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Impacts of climate variables and seasonal water depth on emergent macrophyte biomass production in King'wal riverine wetland, Kenya

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The production of macrophyte biomass holds a crucial role in supporting diverse life forms within wetland ecosystems. However, this biomass production is intricately tied to hydrology of the inland wetland system, which in turn is driven by the local climate's seasonal patterns. The response of macrophyte biomass production to seasonal changes in water depth, influenced by rainfall patterns and air temperatures in the freshwater King'wal riverine wetland of Kenya, remains unclear. This study investigated seasonal productivity of emergent macrophytes in relation to water depth and human-induced disturbances in the King'wal riverine wetland of Kenya. Water depths were measured across four study sites using a graduated meter-ruler. Monthly harvesting of above-ground emergent macrophyte biomass took place just above the soil surface in three 1 m^2 quadrats at each of the four sites, spanning from September 2021 to August 2022. The harvested macrophyte samples were cut, air dried, and oven dried at 65°C to constant weight. The weight was expressed in grams per square meter. Historical rainfall data spanning from 2011 to 2021 was acquired for two stations near the wetland. Daily data for both rainfall and temperature were collected for the study period from three stations: Baraton, Tebeson farm, and Moi University. The Mann-Kendall test was employed, revealing a significant reduction in rainfall (tau = -0.102, P < 0.05) in the area. A negative and significant relationship was established between water depth in the wetland and biomass productivity (rho = - 0.59; P < 0.001). Biomass accumulation and productivity can indicate climate change impacts over a longer period of time.

Key words: Rainfall Anomaly Index, Temperature, above ground biomass, Inland wetland, Kenya.

INTRODUCTION

Macrophytes are keystone species dominating inland wetlands in Kenya and yet are being threatened by seasonality of climate variables. Climate variability is the natural changes observed over a day, weeks, months or years in the climatic variables such as rainfall, wind, temperature, humidity and solar radiation. These changes can vary over time of the day or over a season or multi-seasons that could be for a short period in terms of

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months or several years. Climate variables include air temperature and rainfall patterns which are known to influence the growth and distribution of plants in wetlands. Macrophytes' species dominance and productivity are driven by changes in water depth due to seasonal climatic variables. Climate variables like the amount of rainfall received influence the depth of the water in inland wetlands. This in turn will influence the type of human activities that will take place in the wetland which influence its structure and function (Mitsch and Gosselink, 2015; Junk et al., 2013). When water depth goes below the soil in the wetland, people can access the wetland for various activities but when the water depth is higher above the soil surface, most of the disturbances caused by human activities are reduced as the people cannot access the products in the wetland due to flooding conditions (Rongoei et al., 2014). Therefore, understanding seasonal rainfall and air temperature changes overtime in the inland wetland ecosystems will assist in strategizing on how to manage these ecosystems in the face of climate change and increasing human disturbances.

Macrophytes and their production play an important role in inland wetland ecosystems including the King'wal riverine wetland not only by forming the basis of wetland food chains, but also in providing habitats for several lifeforms (Mitsch and Gosselink, 2015; Gichuki et al., 2001). Other ecosystem services provided by macrophytes include: water purification, filtering of sediments and unnecessary chemicals as well as cycling of nutrients (Hes et al., 2021; Kansiime et al., 2007), and sequester carbon (Craft et al., 2018; Saunders et al., 2014). Macrophytes also provide food, wild fruits, medicinal herbs and other materials to local people directly or indirectly (Chen et al., 2014; Rongoei et al., 2013; IPBES, 2019). Macrophytes provide protection to variety of organisms from predators and provide forage to livestock during the dry season. The macrophytes depend on the wetting and drying conditions in wetlands to maintain their structure and function (Junk et al., 2013). This function makes them suitable for use as bioindicators to assess the status of wetland ecosystem health. Since macrophytes support biodiversity and form the base of food chains in aquatic ecosystems, any stress faced will influence other lifeforms and therefore can be used to detect short-term changes (such as seasonality).

Relationship between climate variables such as rainfall, air temperature, water depth, and macrophytes biomass production have been studied in other wetland ecosystems (Sun et al., 2018; Lou et al., 2016; Dwire et al., 2004). Water depth in wetland influences the extent of the wetland vegetation distribution and its functions as well as species composition. Seasonality in climate variables that lead to changes of rainfall patterns in particular region may change the function of a wetland as well as other services that the wetlands provide to the surrounding communities (IPCC, 2014). Any change that will modify the rainfall patterns or seasonality will alter water depth patterns in inland wetlands and therefore lead to changes in ecosystem structure in general (NICRA-CIFRI, 2016). This is a natural phenomenon that occurs in an annual basis but will depend on the intensity and frequency of the rainfall or drought conditions. These conditions may be prolonged resulting in reduction of wetland productivity. This may occur due to water limitation and consequently lead to wetland vegetation being transformed to terrestrial vegetation.

Inland wetlands are highly productive and support high biodiversity hence local people directly and indirectly depend on them for their goods and services (Chen et al., 2014; Bassi et al., 2014; Mitsch and Gosselink, 2015). However, these inland wetlands and their vegetation are vulnerable to environmental change due to rainfall variability and human-induced disturbances (Rebello et al., 2019). Inland wetlands in Kenya are sensitive to climate variability since they are isolated and fragmented within a catchment that has intensive agriculture. This is the case with the King'wal riverine wetland which joins Yala River that flows into Lake Victoria. Its catchment has intensive agriculture and development activities such as road networks, tea and maize plantations, mining of clay for brick making as well as draining and introduction of eucalyptus woodlots that have led to alteration of the wetland vegetation (MEMR, 2014).

Emergent macrophytes are sensitive to slight changes in water depth which are caused by variability in local rainfall patterns. Studies have shown that plant productivity and other macrophyte ecological parameters are dependent on wetlands' water depth. For example, *Cyperus papyrus* biomass productivity declined as a result of prolonged dry conditions in Nyando floodplain wetland (Rongoei et al., 2014). Furthermore, types of plants and their productivity in a wetland are determined by soil moisture and rainfall variability in other regions (Yu et al., 2019). Some studies done elsewhere have shown that macrophytes growth rate and species richness have been used to indicate changing soil moisture and water depth in wetland ecosystems (Chatanga and Sieben, 2019; Rongoei and Outa, 2016; Cronk and Fennessy, 2009). Wetland changes brought about by rainfall variability include changes in plant community composition which can be observed and quantified. This in turn will influence biomass productivity of a particular wetland as different macrophytes differ in their productivity. Biomass productivity in a wetland is important in provisioning of services for society and the health of the ecosystem (Rongoei and Kariuki, 2019) hence, crucial to study its changes seasonally. In King'wal riverine wetland, studies on climate variables, water depth fluctuation and its relationship with macrophyte biomass productivity has not been done.

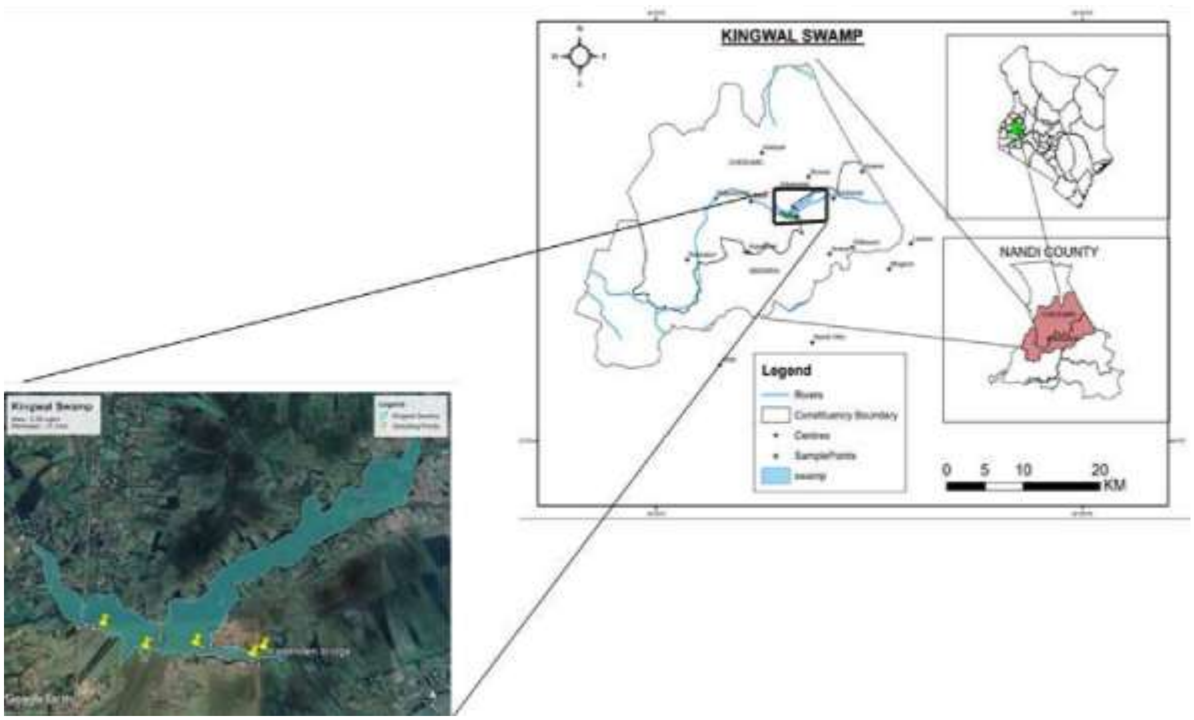

Figure 1. Location of King'wal riverine wetland in relation to the Kenyan map.

The main aim of this study was to understand impacts of climate variables and the seasonal water depth on macrophyte biomass productivity in King'wal riverine wetland with the following objectives: to characterize seasonal rainfall trend (2011-2021) in King'wal riverine wetland; to determine seasonal variation of emergent macrophytes' biomass productivity in King'wal riverine wetland during the study period (September 2021 – August 2022); and to evaluate the relationship between climate variables (rainfall, water depth, and air temperature) and the aboveground macrophytes' biomass productivity in King'wal riverine wetland over the study period. This study hypothesizes that seasonal climatic variables like rainfall, air temperature as well as water depth in King'wal riverine wetland impacts on the biomass productivity of emergent macrophytes.

MATERIALS AND METHODS

Study area

This study was conducted in King'wal riverine wetland which is part of Lake Victoria North Drainage Basin, Kenya. King'wal riverine wetland is located in Nandi County and covers an estimated area of 2.73 km^2 (MEMR, 2012) although this area may vary seasonally depending on rainfall variability. It is located between longitude 0.2574^o N and latitude 35.1665^o E (Figure 1). King'wal wetland is a narrow wetland that stretches from Moi University main campus in the East, and forms part of River Kimondi watershed and River Yala basin in the west (Swallow et al., 2009). The water from River Yala drains into the world's second largest fresh water Lake: Lake Victoria, a shared resource which is a source of livelihood to over 30 million people found in Eastern Africa (IDeP, 2020; MEMR, 2012). King'wal riverine wetland is a swamp that follows the course of river King'wal and comprises of a permanent riverine wetland with water flow that sometimes is visible and at other times not visible due to changes in the wetland water discharge and recharge characteristics. The wetland is dominated by the emergent *Cyperus papyrus* L. vegetation followed by a seasonally flooded area (wet meadow) dominated by other reeds and a combination of herbs and grasses towards the dry land.

The seasonally flooded inland wetland in King'wal is the zone between the emergent papyrus-dominated vegetation zone and the upland area with farms and eucalyptus plantations with a buffer of grass species. This zone is characterized by sedges, reeds and hydrophytic grasses and herbs. The zone is the most dominant and most disturbed by human activities such as animals grazing, cultivation and/or draining activities and may influence the health of the papyrus-dominated zone.

King'wal wetland receives an average rainfall of about 1600 to 2000 mm per annum with temperatures ranging between 18 and 25°C. The area experiences a bimodal kind of rainfall pattern with long rains occurring during the months of March, April and May (depicted hereafter as MAM) and short rains during the months of September, October and November (depicted hereafter as SON). The Dry season falls between the months of December, January and February (depicted hereafter as DJF) (MEMR, 2014).

King'wal wetland is known to be a critical habitat for a population of swamp-adapted semiaquatic antelope referred to as Sitatunga (*Tragelaphus spekii*) which occurs in areas dominated by reeds, bulrushes and sedges and is endemic to sub-Saharan Africa (Warbington and Boyce, 2020; Andama, 2019). Other important biodiversity found within this wetland include mongoose, foxes, snakes, frogs, ant bears, and different species of fish and a variety of birds (CGN, 2018). The wetland is also an important habitat for breeding and feeding for Grey Crowned Cranes (*Balearica regulorum*) (MEMR, 2014) hence, one of the project areas for the Kenya Crane and Wetlands Conservation Project. King'wal wetland is dominated by macrophytes such as papyrus along the river followed by bulrushes (*Typha domingensis*), a number of *Cyperus* spp., reeds such as *Echinochloa pyramidalis* and sedges such as *Pycreus lanceus* (MEMR, 2012). The riparian woody plants are also dominated by water berry plants (*Syzygium guineense*) that grow up to 15-30 m tall. This plant is valued by the local community due to its edible fruits and serves as an herb for treating different ailments. The tree also is important as its leaves are used to feed livestock and its wood is used as a source of energy (charcoal and firewood) for cooking. Other vegetation that occurs within the wetland includes forests, grasslands, shrubs and scrubland forming vegetation zones that can be defined. Vegetation comprising of eucalyptus trees is found along the fringe of the wetland (MEMR, 2014; Ambasa, 2005).

Sampling design

The biomass productivity of macrophyte community changes over time within the wetland hence, monthly sampling at an interval of 26-30 days was done to cover both dry and wet seasons. A standardized ecological field survey was used in order to ensure consistency in sampling effort at each site. Four sampling sites were selected in the wetland depending on the ecological factors such as vegetation zones, water depth as well as based on type and extent of human disturbances. The four sites were selected in order to obtain a representative sample within each locality and were represented as S1, S2, S3, and S4. The sites were also selected based on their accessibility, as well as able to be sampled and wadable during the wet season since the depth was below one meter. However, macrophyte biomass was not determined in S4 in August 2022 due to flood water that rose above one meter from the soil surface. The site selection was also based on information by Kenya Wildlife Service staff that regularly patrols the wetland.

Stratified random sampling was used to collect data from the study site. The stratification was done according to the type of human disturbance that was identified at the sampling sites. The sites identified as having minimal human disturbances did not have human activities at the time of study and had minimal livestock grazing during the dry season. However, those sites identified as most disturbed had human activities that would easily alter or modify the wetland such as digging of channels to drain the wetland, crop cultivation at the edge of the wetland, intensive livestock grazing, burning and growing of eucalyptus plants. Therefore, two sites represented the least disturbed: S1 and S3 and another two represented the most disturbed sites: S2 and S4. During the reconnaissance visit to the wetland, some time was spent walking along the margin of the wetland in order to characterize the vegetation patterns so as to determine where to place the sampling plots.

A 50 m^2 rectangular plot of 5 m by 10 m was placed in each of the four sampling sites. The rectangular shape of the plot of the assessment area was oriented south to north which was perpendicular to river King'wal. This orientation has been known to be efficient as it follows the gradient of moisture in the soil from upland to wetland area where plant communities respond differently (Elzinga et al., 2001). This also incorporated the variability of vegetation within the quadrats. Each plot in each stratum had three 1 m^2 quadrats that were randomly placed as depicted in Figure 2. This size of the quadrat is adequate to be used in emergent wetland vegetation and grassland ecosystems (Herlihy et al., 2019; Andrade et al., 2019; Clarke, 2009). Furthermore, this size of quadrat has been used by other scientists in the tropical areas (Andrade et al., 2019; Rongoei et al., 2014; Terer et al., 2012) and temperate regions (Peterka et al., 2020; USEPA, 2016).

A total of 12 quadrats were used to monitor above ground biomass of wetland emergent macrophytes. The characteristics of the sampling sites are discussed. Least disturbed sites were represented by the code S1 and S3. These sites represented the control samples that were relatively not disturbed by human activities such as cropping, harvesting and burning. The sites represented by S2 and S4 were mostly disturbed. This is due to the human activities that were taking place in these sites. S2 was mainly farming, eucalyptus growing, and grazing of livestock. S4 were mainly affected by channel digging and intensive livestock grazing that was rampant in dry season as this was the only area with available forage. The four study sites were characterized based on dominant vegetation and human activities including livestock grazing and channelization as described in Table 1.

The four sampling sites (plots) were within the seasonally-flooded site of the wetland. The water level was on the surface or below the soil surface during the dry season. However, S2 soil was wet throughout the dry season due to the presence of channels that directed water to the site during the study period. The S3 site was at the edge of the *Cyperus papyrus* L. swamp which receives river King'wal water that floods the site.

Data collection

Ten years rainfall data were obtained for Baraton and Tebeson farm from the Kenya Meteorological Services (KMS) in Kapsabet. These stations are around the wetland ecosystem. Total annual rainfall data for the period 2012 - 2021 and 2011 - 2021 for Baraton and Tebeson farm, respectively were obtained. The data for the two stations were used to understand seasonal rainfall trend over the 10-year period in the study area and to understand the annual variation of rainfall pattern for King'wal riverine wetland. Furthermore, daily rainfall data covering the study period September 2021 to August 2022 were obtained for three stations; Tebeson farm, Baraton university and Moi University. The data was averaged and used to estimate the seasonal rainfall pattern in King'wal wetland during the study period. This was used to determine the relationship between climatic variables (rainfall, water depth and air temperature) and biomass productivity in King'wal riverine wetland over the study period. Daily air temperature data for the study period was obtained from Moi University station only as the other stations did not have the measurements.

Water depth in the wetland study sites were measured on monthly basis from September 2021 to August 2022 using graduated meter ruler. Three 1 m^2 quadrats were randomly placed in each study site. From each 1 m^2 quadrat, three points of water depth measurements were taken randomly resulting to nine measurements in each site. This was averaged to give the mean water depth per site during the study period. Zero value was recorded when the water level was at or below the soil surface.

Monthly data for biomass productivity was taken from the same three 1 m^2 quadrats that were established in each plot from September 2021 to August 2022 covering wet and dry seasons. Above ground dry biomass (hereafter depicted as AGDB) was determined by clear cutting fresh above ground biomass from the three randomly placed quadrats where water depths were measured. Fresh biomass was weighed in the field using the digital balance with an error of 10 g. Subsample fresh biomass was cut into small pieces, reweighed, recorded, packed and placed in labelled bags that were transported to Egerton University, soil

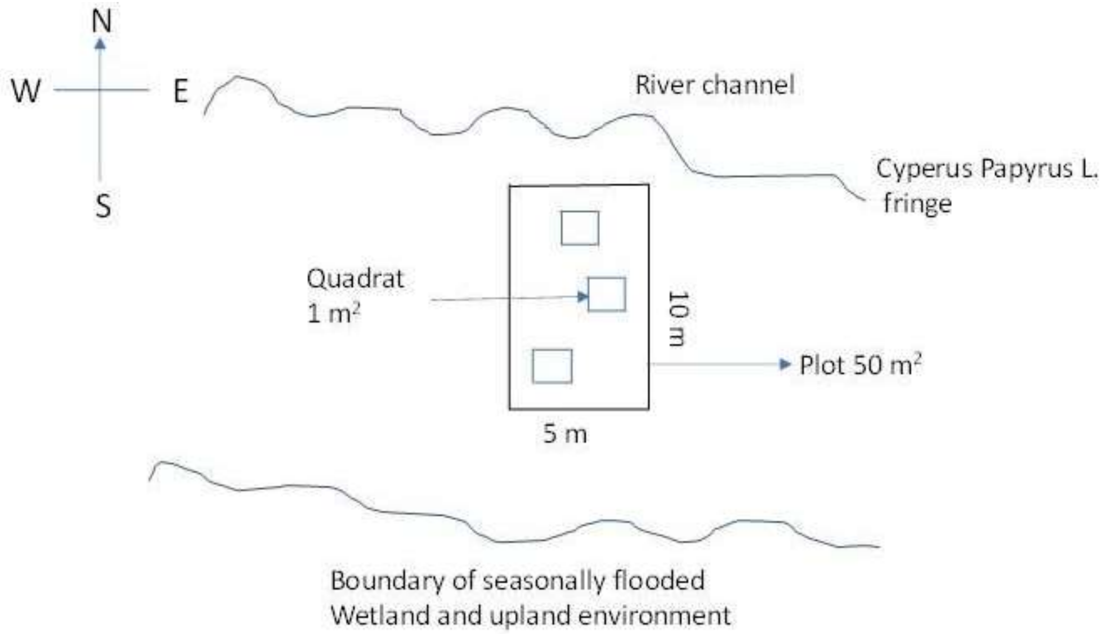

Figure 2. Vegetation survey plot orientation and quadrats.

Table 1. Sampling sites with their disturbance characteristics during the study period.

Sampling site	Dominant vegetation	Human activities
S1	Mixed grass and herbs such as *Cynodon* spp., *Cyperus esculentus*, *Garlium* spp. *Hydrocotyle* spp. *Panicum* spp.	-No human activities were taking place but had a buffer vegetation mixed with grass that was 30 m away from the study site
S2	*Cyperus esculentus* and *Cyperus papyrus, Typha sp., Saggitaria* spp*, Cyperus* spp.	-Burning of *C. esculentus* to extend area of eucalyptus plantation -Planting eucalyptus, -Digging channels, -Livestock grazing -Vegetable planting at the edge of the wetland
S3	*Cyperus esculentus* and *Cyperus papyrus, Polygonum* spp.	-No human activities except limited livestock grazing during dry season at the buffer zone dominated by grass
S4	*Panicum spp*., and *Eleocharis geniculata*, *Cyperus esculentus, C. papyrus*	-Deep channels of up to 1 m to the edge of the wetland -Intensive livestock grazing in both seasons -Shallow well nearby -Mainly flooded in wet season -Bee hives -Plantation of eucalyptus nearby

laboratory. The samples were air-dried at room temperature for 3 days and oven-dried at 65°C for 24 hours to obtain a constant weight. Biomass was obtained by weighing the dried matter which was then recorded as grams above ground dry biomass per meter square (g DM/m^2) for each plot. An average weight was obtained by adding the above dry biomass from the three 1 m^2 quadrats in each plot and dividing by three.

Data analyses

Rainfall data were analyzed using descriptive statistics: mean,

Table 2. Categorization of rainfall events based on coefficient of variance.

Coefficient of Variation (CV) values (%)	Rainfall event
< 20	Less
20 - 30	Moderate
30 - 40	High
40 - 70	Very high
>70	Extremely high

Source: Thomas et al. (2016).

range and standard deviation. Cumulative Departure Index (CDI) and Rainfall Anomaly Index (RAI) were used to understand whether there has been change in seasonal rainfall patterns and rainfall trends over a 10-year period in King'wal Riverine wetland. Exploratory data analysis was used so as to understand the characteristics of the data being used. Mann-Kendal test was used to determine the rainfall trend. The data were arranged and normality was tested using Shapiro-Wilk test. Since most of the data obtained were not normally distributed, Kruskal-Wallis rank sum test was used to assess for significant differences on biomass productivity at different seasons and at different disturbance regimes. This was followed by a post-hoc analysis using Dunn test Bonferroni method. All tests were conducted at 5% probability level. To determine the relationship between water depth and biomass productivity, Spearman's rank correlation analysis was used to determine whether the relationship was positive or negative. Furthermore, nonparametric Spearman's correlation matrix was used to determine the relationship between seasonal climatic variables (rainfall, air temperature and water depth) and AGDB of emergent macrophytes. The R software was used for analysis and data plotting by use of ggplot2 package (Wickham, 2016). All analyses were done using R version 4.1.2 (R Core, 2021) (R Foundation for Statistical Computing; http://www.rproject.org/) and Microsoft Excel.

RESULTS

Characterizing seasonal and annual rainfall trend in King'wal riverine wetland

Rainfall in King'wal riverine wetland was prepared for monthly, seasonal and annual for 10-year (2012-2021 in Baraton) and 11 years (2011-2021 in Tebeson farm) periods. The annual mean and standard deviation of rainfall for Baraton station was 2158.8 ± 343.2 mm while that of Tebeson farm station was 1670.3 mm ± 184.8 mm. The minimum and maximum annual rainfall in Baraton was 1669.4 and 2699.6 mm while in Tebeson farm ranged from 1355.7 to 1931.9 mm. The annual coefficient of variation (CV) was 15.9% for Baraton and 11.1% for Tebeson farm. This showed that there was less variability in annual rainfall over the 10 and 11 years periods, respectively around King'wal wetland according to the categorization of rainfall events based on coefficient of variation (Table 2).

A summary of statistics for rainfall variability in King'wal riverine wetland is depicted in Table 3a (Baraton) and 3b (Tebeson farm). Long rainy season start in March through June (here after referred to as MAMJ) over the 10-year period and contributed the highest percentage to the annual rainfall budget of 43.4 and 42.5 in Baraton and Tebeson farm, respectively. The short rainy season of July to October (hereafter referred to as JASO) contributed 40.0 and 41.5 in Baraton and Tebeson farm, respectively. The dry season started in November to February (hereafter referred to as NDJF) and contributed 16.6 and 16.0% rainfall to the annual budget in Baraton and Tebeson farm stations, respectively. Generally, both stations had less inter-annual rainfall variability of 15.9 and 11.1% in Baraton and Tebeson farm, respectively (Tables 3a and b) over the 10 and 11years periods based on coefficient of variance (CV). To understand the trend of rainfall pattern over the 10-year period in King'wal wetland, the rank-based non-parametric Mann-Kendall (MK) test was used and it showed a significant decreasing trend (tau = 0.102, 2 sided; $P < 0.05$).

The most extreme events of drying and wetting affected Tebeson farm station than Baraton station as depicted in the Rainfall Anomaly Index (RAI) (Figure 3). Baraton University station had high negative RAI values recorded in 2016, 2017 at -2.0 and -1.8, respectively while positive extreme values were recorded in 2014 and 2018 at 2.2 and 1.2, respectively (Figure 3a). Tebeson farm station, experienced high negative RAI values in 2014, 2015, and 2021 of -3.1, -2.0, and -1.8, respectively showing extremely dry conditions (Figure 3b). More so, there was a positive RAI in 2012, 2018, and 2020 of 2.1, 1.5, 2.6, respectively showing extremely wet conditions in the same area.

Seasonal variation in macrophytes' above ground dry *biomass*

Figure 4 depicts the average above ground dry biomass of macrophytes in the four study sites of King'wal riverine wetland during the dry and wet seasons. The minimum range of biomass in dry season was 145.8 g DM/m^2 and

Table 3a. Summary statistics of monthly, seasonal and annual rainfall over Baraton station in a 10-year period (2012-2021).

Rainfall (mm) for Baraton station						
Month	**Mean**	**SD**	**CV (%)**	**% contribution to annual budget**	**Min.**	**Max.**
January	47.5	48.7	102.6	2.2	0	166.4
February	37.2	25.1	67.5	1.7	8.8	82.9
March	156.7	83.6	53.3	7.3	37.4	267.6
April	300.0	137.6	45.9	13.9	118.2	589.9
May	271.3	119.5	44.0	12.6	92.3	446.0
June	209.0	110.2	52.7	9.7	74.9	436.0
July	173.4	63.3	36.5	8.0	55.9	270.9
August	250.3	84.5	33.8	11.6	149.7	376.3
September	241.6	74.9	31.0	11.2	141.5	393.2
October	197.9	79.6	40.2	9.2	47.2	261.1
November	155.8	92.6	59.4	7.2	49.3	343.3
December	118.3	88.3	74.6	5.5	15.0	267.4
Annual	2158.8	343.2	15.9	100	1669.4	2699.6
MAMJ	937.0	300.2	32.0	43.4	665.2	1610.4
JASO	863.1	199.1	23.1	40.0	635.7	1154.0
NDJF	358.7	137.6	38.3	16.6	165.3	612.3

Source: KMD for Baraton University Station (2021).

maximum was 3027.4 g DM/m^2. The wet season on the other hand had the lowest biomass productivity with a minimum range of 64.8 g DM/m^2 and maximum of 831.0 g DM/m^2. Therefore, the highest mean biomass for dry season was 1363 g DM/m^2 in S1 followed by S3 with 1088 g DM/m^2 which were depicted as least disturbed sites. In addition, biomass in dry season was lower in the sites depicted as most disturbed with above ground dry biomass (AGDB) of 953 g DM/m^2 and 814 g DM/m^2 in S2, and S4 sites, respectively. However, wet season showed the lowest AGDB with 430 g DM/m^2, 270 g DM/m^2, 238 g DM/m^2 and 210 g DM/m^2 in S1, S3, S4, and S2, respectively. The above ground dry biomass productivity showed that there was a difference between the least disturbed and most disturbed sites with least disturbed having a higher biomass than most disturbed (KW- χ^2 = 12.3, df = 1, P < 0.001).

Above ground dry biomass was different among the study sites using the Kruskal-Wallis Chi-square rank test (KW- χ^2 = 15.7, df = 3, P < 0.05). A post-hoc analysis using Bonferroni method showed that S1 was different from S2 and S4 (P < 0.05) and not with S3. This confirms the findings in Figure 4 showing S1 and S3 having a higher biomass than S2 and S4 in both seasons. The dry season depicted a higher above ground biomass productivity than in wet season (KW- χ^2 = 86.2, df = 1, P < 0.001).

Rainfall variability, water depth and its relationship with macrophytes' biomass productivity in King'wal riverine wetland during the study period

The daily rainfall data was obtained for three stations: Baraton, Tebeson farm station and Moi University station. The average monthly total rainfall for three stations (around King'wal riverine wetland for the period covering September 2021 to August 2022 varied as depicted in Table 4. The highest mean total rainfall was recorded in the month of August 2022 (341.4 mm) followed by September 2021 (303.3 mm). The lowest mean total rainfall was recorded in the month of December (2.6 mm) as depicted in Table 4.

Water depth in King'wal riverine wetland corresponded with the amount of rainfall over the area. Table.4 depicts the mean monthly water depth in the four study sites during twelve months of the study. The highest water depth was measured in S4 with a maximum depth of 63.3 cm, and the lowest depth was measured in S1 and S2 with a maximum of 38.1 cm and 39.7 cm, respectively. All the study sites were flooded during the wet season and water moved below the soil surface during the dry season. The mean water depth varied between 0 cm in dry season and 63.3 cm above the soil surface in wet season, in the study sites. The four study sites did not show any difference in the water depth among them (KW-

Table 3b. Summary statistics of monthly, seasonal and annual rainfall over Tebeson farm station for 11 years (2011-2021).

Month	Rainfall (mm) for Tebeson farm station					
	Mean	**SD**	**CV (%)**	**Contribution to annual budget**	**Min.**	**Max.**
January	53.6	52.2	97.3	3.2	0	171.1
February	37.8	29.5	78.2	2.3	6.3	97.2
March	105.1	75.5	71.9	6.3	15.7	281.5
April	206.6	101.7	49.2	12.4	82.1	367.6
May	205.0	87.8	42.9	12.3	94.0	395.9
June	192.4	77.2	40.1	11.5	51.4	309.6
July	160.0	59.2	37.0	9.6	71.2	225.5
August	232.6	78.8	33.9	13.9	112.0	330.6
September	163.4	77.0	47.1	9.8	62.3	337.8
October	137.5	63.5	46.2	8.2	62.5	275.7
November	103.2	85.4	82.7	6.2	10.9	274.6
December	72.9	64.8	88.8	4.4	6.4	179.3
Annual	1670.3	184.8	11.1	100	1355.7	1931.9
MAMJ	709.2	191.7	27.1	42.5	460.3	1091.6
JASO	693.6	150.7	21.7	41.5	475.5	894.2
NDJF	267.5	74.3	27.8	16.0	137.2	377.5

Source: KMS for Tebeson Farm station 2021.

χ^2, P > 0.05) but there was a difference between the dry and the wet season (KW- χ^2 = 163.6; df =1; P < 0.001). This is because water went below the soil surface during the dry season in all sites while water rose above 40 cm from the soil surface in wet season in all the sites.

Increase in rainfall depicted a strong negative association with biomass productivity (R = -0.52; P < 0.001). Likewise, as the rainfall increased, there was a corresponding positive increase in water depth in the wetland (R = 0.58; P < 0.001; P < 0.001). In addition, increase in temperature had a positive significant effect on biomass accumulation of emergent macrophytes (R = 0.33; P < 0.001; P < 0.001) (Table 5).

The results showed that there was a negative strong relationship between water depth and biomass productivity (R = -0.59; P < 0.001) (Table 5 and Figure 5). The results combined wet and dry seasons for all the four study sites. The y-axis showed above ground dry biomass of emergent macrophytes in grams and x-axis showed the water depth measured in centimeters in the wetland. Figure 5 depicts a relationship that is negative showing that the higher the water depth from the soil surface, the lower the emergent biomass production using the Spearman's correlation method.

DISCUSSION

Seasonal and annual rainfall trend and its implications on wetland ecosystem

Rainfall patterns determine the kind of environments found in a region hence it is important in understanding the productivity of an ecosystem. Rainfall did not show much variation in King'wal wetland over the ten and 11-year periods. However, interannual and seasonal variations were moderate based on their coefficient of variation (CV). The CV was high to extremely high from January to December in both stations over the 10 and 11 years periods. This implies that there is a high inter-annual variability between months. However, seasonal variability of rainfall showed that there was high variability in the long rainy season and that of dry season while the short rainy season had moderate variability for Baraton station. Tebeson farm station showed that there was moderate inter-annual variability. Rainfall variation based on coefficient of variation was observed in the two stations of King'wal to be low as depicted in Table 2. This implies that the data used was for a short period or near-term period of 10 years hence more historical data will be

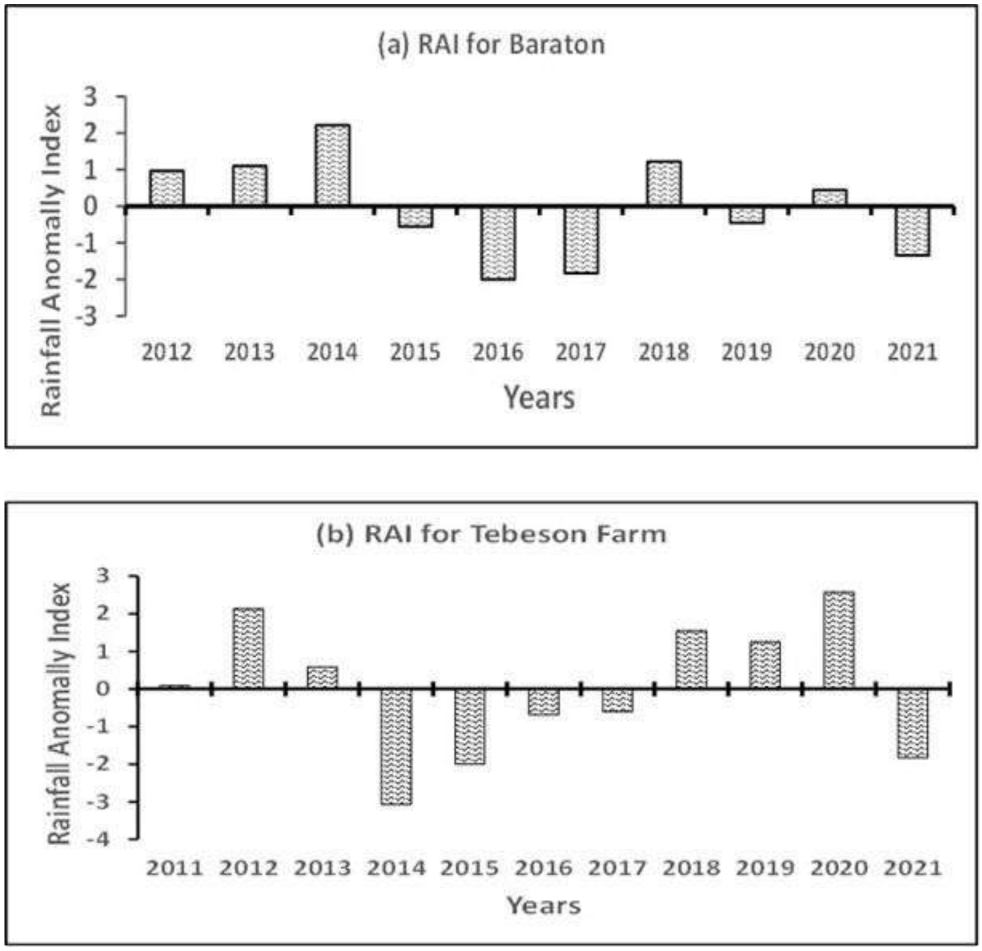

Figure 3. A time series of seasonal Rainfall Anomaly Index (RAI) at (a) Baraton (20122021) and (b) Tebeson Farm stations (2011-2021) in King'wal Riverine wetland, Kenya.

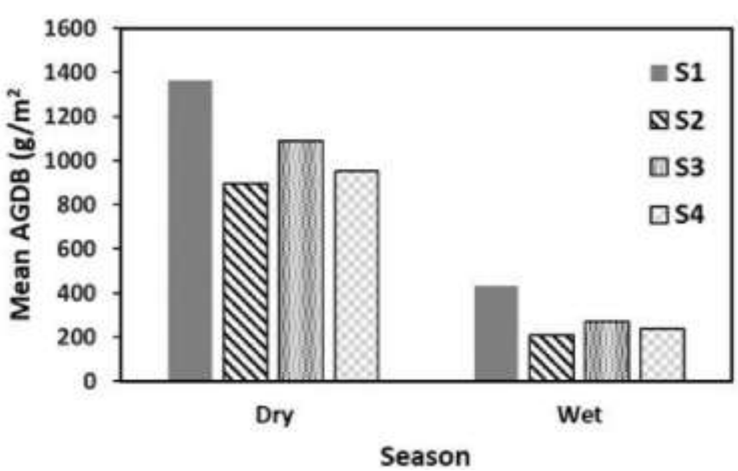

Figure 4. Seasonal variation in macrophytes' above ground dry biomass in the four study sites (S1 and S3 least disturbed and S2 and S4 most disturbed) in King'wal riverine wetland during the period covering September 2021 to August, 2022.

Table 4. Mean total monthly rainfall (mm) from the three stations in King'wal wetland and mean monthly water depth (cm) values relative to the soil surface in the four study sites (S1, S2, S3, S4) of King'wal riverine wetland.

Month	Monthly mean total Rainfall (mm)	S1 Mean ± SEM	S2 Mean ± SEM	S3 Mean ± SEM	S4 Mean ± SEM
September	303.3	25.1 ± 1.1 (15 - 40)	15.5 ± 1.1 (10 - 20)	24.8 ± 2.4 (15 - 38)	34.4 ± 1.0 (30 - 39)
October	146.3	22.0 ± 4.4 (4 - 40)	21.6 ± 1.7 (15 - 30)	40.8 ± 3.9 (25 - 60)	54.0 ± 1.1 (51 - 60)
November	49.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.2 (0 - 2)	0.2 ± 0.1 (0 - 1)
December	2.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
January	41.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
February	63.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
March	86.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
April	224.6	0.0 ± 0.0	1.6 ± 0.8 (0 - 5)	0.0 ± 0.0	0.0 ± 0.0
May	177.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
June	139.2	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 1.0 (0 - 7.2)	0.8 ± 0.2 (0.4 - 2)
July	262.9	0.0 ± 0.0	2.0 ± 1.2 (0 - 9)	0.0 ± 0.0	0.0 ± 0.0
August	341.4	38.1 ± 2.4 (25.8 - 50.2)	39.7 ± 2.2 (20 - 58.7)	34.4 ± 4.6 (10.7 - 58.3)	56.6 ± 1.5 (50 - 63.3)

Numbers are means and standard error of mean of nine measurements in each site over the study period (September 2021 to August 2022).

Table 5. Spearman's correlation matrix between climate variables and biomass productivity.

Parameter	Water depth (cm)	AGDB (g/m^2)	Rain (mm)	Temperature (°C)
Water depth (cm)	1.00	-0.59	0.58	-0.40
AGDB (g/m^2)	-0.59	1.00	-0.52	0.33
Rain (mm)	0.58	-0.52	1.00	-0.48
Temperature (°C)	-0.39	0.33	-0.48	1.00

required so as to make informed conclusion. Nevertheless, the short period was able to give annual trend of rainfall variability in King'wal riverine wetland which can be used to make decision on the ecosystem management in the context of climate change. The annual variations follow the El Niño and La Nina episodes that are higher and lower than the average rainfall (Parry et al., 2012).

The rainfall trend in the region seems to be on a decreasing manner while their frequency seems to increase and are expected to continue according to a Kenyan profile on climate change (MFA, 2018). Rainfall variability at the study site depicted up and down movements showing that there are frequent flood and drought events over the 11-year period. This is in line with other studies that have been done within the East Africa region (Mwangi et al., 2020; Tierney et al., 2015; Shikuku et al., 2010). Furthermore, seasonal variation in the long rainy season (MAMJ) seems to be decreasing over the years, while the short rainy season (JASO) seems to be increasing with time. This implies that there is a shift in rainfall since the short rainy season tend to have more rain than long rainy season and therefore supports what others have found out in the region (Mwangi et al., 2020). As a result, long rains have become unreliable affecting plant growth and biomass production in the wetland ecosystem.

Changes in the seasonal patterns of rainfall due to climate change combined with the human activities in the wetland are expected to modify and alter wetland functions (Poff, 2018). King'wal riverine wetland is influenced by various anthropogenic activities such as creation of channels, crop cultivation at the edge of the wetland, grazing of livestock, burning of wetland vegetation and conversion of wetland vegetation to *Eucalyptus* woodlot. All these activities have a significant influence on the availability of moisture which in turn will affect the kind of vegetation that grows in the wetland. Coupled with rainfall variability, the impacts to wetland macrophytes' structure and function will be significant. For example, above ground dry biomass productivity is expected to be altered by rainfall variation which will also influence the flow of rivers and water levels in the wetland and ultimately affect diverse organisms that are being supported by the wetland. Understanding seasonal rainfall patterns and the growing human disturbances in inland wetlands is important for managing the productivity of these ecosystems. This has gained support from

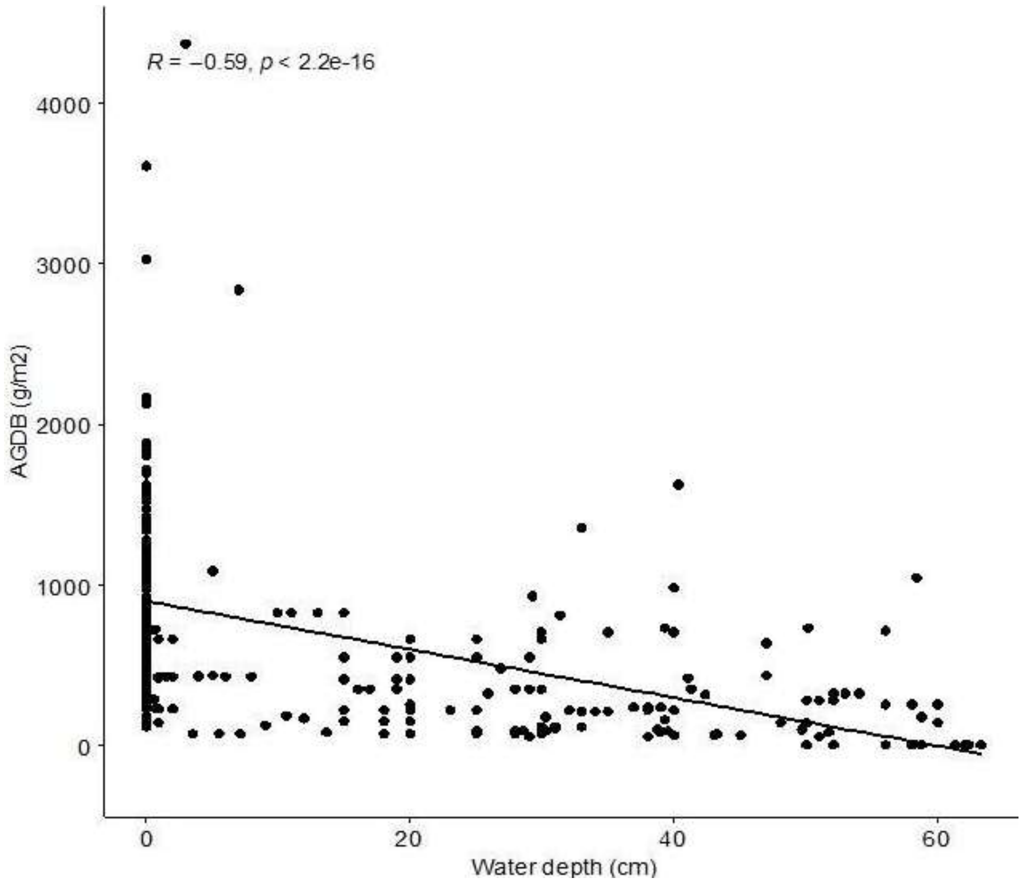

Figure 5. Relationship between water depth and above ground dry biomass (AGDB g/m^2) of emergent macrophytes using the Spearman's correlation over the study period (September 2021 to August 2022) in King'wal riverine wetland.

different researchers (Ndehedehe et al., 2021; Talbot et al., 2018; Keddy et al., 2009). Hence, emergent macrophytes biomass can serve as a good bioindicator for short- and long-term impacts of climate variability especially in inland wetlands influenced by anthropogenic activities.

Relationship between climate variables and biomass production in inland wetlands

Climate variables such as rainfall, temperature and water depth or soil moisture are variables that are relied upon by inland wetlands for their productivity and provisioning of ecosystem services. Rainfall pattern influences the water depth in wetland ecosystems which is important in determining the kind of macrophytes that can grow. Emergent macrophytes rely on water depth, nutrient availability, and temperature for their growth and to perform their functions. Water depth fluctuations in wetland ecosystem are varied by seasons which are common in tropical aquatic ecosystems (Rongoei et al., 2014; Osborne, 2012). Although, such fluctuations may be influenced by the presence of different macrophytes adapted to human disturbances. At the same time temperature in tropical environment drives most of the wetland ecosystem processes that lead to its high productivity and support high biodiversity.

Water depth in the wetland will determine the kind of human activities that are practiced by the surrounding communities. Human activities that influence the wetland vegetation include burning, harvesting, draining and conversion to other uses. Most of these activities will lead to lowering of water below the root zone of the plants and may lead to elimination of moist-dependent plants while promoting those that are more tolerant to dry soil. This will change the species composition, biomass production and diversity of the wetland. For example, harvesting of vegetation during dry season will reduce the biomass of the subsequent productivity which will reduce the ecosystem services available for other organisms (Rongoei and Kariuki, 2019). There is a connection between disturbance patterns and the hydrological regime (Rongoei et al., 2013) which determines human disturbance intensity in wetland ecosystems. This implies that wet season will prevent many human activities from being practiced in the wetland while dry season will open opportunities for more disturbances. This was observed in King'wal riverine wetland where burning, channel digging and growing of eucalyptus plants during the dry season took place which supports dry soil tolerant plants.

Water levels during rainy season will determine the kind of macrophytes that will grow in a particular wetland. The flooding events too bring nutrients and sediments into the wetland enabling plants to grow faster but may affect others due to modification of the substrate condition. For example, in S4 site, the water level was high and therefore inhibited the growth of other aquatic plants and was only confined to species such as *Eleocharis* spp. and *Panicum repens*. These plants can tolerate high water levels as long as they are not totally submerged in water (Hanlon and Brady, 2005) and known to be dominant in the inland freshwater wetland ecosystems of East Africa (Irakiza et al., 2021).

Water depth in the wetland is influenced by seasons and disturbance regimes. This will influence biomass productivity either positively or negatively depending on the water depth, temperature and the type of plants present (tolerant or non-tolerant to flooding). The findings of this study showed that biomass productivity corresponded negatively with rising water levels in the wetland (Figure 5). These findings confirm what others have found out in other regions (Dai et al., 2020; Ward et al., 2013; Lou et al., 2016; Cronk and Fennessy, 2009). This implies that the increasing water depth will inhibit growth of other plants and therefore will reduce biomass production. Less above ground biomass production is known to be influenced by plant adaptation to disturbances and abiotic factors (Mokrech et al., 2017). The disturbance that was observed at the study sites may have influenced biomass production. Disturbance has been found by other researchers to affect wetland ecosystem in different ways (Rebello et al., 2019; Keddy, 2000). They found out that disturbance can lead to mortality of plants as well as reduction in biomass productivity which was observed also in King'wal wetland.

The extreme water fluctuations in wetland negatively influenced the biomass of wetland plants. This reduced productivity as most plants are not adapted to submerged conditions which are in line with what others have found (Lou et al., 2016). At the same time, increased temperature led to increased biomass of plant community in the wetland that was observed from the Spearman's correlation matrix. The findings were in line with what others have found out in other regions (Daufresne et al., 2009; Rasmussen et al., 2011). They showed that macrophyte species richness and coverage increased with increased temperatures as a result of temperature-induced growth rates. This will in turn increase biomass productivity of an ecosystem depending on the type of macrophytes tolerating high temperatures in a changing climate.

CONCLUSION AND RECOMMENDATIONS

Climate variability and water depth seasonality influenced emergent macrophyte productivity in the study wetland. King'wal riverine wetland in Nandi County shows different varying rainfall variability that has influenced the water depth in the wetland affecting biomass productivity. The inter-annual variability of rainfall in the stations around the wetland influenced the type of vegetation and their productivity in inland wetland. Inland wetlands are vulnerable to climate variability as a result of rainfall patterns leading to high or low water depth in the wetland. This interacts with human associated disturbances to influence what happens to the biomass productivity. Biomass productivity was relatively higher in least disturbed sites than in those sites that were disturbed by human associated activities. Implying that higher biomass productivity which is an important function of the wetland is associated with a health wetland ecosystem. Therefore, this can serve as a good indicator of the impacts of climate variability and water depth fluctuations for an inland wetland ecosystem. This study will form a baseline for future research that will determine the changes in ecosystem functions over a longer period of time. Understanding the impacts of climate variability on inland wetland macrophytes biomass productivity is crucial for developing ways to conserve and restore inland wetland ecosystems and achieve resilient ecosystems.

Although water depth in the wetland explained most of the declining above ground biomass, other factors may have played a role too in influencing the biomass decline and need to be explored further. Such factors may include soil nutrient characteristics, impacts of planting eucalyptus on the water depth in wetland, and effects of livestock and wildlife herbivory on macrophyte biomass productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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