for a better understanding of the water quality. However, a survey of water sources and ponds suggested that low pH and alkalinity were the usual problems.
2. The area around the water source and watershed of the pond should be examined for sources of erosion that could create turbidity in the ponds or for pollution that could be harmful to fish. Highly polluted sites should be neglected for building new ponds. Erosion on watersheds usually can be prevented by establishing grass cover.

3. Many ponds in Uganda have acidic bottom soils and lower alkalinity than necessary for good fish production. Although this limitation is easily corrected by liming, there does not seem to be a source of good quality liming material. The best product located (Neel Kanth hydrated lime) had an effective neutralizing value of only 50% of best quality agricultural limestone.

4. Hydrated lime at applications above 100 kg/ha of high quality product will raise pond pH enough to sometimes kill fish. Thus, the hydrated lime product would have to be applied to the pond bottom between crops when there are no fish in the pond. The pond should be allowed to stand after refilling until the pH is below 8.5. This usually will take about 2-3 weeks, but if the pond owner has a pH meter or kit, the pH can be measured and possibly allow less fallow time.

5. The recommended rates for the use of the Neel Kanth hydrated lime for ponds of different alkalinities follow:

Alkalinity (mg/L)	Neel Kanth hydrated lime (kg/ha)
Below 10	8,000
10 - 20	6,000
20 - 40	4,000
Above 40	0

6. Farmers should urge the government to either establish some standards for liming materials or import liming materials of better quality than the domestic products. Note: Possibly there are other sources of liming materials of better quality that were overlooked in the study.

7. If pH is below 4.5 in pond water, there will be not alkalinity. The best option usually is to abandon such sites. But, if desired, high rates of liming can be tried.

8. Liming material should be spread uniformly over ponds. It should be applied at least 2 weeks before phosphate fertilizer is applied to ponds. Liming material can be applied before, at the same time, or soon after the first application of organic fertilizer.

9. Alkalinity should be measured annually in ponds and liming materials re-applied in accordance with measured alkalinity (see #5).

10. In ponds where feed will not be applied, fertilizers are necessary to increase fish production. Organic fertilizers such as fresh-cut grass, leaves, livestock manure, or chicken manure may be used. Alternatively, chemical fertilizers such as urea and triple superphosphate may be used to fertilize ponds.

11. It is difficult to establish the maximum safe amount of organic fertilizers

for a pond, because organic fertilizers vary in water and nutrient content. The maximum rate probably should not exceed 200 kg/ha/day for grasses, hay and leaves or 100 kg/ha/day for animal manure. Of course, organic fertilizers may be applied daily, every other day, three times weekly, or even weekly. But, organic matter uses oxygen as it decomposes. <u>Warning</u>: Excessive organic fertilizer application can lead to dissolved oxygen depletion and fish kills may result.

12. Chemical fertilizers have a known nutrient content making the application rate easier to determine. The most common chemical fertilizers used in ponds are urea and triple super phosphate. Satisfactory application rates usually are 15 – 20 kg/ha triple superphosphate.

13. Fertilizers should be applied at 1-2-week intervals until a good phytoplankton bloom is established. Afterwards, fertilizers should be applied as necessary to maintain the phytoplankton bloom.

14. The abundance of phytoplankton typically is gauged by water clarity. In a properly fertilized pond for tilapia, underwater visibility usually will be around 30 – 40 cm.

15. The underwater visibility can be checked with a ruler or other measuring stick to which a white object is attached at the end. The measuring device is extended vertically downward into the water until it first disappears from sight. The depth of underwater visibility is read from the ruler at the water surface. <u>Note</u>: It is possible to

purchase a Secchi disk for measuring water clarity. This device is a weighted 20-cm diameter disk with calibrated line attached. It is lowered into the water and the depth at which it disappears is recorded.

16. Fertilizers should be re-applied when the underwater visibility is less than 45 cm. Do not wait until the water clears more before making another fertilizer application. A high abundance of phytoplankton must be maintained to support fish production.

17. Another reason for maintaining a good phytoplankton bloom is for underwater weed control. In clean ponds, dense infestations of underwater plants that are undesirable in fish ponds may grow profusely.

18. The fertilizers for applying in a pond should be weighed and placed in a large pail. The pail should be filled with water and 15 – 30 minutes allowed for fertilizers to dissolve. The water and fertilizer should be stirred vigorously for 2 – 3 minutes after which the mixture should be splashed over the pond surface.

19. Dense phytoplankton bloom (underwater visibility less than 10 – 15 cm) should be avoided because too much phytoplankton may result in nighttime dissolved oxygen depletion and fish mortality.

20. Farmers may choose to feed tilapia in ponds rather than to fertilize ponds to increase tilapia production.

21. In ponds with feeding, it still is desirable to apply agricultural limestone to ponds with low alkalinity water.

22. Pelleted feed should be applied one or two times daily. Usually, it is more effective to fish growth the daily feed allowance is offered in two applications rather than a single application.

23. The feed application rate should be gradually increased as the fish grow. Usually, early in the grow-out period, feed is applied at 3- 4% of the estimated weight of fish in the pond. Later, the feeding rate may be reduced to 2.5% or even 2 % of fish weight in ponds.

24. Water from feeding enrich ponds with nutrients leading to phytoplankton blooms. Too much phytoplankton can cause dissolved oxygen depletion especially at night.

25. Tilapia are hardy and withstand low dissolved oxygen concentration well. But, low dissolved oxygen concentration can kill them.

26. To minimize the possibility of fish kills from oxygen depletion, daily feed input probably should not exceed 75 kg/ha/day, but to be safe, a limit of 50 kg/ha/day is prudent.

27. Ammonia can be toxic to fish, but if dissolved oxygen concentration is adequate in ponds with feeding, ammonia toxicity to tilapia is seldom seen.

28. Some fish farmers apply bacterial products (usually living cultures of bacteria) often called probiotics to ponds for removing ammonia and improving other aspects of water quality. There is no evidence from research that probiotics are effective aspects of water quality.

29. Water exchange may be used in pond with feeding to increase the dissolved oxygen supply and allow greater feed input and fish production. Rates of water exchange from 25% to several hundred percentage of pond volume per day have been used, but there is no reliable method for determining the acceptable feeding rate at a water exchange rate other than by monitoring the dissolved oxygen concentration.

30. Another way to increase fish production in ponds with feeding is to apply mechanical aeration. The relationship between aeration rate and fish production is well established.

31. Several kinds of aerators are available, but paddlewheel aerators are most commonly used in fish ponds. Both electric and diesel-powered devices are available.

32. The general "rule of thumb" for aeration is to install one horse power (hp) of aeration for 500 kg of fish above 2,000 kg/ha. For example, to produce 5,000 kg/ha of fish, the calculation of aeration requirement follows:

33. 5,000 kg fish/ha - 2,000 kg fish/ha = 3000 kg fish/ha 3,000 kg fish/ha/500 kg fish/ha/hp =

6 hp aerators/ha

34. Aerators should be placed in water of 0.75 m or more in depth. When multiple aerators are installed in a pond, they usually are positioned to cause a circular water flow pattern.

35. Ponds usually have high dissolved oxygen concentration during the day, and aerators can be turned off. The critical period for aeration in fish ponds typically is at night.

36. Ammonia often accumulates in ponds with feeding and aeration because of large feed input. Ammonia is toxic to fish, but tilapia is quite tolerant to ammonia. Unless total ammonia nitrogen concentrations consistently are 5 – 10 mg/l, ammonia stress or toxicity would not be expected unless pH in pond water was above 9. Test kits can be purchased for measuring pH and ammonia, but ammonia and pH monitoring in tilapia ponds is not usually necessary.

37. The only effective way of reducing ammonia concentrations in ponds (aside from lowering feed inputs which is not desirable and does not provide immediate ammonia reduction) is to flush water through ponds.

African Catfish

38. This air-breathing species is very tolerant to low dissolved oxygen and poor water quality conditions. As a result, little water quality management is necessary.

39. The only recommendation is to apply liming materials to acidic, low alkalinity ponds. The instructions for liming tilapia ponds may be followed.