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Potential Influence of Climate on Ugandan Aquaculture

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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 temperature trend for all regions except the Eastern region (p = 0.4222, tau b = 0.027) showed increase of aquaculture production the future. The 12-month SPI showed all regions having near-normal SPI (-0.99 to 0.99) but with the Central region having the 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 lower evaporation rates compared to others. Overall, potential climate effects on aquaculture are not a major issue in the country if climate smart strategies are adopted.

Keywords: Climate variability, aquaculture, Uganda

Introduction

The World Meteorological Organization [1] 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 [2,3] which in turn affects fish productivity [4].

Fish are poikilothermic with each species having a specific temperature range. Temperatures outside the optimum range cause poor growth, reproduction complications, and increases sensitivity to parasite and disease infestation [5]. Extended periods with the temperatures outside the optimal range for a species result in it being unsuitable for aquaculture at a location.

Boyd [6] 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 [4]. Yoo and Boyd [7] expressed the importance of precipitation excess and deficit in fisheries and aquaculture. Nicholson [8] puts Uganda among the countries with frequent occurrence of drought and plagued with floods which have devasting effects on livelihoods, mainly if both occur in the same year [9].

Droughts, floods, landslides, windstorms, and hailstorms also have been reported to contribute well over 70% of the natural disasters, destroying an average of 800,000 hectares of crops valued at $ 33 million annually [10]. Such events could also have negative impacts on pond fish culture as well. Heavy precipitation excess can lead to large volumes of runoff containing suspended soil particles. The suspended matter increases pond turbidity, which in turn lowers light availability for primary production, and suspended particles smother benthic organisms and settle on fish eggs [5]. A precipitation deficit leads to an excessive decrease in pond water levels that causes crowding, destructs spawning areas and benthic food availability, favors the growth of pondweeds, and increases the concentration of dissolved substances [7, 5].

Even though Uganda has a tropical climate, fluctuations in 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 [1]. In Uganda, climate variability is mainly the result of remote forcing by the 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 [11].

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 [12, 13].

Aquaculture in Uganda depends on rainfall, streams, and wells for water during production in outdoor ponds [14, 5]. 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.

Several studies have been carried out on the effects of climate variability on agriculture and fisheries in Uganda. For example, Phillips and McIntyre [11] and Timmers [15] focused on livestock and crops, and Vianny et al. [16] and Musinguzi et al. [17] discussed climate variability effects on the capture fisheries sector. Although much general information is available on agroclimatology, there are few works on fisheries production. Szumiec [18] and Kapetsky [4] discussed the effects of climate on aquaculture, but they did not address the practical use of climate variability in aquaculture. The review [5] focused on the possible use of climate information in aquaculture, but this work was mostly about principles related to climate and aquaculture.

The present study was conducted to consider the practical use of climate variability information in the planning of aquaculture production cycles in Uganda. The specific 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.

Methods

Uganda is centered at 1.3733° N, 32.2903° E in East Africa. It has a tropical climate, with air temperature ranging from 16 ° C to 30 ° 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 [19,20].

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. 1). The Central and Western region has a bimodal rainfall while the Northern region has unimodal rainfall and Eastern region has intermediate rainfall [21,11].

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 the Ugandan climate [22]. Means, minimum and maximum of temperatures, annual rainfall totals, and evapotranspiration were computed and compared among the different regions using ANOVA test using Statistical Analysis System (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. [23] 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 [14, 24). Mean temperatures were further compared to the optimum range of African catfish and Nile tilapia of 26 - 32 °C [14]. Deviations from the long-term mean were also computed to visualize how the temperature fluctuates over the years, and these were standardized to allow comparison among the regions [25].

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 [26,7]. The SPI was also noted to be more suitable for monitoring rainfall patterns, especially droughts than other indices [27,28].

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 [28]. The 12-month SPI reflects long-term precipitation patterns and is tied to stream flows, reservoir levels, and even groundwater levels at longer timescales [30]. The SPI of the different regions were further compared.

Potential evapotranspiration (PET) was computed using the Blaney-Criddle model adopted from Ssegane, et al. [31] as shown below;

PET = p [(0.46 x T_m + 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; T_m = the mean temperature. The mean temperature was calculated by the usual method of averaging the maximum and minimum temperatures in the region.

Water budgets for the different regions were determined by subtracting the outflows (evapotranspiration and seepage) from the inflows (precipitation) [32]. This allows water requirement (WR) to be estimated for production cycles for the different regions as shown below;

WR = [(P x 1.1) – (PET x 1.3) – S], where P is mean monthly precipitation, PET is monthly potential evapotranspiration, S is mean seepage of 80 mm/month and the factors 1.1 and 1.3 were to compensate the amount of rain that drain into the pond through the pond dikes and the higher evaporation from free surfaces for small open ponds respectively.

Furthermore, estimated monthly required inflows in liters per minute per acre farm were calculated with assumptions adopted from Yoo and Boyd [7].

Results and Discussion

Mean temperature, mean annual rainfall, and mean potential evapotranspiration were higher for the Northern and Eastern region than the Central and Western region (Table 1). This agreed with an earlier climatic assessment by Phillips and McIntyre [11]. Higher mean rainfall for the Eastern region can be attributed to Lakes Victoria and Kyoga and mountain Elgon's influence [33]. 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 by orographic lifting, especially when there is a surge of the moist Congo air mass converging with the prevailing synoptic easterlies during July-August [34]. The mean evapotranspiration rates were highest in the Eastern region, then the Northern region, followed by the Central region and least in the Western region.

There were significant differences in the mean temperature ($F= 836.06$, $p < 0.0001$, $df = 3$, at $p = 0.05$), mean annual rainfall ($F = 41.66$, $p < 0.0001$, $df = 3$, at $p = 0.05$), and mean potential evapotranspiration ($F= 11.43$, $p < 0.0001$, $df = 3$, at $p = 0.05$) among the regions (Table 1). The post-hoc multiple comparison test by Tukey's Studentized Range (HSD) showed mean temperatures, and mean potential evapotranspiration were different among regions. Mean annual rainfall was also different among regions apart from that of Eastern and Central region, which were similar (Table 1). This was in line with data reported by Nicholson [12] 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 a mean temperature below the optimum range of 26 ° C to 32 ° C [35] apart from the Eastern region over the years (Fig. 2). Although the temperatures were out of the optimum range for the culture of African catfish and Nile tilapia, they were not outside the range tolerated by these species, which has a lower limit of 20 ° C [35,14] apart for the Western region (Fig. 2). The lower temperature in the Western region possibly could allow a culture of cool-water fish species such as trout in some areas.

Seasonal Mann Kendall output showed a positive increasing trend in temperatures among the regions apart from the Eastern region (Table 2). This implies increasing temperatures in those regions which will favor aquaculture production in the future. The strength of the slope was weak for the regions that had the trend as the temperature varied between 0.002 ° C/yr. for the Eastern region to 0.058 ° C/yr. for the Northern region (Table 2).

Deviations from the long-term mean (Fig. 3) showed that there were high temperature fluctuations in the Western regions than other regions over the years. However, the fluctuations were within 6 ° C for all regions, which was noted to be suitable for young fish but not larger fish [35]. Furthermore, Szumiec [18] observed that a difference of 1 ° 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. [29] (Table 2). Eastern region and Central region also were near normal although Central region had the highest SPI (Table 2). The classifications were made, according to McKee et al. [29]. 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. 4). 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 [36]. 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.

The Central region had the least water requirement compared to other regions (Fig. 5), which were 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 the dry season [37].

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 [38]. 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 the December-February period, which is the longest dry season (Table 3). 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. [39] and Funk [40].

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 [34,39]. The high-water requirement in the northern zone 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 [9].

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 [32].

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 are 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 the period of water deficit coincide with the 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.

Data Availability

Data will be available on the Harvard dataverse, and it could be assessed using the title of the manuscript.

Conflicts of Interest

No conflicts exist. Submitting authors are responsible for co-authors declaring their interests.

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Table 1. 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 ($^{\circ}$C)	17.80	22.60	19.90	19.30
Maximum Temperature ($^{\circ}$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}
Mean Potential Evapotranspiration (mm/month)	151.2 ± 4.17^{a}	160.0 ± 4.86^{bc}	156.6 ± 4.80^{ac}	145.3 ± 3.94^{b}

Table 2. 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 3. Monthly water requirement (inflows) in liters per minute (lpm)/ 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

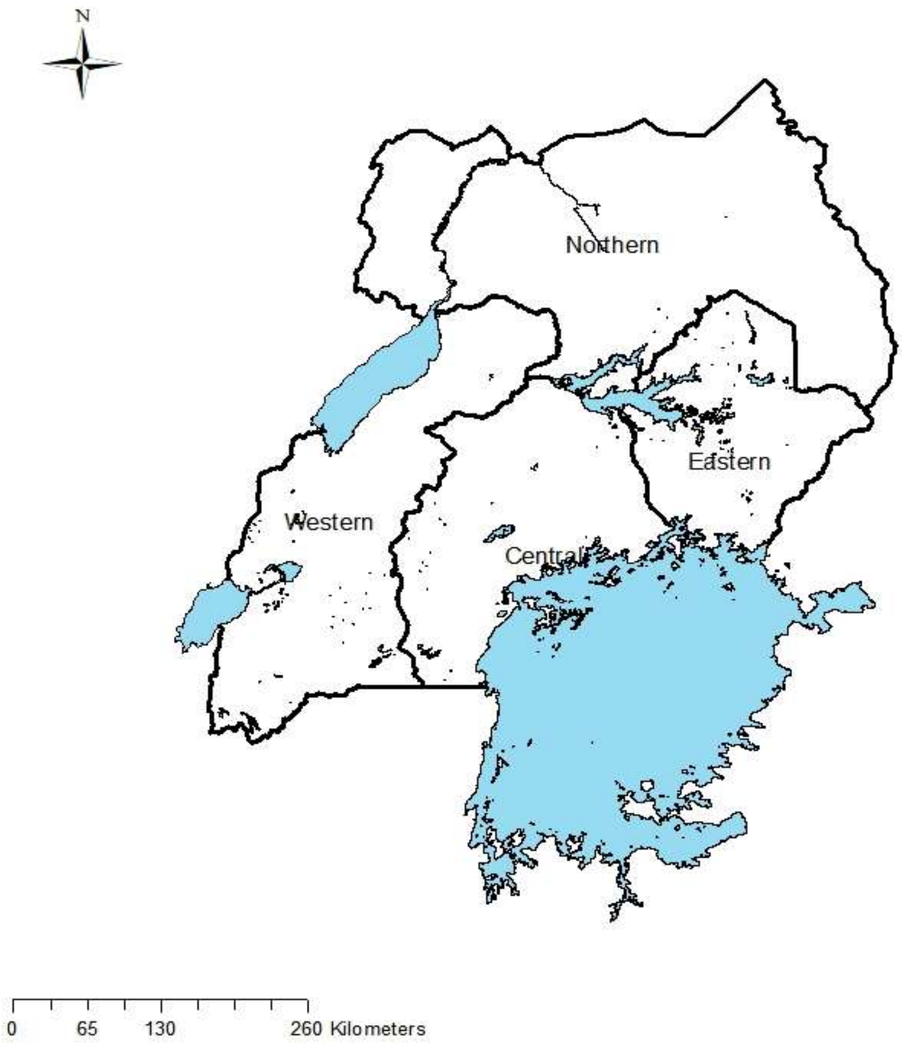

Figure 1. Administrative map of Uganda showing the different regions

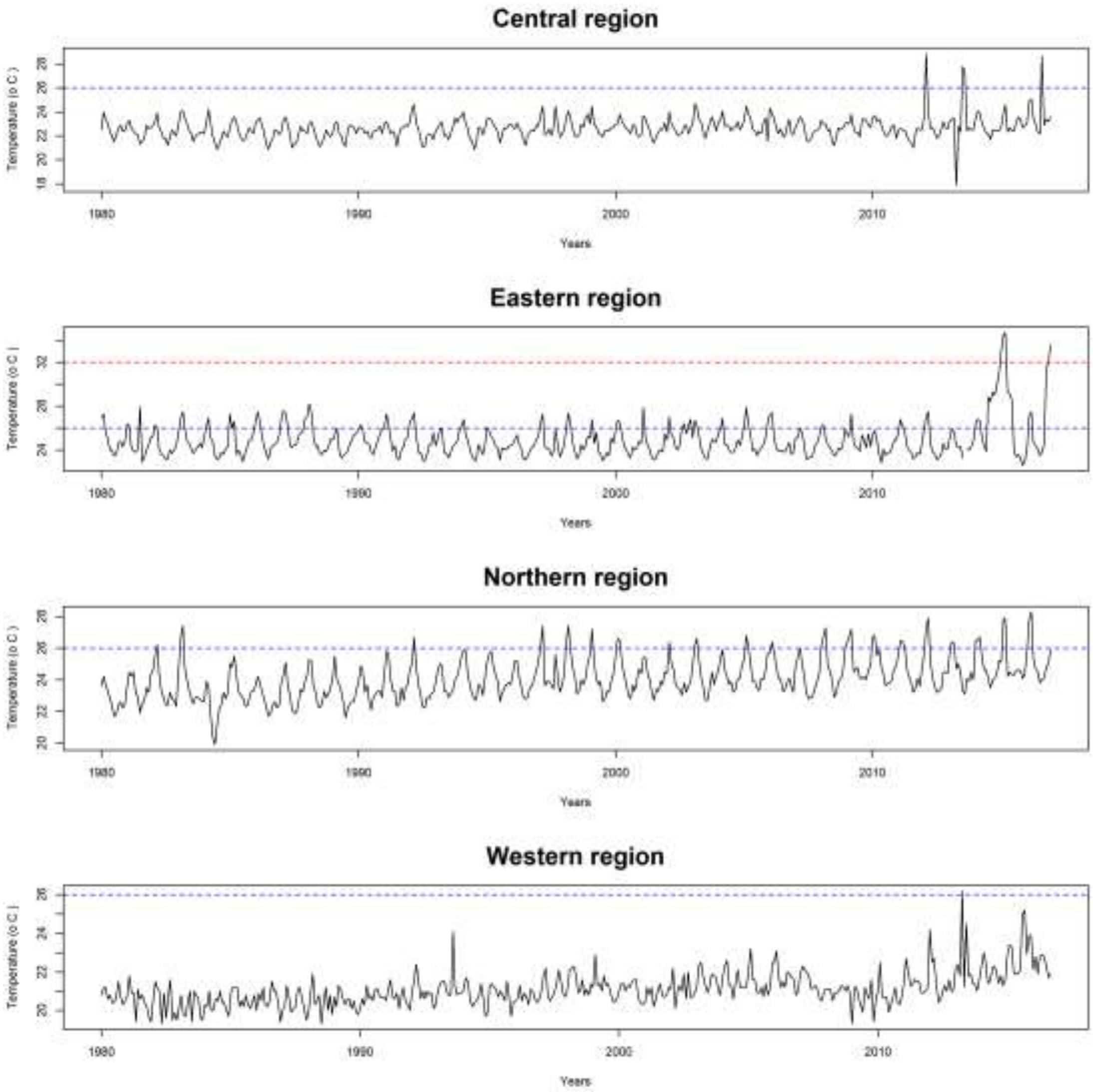

Figure 2. Mean Temperature for different regions for period 1980-2016 and how they relate with the optimum temperature range for culture of Nile tilapia and African catfish (26- 32 ^{0}C)

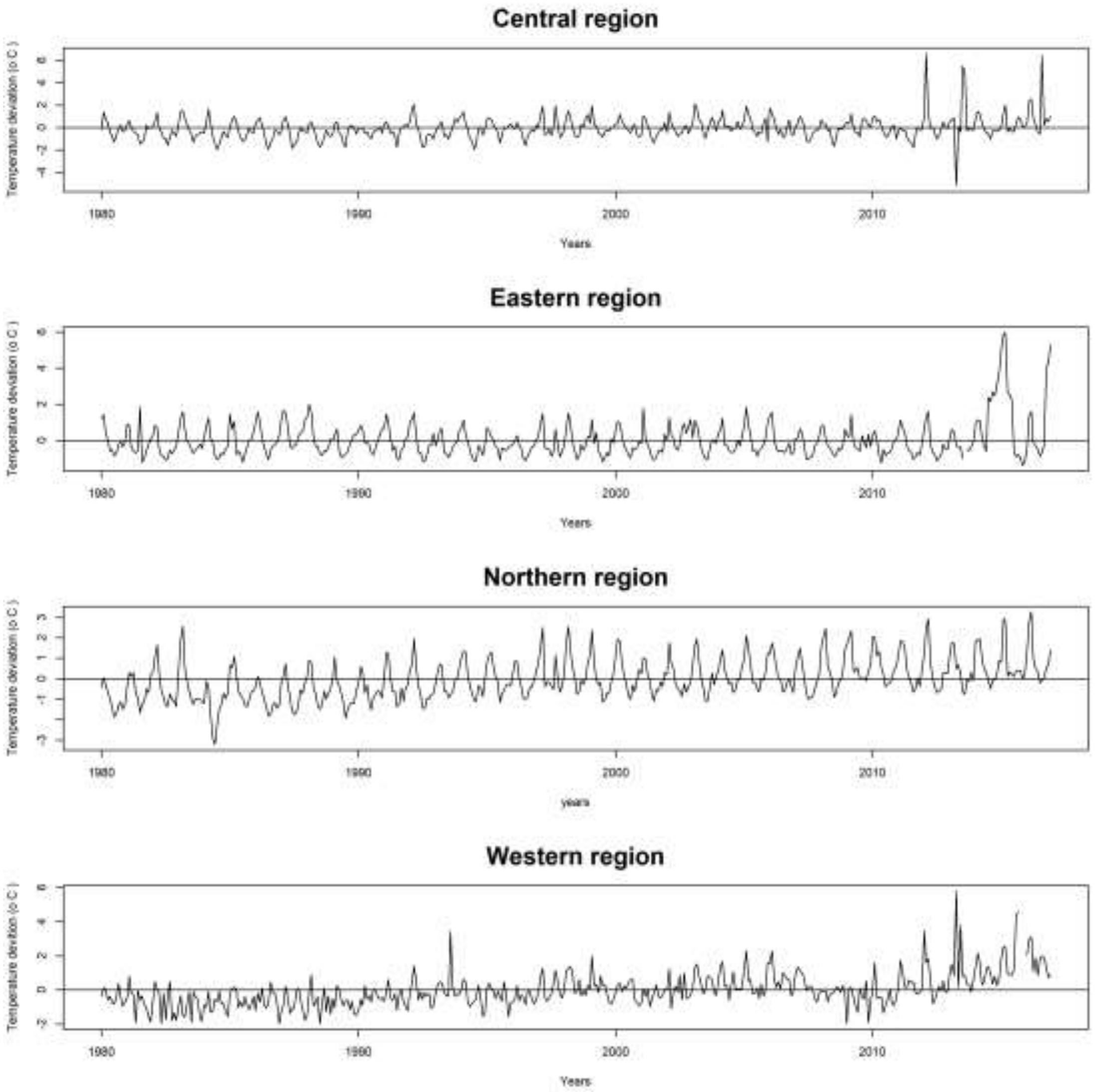

Figure 3. Temperature deviations from the long term mean for the different regions for a period 1980-2016

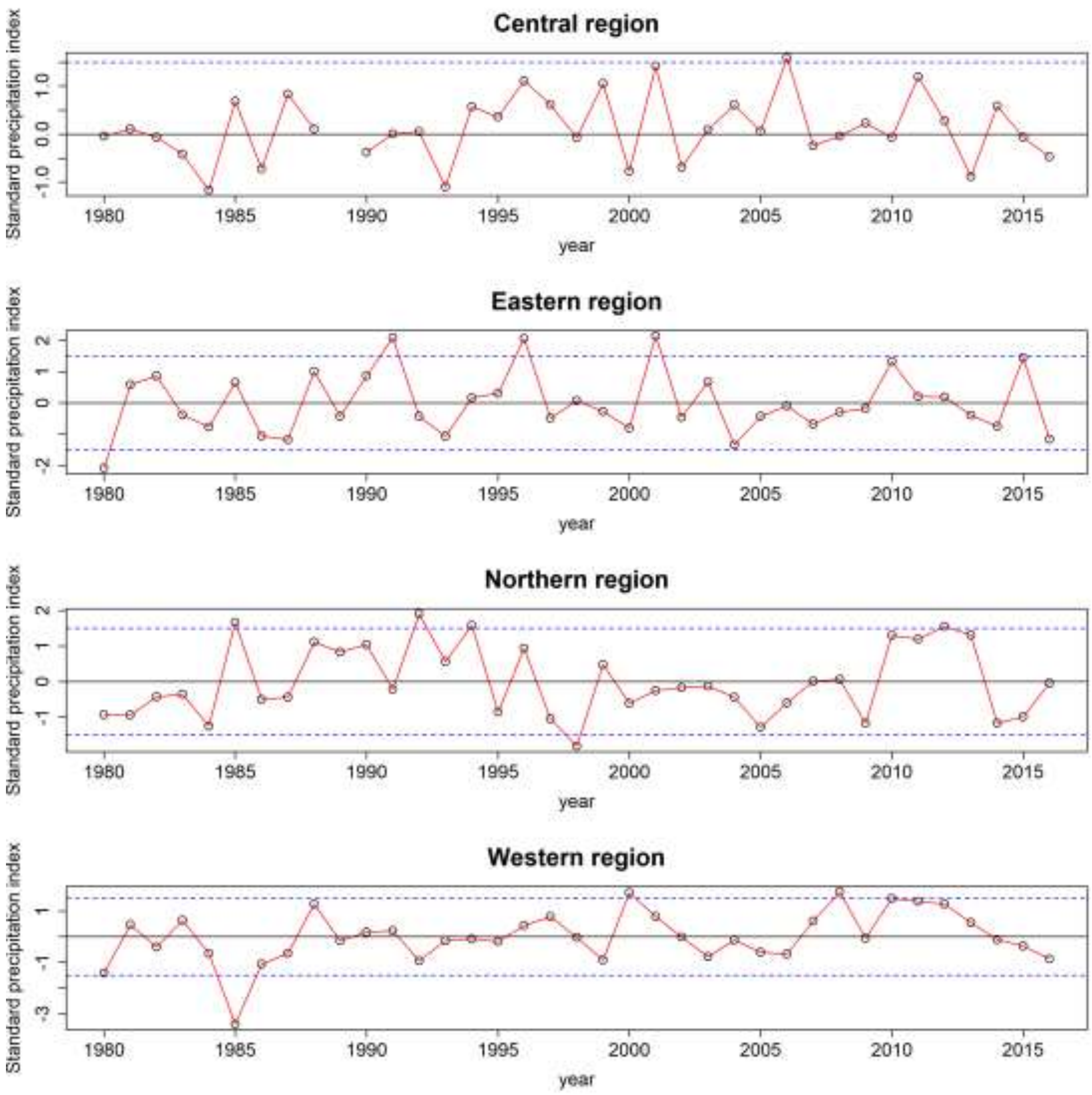

Figure 4. 12-month Standard precipitation index for the different regions for a period of 1980- 2016

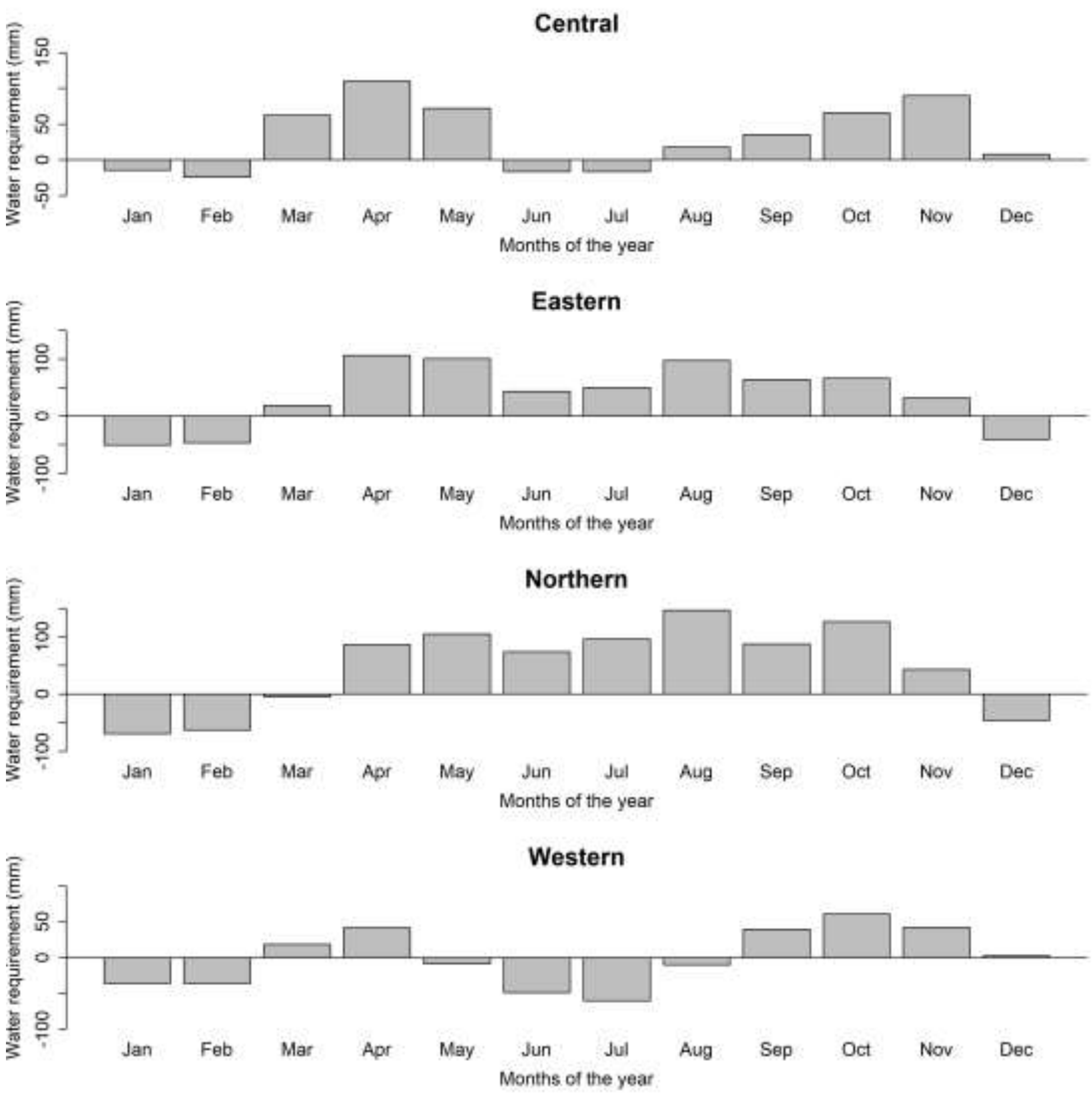

Figure 5. Monthly water requirement for rainfed ponds the different regions