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Full Length Research Paper

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.

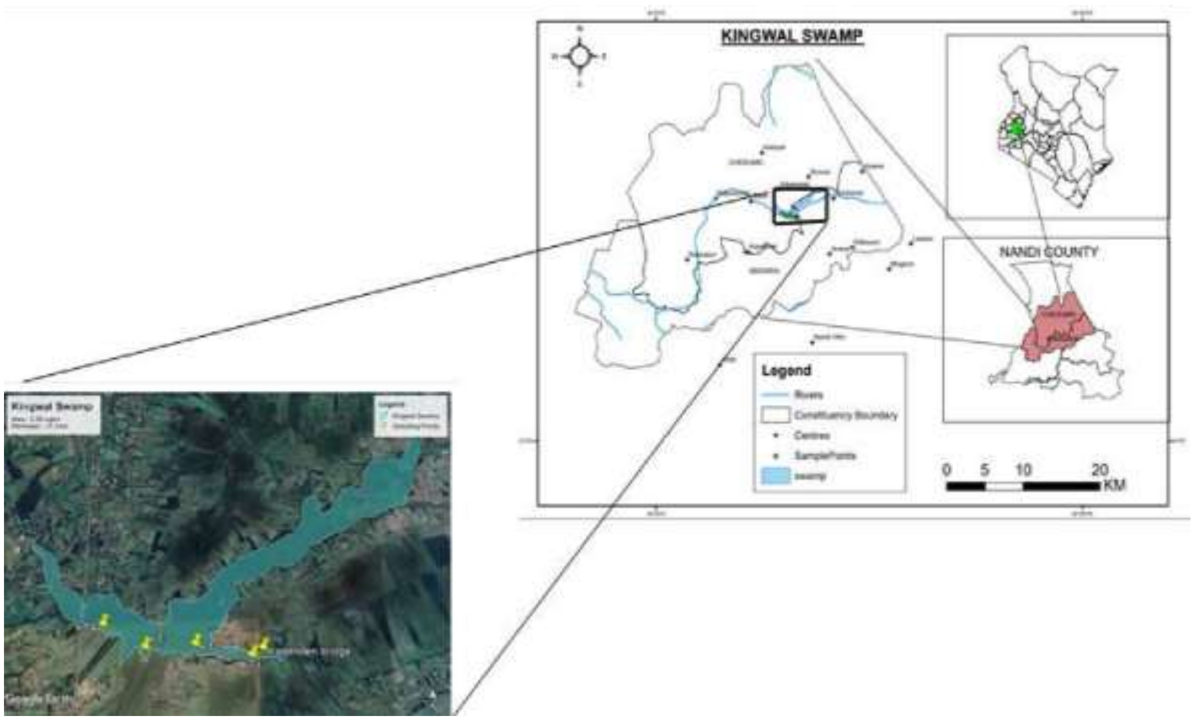

Figure 1. Location of King'wal riverine wetland in relation to the Kenyan map.

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

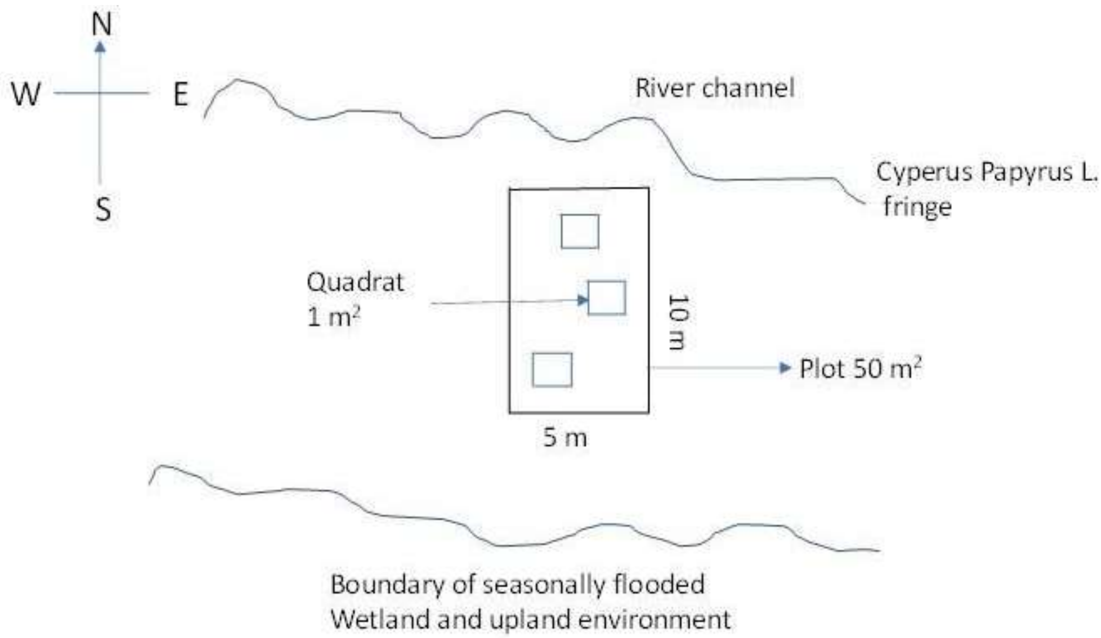

Figure 2. Vegetation survey plot orientation and quadrats.

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

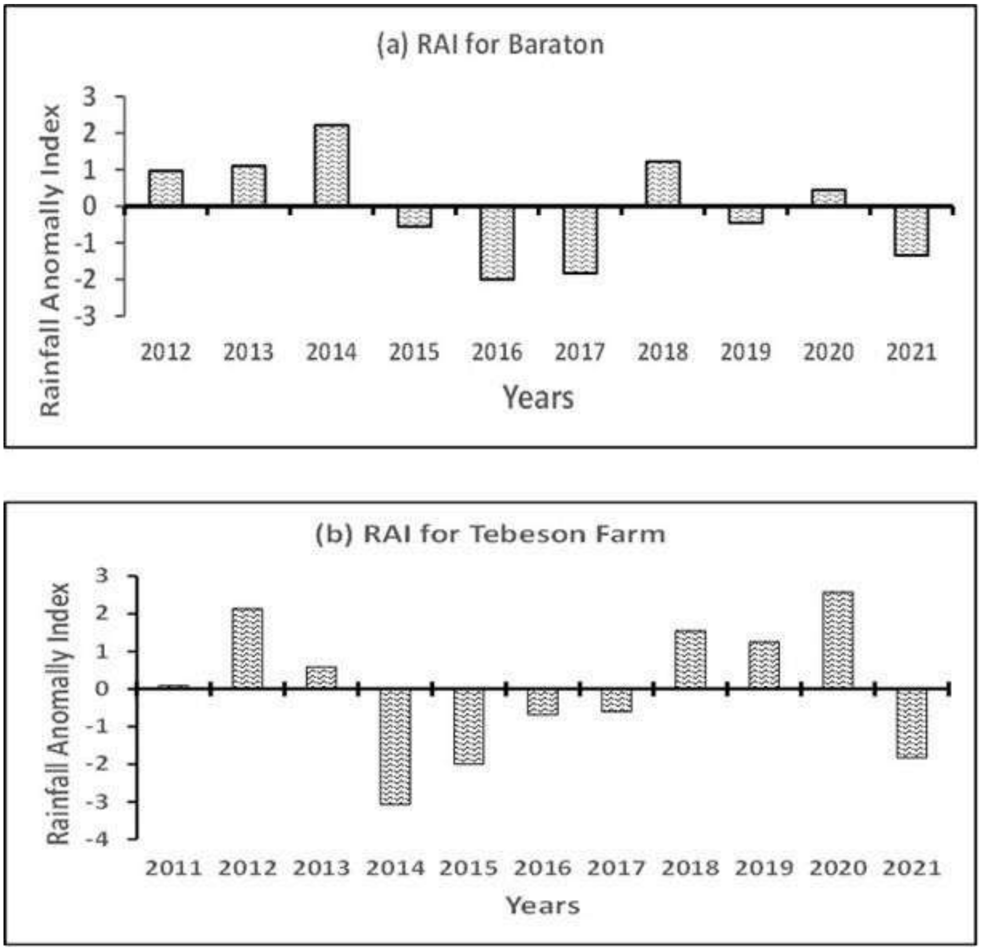

Figure 3. A time series of seasonal Rainfall Anomaly Index (RAI) at (a) Baraton (20122021) and (b) Tebeson Farm stations (2011-2021) in King'wal Riverine wetland, Kenya.

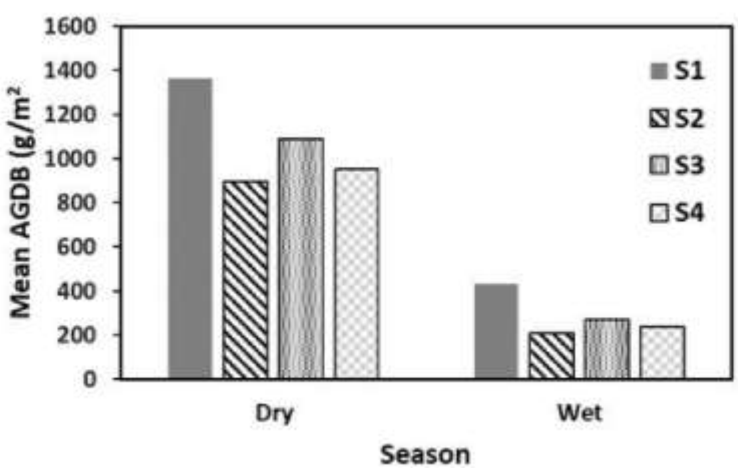

Figure 4. Seasonal variation in macrophytes' above ground dry biomass in the four study sites (S1 and S3 least disturbed and S2 and S4 most disturbed) in King'wal riverine wetland during the period covering September 2021 to August, 2022.

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

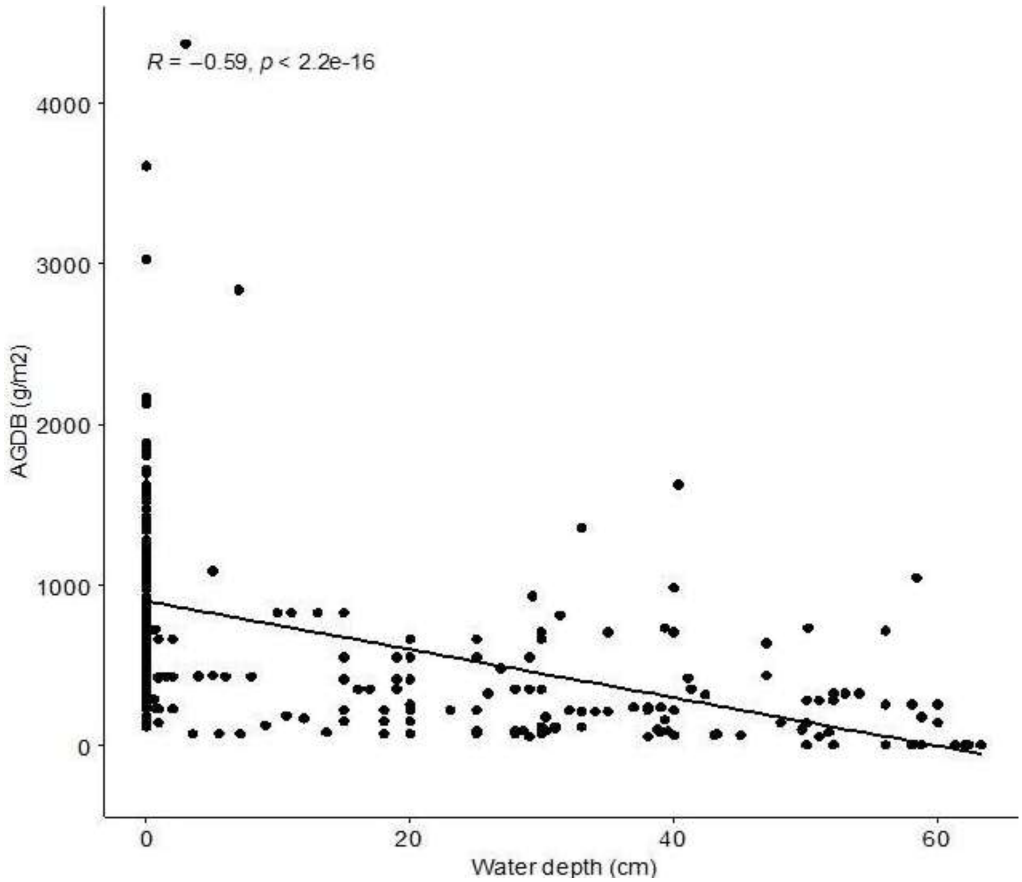

Figure 5. Relationship between water depth and above ground dry biomass (AGDB g/m^2) of emergent macrophytes using the Spearman's correlation over the study period (September 2021 to August 2022) in King'wal riverine wetland.

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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Stakeholder perceptions of wetlands management effectiveness in Cameroon

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Wetland ecosystems and the fisheries that depend on them are vital to the survival of million individuals in poor nations. Although this habitat is contracting because of heavy pressure brought on by the expansion of the population and the increase of human activity in Cameroon. Yet it is crucial to evaluate the management practices used to ensure its durability. In this study, we look into wetland stakeholders' perspectives. Therefore, it is important to assess the management to make a strategic suggestion for the formulation of a national strategy. Totaling, 277 individuals were interviewed from the Rio del Rey, Ebogo, Barombi, and the Cameroonian portion of Ntem wetlands, and Dschang's municipal lake. The samples were taken utilizing a structured questionnaire between 4 February and 20 July 2001, when fishing was at its peak. Results show that 95.6% of management actors believe that this ecosystem is significant and valuable (χ^2=21.965; ddl = 15; P=0.015); furthermore, the results show that 86.7% of respondents are unaware of any laws or other legal instruments that are currently in effect. From one site to another, there were substantial differences in how local management committees were seen (χ^2=27.29; P<0.05). Additionally, various institutional issues discussed include the following: weak institutional cooperation (28%)> inadequate legislative policy (24%)> conflicts of interest (21%)> inadequate funding (18%)> lack of political will on the part of the authorities (6%%)> inadequately qualified people (3%). The study also shows that Cameroon's wetland suffers from a lack of adequate restrictions. Consequently, it is essential to implement wetland management strategy.

Key words: Wetlands, national strategy, sustainable management, perception, Cameroon.

INTRODUCTION

Worldwide, wetlands cover approximately 15 million hectares, predominantly in countries blessed with tropical or subtropical climates. In Africa, there are over 3.2 million hectares of wetlands, accounting for 19% of the

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global wetland coverage. This corresponds to an area of about 20,410 km^2 (12% of the world's mangroves) (Ajonina et al., 2005; Alongi, 2009). The wetland ecosystem and its associated fisheries are critical to the livelihood of 275 million people in developing countries who traditionally harvest timber, non-timber forest products, shrimp, fish, and fuel wood from them (UNSG, 2011). Wetland ecosystems also support essential ecological, cultural, and aesthetic functions. Specifically, they export materials that support near-shore food webs, including prawns and shrimp (Rodelli et al., 1984; Sasekumar et al., 1992); they intercept pollutants, land-derived nutrients, and suspended matter before these contaminants reach deeper water (Marshall, 1994; Rivera-Monroy et al., 1995). Furthermore, wetlands host a wide variety of biodiversity, providing habitats for fauna including mammals, fish, crustaceans, reptiles, amphibians, avian species, and aquatic and terrestrial insects (Hogarth, 2015).

The anthropogenic activities impact land use and land cover across the extent of the world's mangroves (Thomas et al., 2017). Thus, wetlands perform multiple intangible and tangible services to humans and the environment. Unfortunately, this ecosystem is shrinking under heavy pressure from the intensification of human activities, environmental changes, rapid rising economies, and population growth (Short, 2003; Turner et al., 2002). The rate of wetland loss has reached the proportion of a national crisis (Wanzie, 2003). The recent loss of tropical wetlands area is a result of the conversion of wetlands to other land uses such as agriculture, mariculture, aquaculture, urbanization, coastal developments, forestry, and degradation due to pollution from pesticides and fertilizers. The loss of mangroves for oil palm plantations is a result of rising erosion, rising sea levels, and increased sedimentation, which are also causing mangroves to recede in Central Africa (Ajonina et al., 2008). According to FAO (2005), approximately 8% of mangrove cover in the last 25 years has been lost in the Eastern Africa region, with an average of 30% in West-Central Africa since 1980 (UNEP-WCMC, 2007). Globally, these provisioning services provided by wetland ecosystems are diminishing, putting the livelihoods of coastal communities at risk. The loss of wetlands has led to the loss of lives by increasing their vulnerability to natural phenomena such as tropical storms, surges, inundation, hurricanes, and tsunamis or cyclones. Moreover, the rapid growth of the human population has led to an increasing demand for fisheries resources in the Cameroonian market, and the technology made available to fishermen is of high quality and has therefore led to further destruction of wetland areas (Feka et al., 2009).

Given the importance of ecosystems and the risks involved in their disappearance, it is therefore mandatory to emphasize the sustainability of natural resources for poverty alleviation. The Cameroon government and several non-government organizations (NGOs), such as the Cameroon Wildlife Conservation Society (CWCS), have set up and implemented strategies geared towards the conservation and better management of wetlands (Ajonina et al., 2016). Some studies have been done on the sustainable management and development of wetlands in Cameroon, but none of them have specifically focused on the national strategy for wetlands management in Cameroon. Mangroves, rivers, and oceans are frequently the subject of attention, but no overarching wetlands management strategy has yet been established. Wetland conservation has become increasingly accepted as an important issue. Cameroon ratified the Convention on Wetlands of International Importance (Ramsar) Convention that was adopted in 1971, amended in 1982, and ratified in 1987. On March 20, 2006, Cameroon gained access to the Convention on Ramsar and currently has 7 sites designated as Ramsar sites (about 827.060 ha) (Kometa, 2013; Kometa et al., 2018). In addition, the major recent achievements under the wetlands conservation program in Cameroon are as follows: promoting training activities and public education; actively promoting legislation and policy; strengthening the wetland management and protection institutions through the establishment of a national wetland management strategy (Ajonina et al., 2008; Kometa et al., 2018; Mzoyem et al., 2019; Wanzie, 2003). The implementation of a national strategy could contribute to both national wetlands conservation and global mitigation of climate change and will aim to address urgent problems related to wetland ecosystem conservation and management. Moreover, it can reduce poverty and the dependence of coastal communities on services rendered by wetlands. It is therefore crucial to know the perceptions of stakeholders in wetland management in order to better understand current realities and future challenges. The aim of this study is to determine measures of wetland management in Cameroon, at which level they are implanted, and what are the strategic axes to be improved for the good management and sustainability of wetlands.

MATERIALS AND METHODS

Description of the study site

A total of 05 sites located in different regions of Cameroon (Latitude: 03°23'09"N - 5°26'57"N and Latitude: 8°43'E - 11°29'20"E) covering 208.400 ha were selected for this study. These sites included four Ramsar sites: the Ebogo wetland, the Cameroonian part of the Ntem River, Lake Barombi Mbo, the Rio Del Rey estuary, and one non-Ramsar site: the municipal lake of Dschang (Figure 1 and Table 1). The sites were those wetlands mostly managed under the Ministry of Environment and Sustainability (MINEPDED) or a private company. Site selection criteria included accessibility to riparian populations, financial resource availability, and safety status in the selected area. Semi-

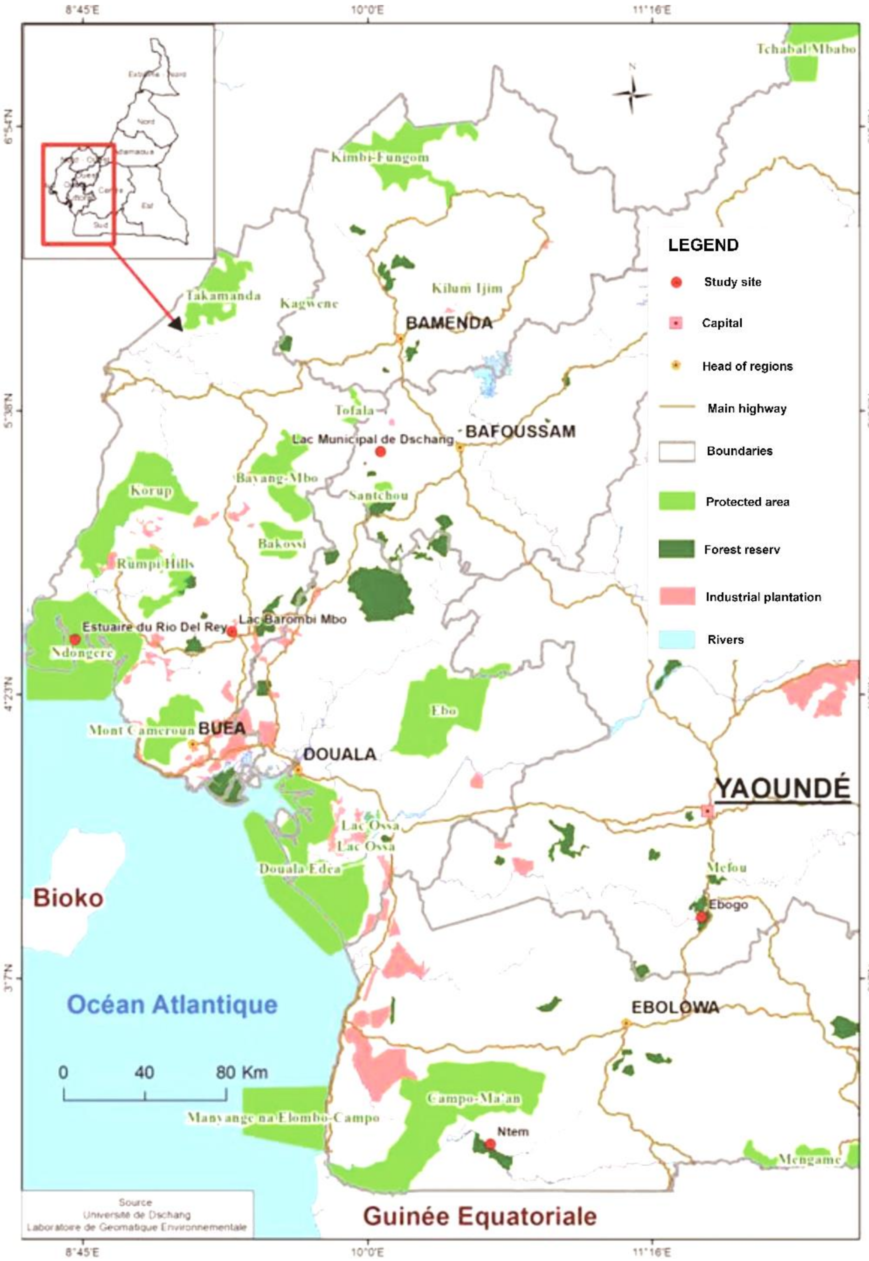

Figure 1. Study sites.

structured questionnaires, a digital camera, boots, a coat, a notebook, and a computer were used to facilitate data collection.

Data collection

Relevant data for the study were obtained from primary sources using structured questionnaires and interviews (Photo 1). A total of 277 questionnaires were administered across five sites during the period between November 2016 and June 2017. The target populations were the government institutions in charge of managing wetland (24.90%) (MINEPIA, MINFOF, MINEPDED, MINADER, MINEPAT, MINRESI, MINESUP), three NGOs (FAO, UICN, WWF), and the coastal communities (75.1%) (Table 2). The total number of participants was determined randomly, and every participant was chosen according to their availability during the field study period and their implications for wetlands. People of various sexes, ages, and groups involved in different stages of the activities in the wetland were consulted to provide a balanced picture of their perception. The information was collected on the following aspects: knowledge of wetland and the use of its resources; management policies; the existence of the laws that regulate the management of wetland; the main problems related to the regulated management of wetland; their opinion on what has already been done in the management of wetland at different levels (local and national); and the implementation of a national wetland management strategy.

Data analysis

The socio-economic data were analyzed using simple descriptive statistics. The Chi-square and homogeneity test, and Pearson correlation were used to determine the independence of the parameters from the variables. SPSS software v23.0 was used for data sorting and analysis. The Chi-square is denoted by χ^2, and the formula is (Ajonina et al., 2005):

$$\chi^2 = \sum_{i=1}^{t} (n_i - t_i)^2 / t_i \ ,$$

where χ^2= Chi square value test; n_i= frequency observed in a class; and t_i = Expected frequency.

RESULTS AND DISCUSSION

General knowledge of the respondents regarding wetlands in Cameroon

The survey of 277 hearings revealed that only 10.1% had a good knowledge of wetlands in general and their distribution in Cameroon in particular. This suggests that the majority of the respondents had limited or insufficient knowledge about wetlands and their geographical spread within the country. The survey results highlight the need for more awareness and education regarding wetlands among the general population. Indeed, some actors exploiting the resources of this ecosystem like fishermen had never heard of wetlands while using it for they daily income. Our study highlighted the need for improved communication strategies to raise awareness among the population. According to Abbot et al. (2001), there is a dearth of knowledge about wetlands due to insufficient awareness campaigns and educational programs. However, among the 10.1% of respondents with good knowledge, based on educational level, university-educated had a better understood of the concept of wetland. This indicates that there was a higher awareness of wetland among university-educated respondents, possibly due to the higher level of environmental education they receive compared to those without university education. Based on respondents' daily activity, fishermen followed by farmers was those who have recognized wetlands and their importance. This was explained by the fact that their subsistence activities and sources of income depend on this ecosystem. The majority of activities carried out by riparian populations at its sites have been passed on from one generation to another. Although previous studies suggested a strong gender differentiation in the activity in the use of services provided by wetlands (Ajonina et al., 2005), indeed, our study showed that age and gender do not have a significant influence on their knowledge of wetlands (P=0.06). About 95.6% of actors involved in management thinks wetlands are important (χ^2 = 21.965, ddl = 15, P = 0.015). It also shows that there is a highly significant difference between the sector of activity (χ^2=104.969, ddl = 5, P = 01001).

Perceptions of the respondents regarding wetland management in Cameroon

Perception of the local communities regarding wetland management by local communities in Cameroon

The data analysis of the question based on the existence of effective regulation for wetland management reveals that 86.7% of respondents are not aware of the existence of any law or instrument in force. While 9.84% of them said with certainty that there was no law, 3.46% were not convinced of its existence. These results revealed a lack of awareness of wetland management. These results also reflect the lack of awareness of the management of these ecosystems and the penalties incurred. This lack of awareness can have detrimental effects on the preservation and conservation of wetland areas. Without proper knowledge of the laws, individuals may unknowingly engage in activities that harm the delicate ecosystem of wetlands. Additionally, a lack of awareness can hinder the enforcement of these laws, as people may not report violations or take necessary action to prevent damage to wetlands. Therefore, as Jennifer and Loewenstein (2000) concluded, it is crucial to address this issue of awareness and educate the public about wetland management laws to ensure the effective preservation of these valuable ecosystems.

On the other hand, the Chi-^{2} test shows as sex (χ^2 = 0.928, ddl = 1, P > 0.05), age (χ^2 = 0.54, ddl = 2, P > 0.05) and level of study (χ^2 = 3.517, ddl = 2, P > 0.05) did not influence the perception of the respondents (Table 2).

The perception of the existence of local management committees varied significantly from one site to another (χ^2 = 27.29, P < 0.05) linked to the fact that the riparian communities tend to organize themselves for the sustainable management of their sources of daily incomes. However, there is a significant difference in perception of management measures from one site to another (χ^2 = 11.55, P = 0.021) (Table 3). This result can be explained by the fact that the severity of the threat was not the same from the coast to the south. The presence of an effective local management community in some sites leads to awareness of its populations in the management of wetlands (biodiversity) in a sustainable manner. These differences can also be explained by the degree of use and the benefits to populations of wetland

Table 1. Description of the study sites

Wetlands	Location	Administrative region	Areas (ha)	RAMSAR N° site
Municipal lake of Dschang	5°26'57"N - 10°04'05"E	West	40	No classify
Barombi Mbo Crater Lake	04°40'N - 09°22'E	South East	415	1.643
Estuaire of Rio Del Rey	4°37'N - 8°43'E.	South West	165.000	1.908
Ebogo wetland	03°23'09"N - 11°29'20"E	Centre	3.097	2.068
Cameroonian part of the Ntem River	02°22'45"N - 10°33'13"E	South	39.848	2.067

Table 2. Characterization of the stakeholders.

Variable	Number of stakeholders	Sex ratio		Age			Education level	
		M	F	<35	35-55	>55	High school	University
Institutions	60	93	7	/	70	30	6	94
Coastal communities	208	79.7	20.3	17.87	58.45	27.68	60.59	9.36
NGOs	9	90	10	/	69.57	30.43	5.88	94.12

Table 3. Analysis of respondents' perception of the existence of law on wetland management in Cameroon.

Question	Response	Sex		Age						Level of education					
				<35		35-55		>55		Primary school		Secondary school		University	
		W	M	W	M	W	M	W	M	W	M	W	M	W	M
Is there a specific law on wetlands in Cameroon?	Yes	3	24	0	3	3	20	0	4	0	1	0	0	0	26
	No	2	39	0	3	2	28	0	9	0	0	5	3	0	38
Test of Chi[2]	χ^2	0.928				0.54						3.517			
	P	0.335				0.763						0.172			
	ddl	1				2						2			
	Sig	NS				NS						NS			

P: Probability; ddl: degree of liberty; Sig: significant; NS: non-significant; S: significant; W: women; M: male.

services. In line with our statement, previous studies reported that by implementing robust wetland management laws, governments can establish clear guidelines and standards for wetland protection, restoration, and sustainable use because these laws can help prevent further

Table 4. Analysis test of existing management tools for the study sites.

Question	Response	Sites					χ^2	Ddl	P	Sig.
		Barombi	Dschang	Rio del Rey	Ebogo	Ntem				
Is there a local management committee for your wetland?	No	42	118	60	88	101	27.29	4	0	S
	Yes	38	34	44	25	620				
Are there any protection measures for wetland in your locality?	No	80	154	104	110	159	11.55	4	0.021	S
	Yes	0	0	0	3	6				

P: Probability; ddl: degree of liberty; significant; NS: non-significant; S: significant; W: women; M: male.

degradation, regulate human activities within wetland areas, and promote responsible land use practices (Clare et al., 2011; Jenni and Loewenstein, 1997). Therefore, there was a need for important actions to maintain a balance between the ecological potential of the remaining mangrove ecosystems and the needs of the local coastal communities.

Perceptions of institutional actors regarding wetland management in Cameroon

The results presented in Table 4 show that there was a highly significant difference in the actor's perception of the institutional context, the existence of a wetland policy, or a global law for wetland management in Cameroon. The results also showed that the actors working in MINEPDED, MINFOF, and NGOs have better knowledge of the regulations relating to the management of wetland (ddl = 20, $P < 0.05$) compared to other institutions such as MINEPAT. Although 86.6% of its actors believed that there was a wetland management policy in Cameroon and 89.9% believed there were laws for wetland management in Cameroon, 66.5% of them agreed that the current institutional context in Cameroon was not conducive to the sustainable management of wetlands.

Although, according to the existing policy and legal framework review, this study indicated that there was no specific policy for wetland management in Cameroon. The management of mangroves, which are one type of wetlands, falls under Cameroonian legislation of 1994 on forestry, wildlife, and fishing. This result is in concordance with those found by Ajonina et al. (2008), who reported that Central African countries suffer from a lack of appropriate legislation.

Perception of threats and consequences related to the management of wetlands in Cameroon

Shortcomings linked to or threatening the management of wetlands

Here, we highlighted the thoughts of multiple actors involved in wetland management about the current institutional context in Cameroon. The different institutional problems mentioned were as follows: Weak institutional collaboration (28%) > insufficient legislative policy (24%); conflicts of interest (21%); insufficient funding (18%); lack of political will by the authorities (6%); insufficiently qualified personnel (3%). This highlights the importance of enhancing cooperation between institutions to address wetland management effectively. Other issues, such as insufficient legislative policy, conflicts of interest, and insufficient funding, contributed significantly to the overall complexities of wetland management. According to Calhoun et al. (2017), one significant challenge was the lack of coordination and communication among different stakeholders involved in wetland management. Additionally, these multiple gaps are linked to the absence of a specific institution responsible for the management of these highly vulnerable ecosystems. The absence of this organ leads to a lack of understanding of the role played by each actor in wetland management. Research conducted by Kometa (2013) revealed that insufficient training appears to be the least of the problems identified by the respondents, which suggests that the stakeholders were more focused on the financial aspect.

About the main threats to wetland in Cameroon,

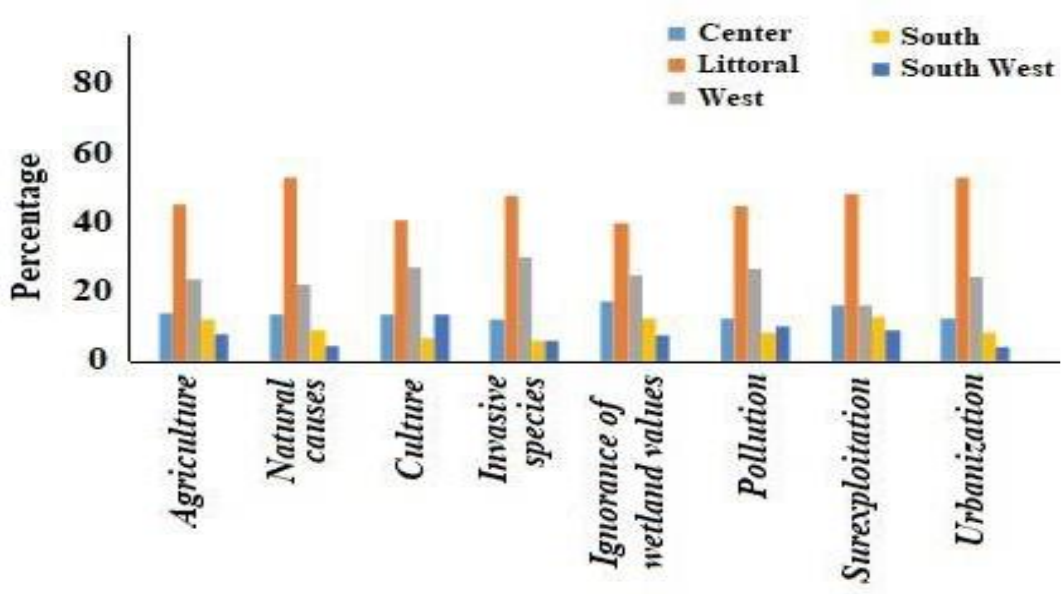

Figure 2. The different threats of wetland following the regions.

the respondents noted the following points: over-exploitation, the presence of invasive species, urbanization, agriculture, pollution, ignorance of wetland values and their importance, natural causes (erosion, climate change, etc.) (Figure 2). According to Feka et al. (2009), about 42.839 m^3 of mangrove wood is extracted annually around the Douala-Edea Reserve in Cameroon (Yoyo I, Yoyo II, and Mbiako) for fish cooking and/or smoking. The threat analysis revealed that over-exploitation (37%), urbanization (23%), agriculture (21%), and pollution (12%) were the main threats exerting the greatest pressure on wetlands in relatively all the sites studied. This distribution varies from one region to another, probably because of the different challenges they face and their needs (Figure 2). The littoral region was dominated by overexploitation, urbanization, fisheries, agriculture, invasive species, and cultures. The same causes were identified in the West, but with less significance. The southwest region was dominated by insecurity. Overall, the littoral region was the one with the most threatened wetlands, followed by the west region and the south. By the way, it is well documented that mangrove wood, for instance, is an important livelihood and source of energy for coastal communities in West-Central Africa (Walters et al., 2008).

Moreover, 72% of the respondents believed that this ecosystem is overexploited, which can be explained by the regulatory and institutional vacuum, hence the need to develop a specific national strategy for wetland sustainable management in Cameroon. These results were similar to those of the research conducted by Ellison and Zouh (2012) on mangrove management. The overexploitation of these environments included the loss of mangrove productivity services, disturbance of ecological processes, and harmful repercussions such as the decrease in the area of the sites, the disruption of the services rendered by this ecosystem, the emergence of new invasive species, the degradation of its habitats, water conflicts for agricultural and livestock breeding, the disappearance of some wildlife species, the reduction of water volume, and the increase in poverty as revealed by Kometa (2013) and Kometa et al. (2018).

Strengths and weaknesses of management tools

Wetland conservation in Cameroon requires the implementation of various management tools to ensure the effective preservation and sustainable use of these valuable ecosystems. Several management tools have been employed in wetland conservation efforts in Cameroon, and their strengths as well as weaknesses are presented here.

Strengths

Cameroon, being rich in biodiversity, presents a unique set of challenges for wetland conservation. However, management tools have been developed to address these challenges and ensure the effective conservation of wetlands in the country. Some strength of these management tools are: favorable international context with ratified conventions, including those that protect wetlands; the major players in the management of mangroves and associated wetlands are generally known; existence of comprehensive environmental protection regulations in Cameroon; several donors are interested in the sustainable management of Cameroon's wetlands. The framework law imposes the implementation of environmental impact studies on projects by industrial enterprises. According to Wanzie (2003), these tools have facilitated the involvement of various stakeholders, including local communities, government agencies, and non-governmental organizations, in the decision-making processes related to wetland conservation in Cameroon. This participatory approach allows for the incorporation of diverse knowledge systems, perspectives, and priorities, leading to more comprehensive and sustainable wetland management strategies.

Weaknesses

Management tools for wetland conservation in Cameroon have several weaknesses that hinder their effectiveness. Feka et al. (2009) reported that one of the major weaknesses in Cameroon was the lack of adequate funding and resources. Wetland conservation requires substantial financial investment for activities such as monitoring, restoration, and enforcement of regulations. However, the limited funding available for wetland management in Cameroon often results in inadequate staffing, a lack of equipment, and insufficient research and monitoring. Our study highlighted other factors, such as the physical framework of wetlands, which is still not well known. Lack of a national wetland management strategy in Cameroon; conflicts of jurisdiction between different administrations related to overlapping responsibilities, poor coordination, or insufficient capacity; weak EIA analysis focuses on wetlands for major investment projects or lacks monitoring of the implementation of environmental management plans; low inclusion of wetlands in global laws; policy gap and multi-sectoral strategy for sustainable wetland management; poor local organization of the population through the lack of local management committees; lack of developmental initiatives by the population; few Ramsar sites exist despite the diversity and richness of Cameroon's wetlands.

Focal points for the establishment of a national strategy

The analysis of the data showed that 90.9% of the respondents were in favor of the development and implementation of a national wetland management strategy. Regarding the approach to be followed, 77.78% of respondents were interested in a centralized approach, while 27.25% were in favor of a decentralized approach. The χ^2 test carried out shows that there was no significant association between the way an individual perceives the development of a management strategy and his gender (χ^2 = 0.169, ddl = 1, $P > 0.05$), his age (χ^2 = 1.031, ddl = 2, $P > 0.05$) or his level of education (χ^2 = 0.432, ddl = 2, $P > 0.05$) (Table 5 and 6). These challenges could be overcome by developing fundamental adaptive and sustainable strategies (Feka et al., 2009). The implementation of this strategy must integrate existing activities and initiatives in the process of starting up. At the level of local populations, several actions were underway. The development of this action plan was suggested to be based on the achievements of the present actions, which were achieved with good results by local communities. In addition, for reasons of complementarity, the action plan must integrate all the initiatives that are consistent with the provisions of the Poverty Alleviation Strategy and the national biodiversity strategy. Thus, the strategic axis formulated with regard to the current situation of wetland management in Cameroon is as follows (Table 7).

Axis I: Regulating access to wetland resources and the rural economy of wetland

By developing sustainable cultivation and breeding practices in wetlands and creating alternative activities to overexploitation that ensure conservation and renewal of resources.

Axis II: Establish a governance system and a legal framework specific to wetlands

This axe includes institutional and human capacity building. The establishment of a harmonized legal and institutional framework and the consideration of wetland at all levels of decision-making.

Axis III: Preserve and reclaim wetlands

Here, it includes participatory management of wetlands classified as Ramsar sites in order to promote sustainable management and research in wetland ecosystems; promote sustainable techniques for the exploitation of natural resources.

Axis IV: Improve the management and planning of watersheds

Restoration or rehabilitation of wetland ecosystems to curb and reverse their degradation in order to increase their production functions.

Table 5. Stakeholder knowledge analysis test of wetland management tools in Cameroon.

Questions	Response	CTD	MINADER	MINEPAT	MINEPDED	MINEPIA	MINESUP	MINFOF	MINRESI	ONG	OSC	PRIVE	χ^2	Ddl	P	Sig
Does the current institutional context favor the sustainable management of the wetland?	No	4	20	16	25	13	13	39	0	32	15	7				
	Yes	6	7	15	45	12	19	20	4	6	7	8	78.704	20	0.001	S
	Don't know	0	0	0	3	4	7	11	3	14	10	6				
Is there a wetland management policy in Cameroon?	No	0	23	21	37	17	7	42	4	37	14	8				
	Yes	10	4	10	36	7	32	20	0	15	14	0	182.557	20	0.001	S
	Don't know	0	0	0	0	5	0	8	3	0	4	13				
Is there a law for the management of wetlands in Cameroon?	No	0	9	21	10	9	7	20	0	8	4	8				
	Yes	10	16	10	60	20	25	50	4	30	24	0	147.609	20	0.001	S
	Don't know	0	2	0	3	0	7	0	3	14	4	13				

Table 6. Respondents' perceptions of the development of a national wetland strategy

Question	Response	Sex		Age						Level of education					
				<35		35-55		>55		Primary school		Secondary school		University	
		F	M	F	M	F	M	F	M	F	M	F	M	F	M
What do you think of the development of a national wetland strategy?	Need	1	18	0	3	2	10	0	4	0	0	1	0	0	18
	Important	4	45	0	4	3	35	0	9	1	0	2	0	2	44
Test Chi^2	χ^2	0.169		1.031						0.432					
	P	0.681		0.597						0.806					
	ddl	1		2						2					
	Sig.	NS		NS						NS					
What approach do you recommend?	Centralized	5	40	0	4	5	32	0	4	0	1	0	2	4	38
	Decentralized	0	23	0	3	0	10	0	9	0	0	0	1	1	21
Test Chi^2	χ^2	2.758		10.087						0.52					
	P	0.097		0.006						0.771					
	ddl	1		2						2					
	Sig.	S		HS						NS					

F: Female; M: Male.

Table 7. Strategic axes for the implementation of a national wetland management strategy.

GLOBAL OBJECTIVE: PROMOTING SUSTAINABLE MANAGEMENT OF WETLAND ECOSYSTEMS IN CAMEROON		
Specific objectives	**Expected results**	**Activities**
Axe 1: Regulating access to wetland resources and the rural economy of wetland		
Reducing overexploitation of wetland resources	Over-exploitation of wetlands is reduced	Strengthen the control of extractive activities; Define periods and areas of exploitation; Developing fish farming as an alternative to overfishing.
Enhance positive experiences and initiate actions on wetlands in urban areas	Wetland experiences are valued	Valuing agricultural products from wetlands; Developing ecotourism in wetlands
Axe 2: Establish a governance system and a legal framework specific to wetlands		
Ensure collaboration between stakeholders	Collaboration between stakeholders is ensured	Encourage the establishment of local management committees; Develop communication, awareness and training on wetlands
Harmonization of sectoral policies	Sectoral policies are harmonized	Develop/update mangrove policies and legislation Integrating wetlands into the process of creating protected areas
Axis 3: Preserve and reclaim wetlands		
Reduce encroachment on wetlands	Wetland encroachment is reduced	Develop participatory management plans for sites of international importance; Develop participatory management plans for sites of international importance and accelerate the preservation of the most sensitive wetlands; Control the proliferation of invasive species; Reducing various forms of pollution
Axis 4: Improve the management and planning of watersheds		
Managing wetlands in a rational way	Wetlands are managed rationally	Reforest degraded mangroves; Avoid wetland drainage
Improving knowledge of wetlands	Wetland knowledge is improved	Assess the potential for carbon storage by Cameroonian mangroves; Assessing the animal and plant potential of wetlands; Mapping wetlands and updating them to make them available to decision makers; Increase awareness of wetlands (general public and school); Strengthen the technical skills and capacities of actors for the sustainable management of Cameroon's wetlands.

Conclusion

The absence of specific laws on wetland management was identified as a constraint on management at the national level. However, laws do exist for the protection of the environment in a general framework and of its natural resources. Wetland management tools are therefore based on regulatory modalities and are not well known.

At the institutional level, there is the national Ramsar committee. The main weaknesses are the fact that the national Ramsar committee has no function, conflicts of interest, and a lack of specified staff at the institutional level. The recommendations for integrated management are based on four strategic areas: (i) regulating access to wetland resources and the rural economy of wetland; (ii) establishing a governance system and a legal framework specific to wetlands; (iii) preserving and reclaiming wetlands; and (vi) improving the management and planning of watersheds.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Energy flow management to enhance cost-effective crop production in Hilly Tribal Villages - Southern Odisha, India

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The objective of this study is to assess the energy budget of crop production in the Niyamgiri hill agro-ecosystems, exploring the interdependency between agricultural systems and natural forest ecosystems. The cultivated area is categorized based on different cropping patterns, with four prevalent agriculture practices in the villages: (i) shifting cultivation (Podu) in high hill areas, (ii) mid-hill orchards below the Podu area, (iii) home gardens adjacent to habitations, and (iv) valley cultivation near stream beds. Distinct differences in energy input and output values were observed among the various cultivation types and villages in the Niyamgiri hill ecosystem. Hill agriculture relies significantly on the surrounding forest ecosystem and serves as a major energy consumer. The energy dynamics data reveal that biomass from the forest plays a crucial role in the material flow of the village ecosystem. This is evident through its contribution to minor forest products, firewood, small timber (poles) and bamboo. These village ecosystems rely entirely on biomass for fuel and fodder, highlighting their dependency on the nearby forest. Examining import and export figures for various food items indicates that tribal village ecosystems are open and partially independent. Achieving sustainable production requires an interdisciplinary approach, with collaboration between the agriculture, horticulture, and forest departments. Enhancing animal resource output has the potential to improve socio-economic productivity. Furthermore, value addition to agriculture and horticulture products in villages can boost the local economy and livelihoods, reducing dependency on natural resources in the region.

Key words: Agroecosystem, energetics, horticulture, natural resources, forests, Dongaria, tribal, villages.

INTRODUCTION

Hill agriculture lands are undulating sites where human inhabitants engage in complex poly-culture and agroforestry practices. The traditional cultivation methods on the ridges and in valleys by small farmers prove reasonably productive and stable, exhibiting a high return per unit of labor and energy (Netting, 1993). This type of agriculture closely resembles natural ecosystems, not only in physical structure but also in terms of the organic

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environment, disease-resistant rich biodiversity, and stability. Despite being mostly rainfed, the sustainability of this agriculture practice has been proven over centuries.

Small and marginal farmers cultivate using long-tested traditional varieties, showcasing a lack of reliance on genetic conservation and taxonomy knowledge. However, their farming practices indirectly contribute to the conservation of biodiversity, making them key players in maintaining the sustainable natural gene pool. Ethnic tribal communities residing in remote hilly areas practice subsistence organic farming, utilizing natural resources such as soil and water. They cultivate in small-scale diversified systems, employing local resources and complex crop arrangements in valleys and slopes. These people, living in tropical hilly regions, are extremely poor, relying on the vast, diverse and risk-prone marginal environment (Conway, 1997).

A scientific ecological approach is crucial to developing systems and technology tailored to the specific environmental and socio-economic conditions of small farmers without increasing risk or dependence on external inputs. Agro-ecosystems should be resource-conserving yet highly productive systems, incorporating practices such as polyculture, agroforestry and the integration of crop and livestock (Altieri, 1995). Understanding and appreciating the services provided by various ecosystems, including agro-ecosystems, could help address the challenges of ecosystem management for long-term sustainable food production.

The study on the flow of energy through an ecosystem is useful in understanding its functioning (Loucks and Dalesio, 1975). Traditional hill and hinterland agricultural production systems in India are solar-powered ecosystems (Mitchell, 1979), as all work depends on solar energy to produce crops, ultimately consumed by humans and animals. The present study analyzes the energy budget of crop production in hill agro-ecosystems of the Niyamgiri range in Rayagada district, Odisha, situated in the eastern part of India. The study also discusses the interrelation between agro- and natural ecosystems.

The Niyamgiri Hill Range comprises about 164 villages dependent on forest resources for their livelihood. The magnitude of changes due to the interdependency of agro-ecosystems and forest ecosystems has led to both ecological and economic erosion.

LITERATURE REVIEW

Various studies on tribal village ecosystems in India have addressed biomass production, consumption, material and energy dynamics (Rabindranath et al., 1981; Nisanka and Mishra, 1990; Nayak et al., 1993). The tribal village ecosystem in India primarily functions by recycling resources within the system (Mishra and Ramakrishnan, 1982), and the practice of converting forest to agriculture by tribal people has been a traditional cultivation method (Schenldar, 1995; Anderson, 1990). The ecosystem is dynamic, and model cultivation practices must be developed in tropical areas to address converted ecosystems (FAO, 1993).

The tribal population traditionally maintains a close connection with nature, and studying their relationship with the environment provides insights into socio-economic and cultural links within the ecosystem (Sahoo and Misra, 1992; Rao et al., 2003). Biomass energy and human labor are driving forces for the functioning of agriculture-based village ecosystems (Nisanka and Mishra, 1989; Rao et al., 2003). Ecologists have attempted to correlate changes in plant and animal diversity with different scales of natural/anthropogenic disturbances (Van Der Maarel, 1993; Nautiyal et al., 2003; Maikhuri et al., 2004), emphasizing the need to improve agro-ecosystem production through rainwater management, the application of organic manure, protection of existing forests, and agroforestry practices (Dash and Mishra, 2001).

Traditional resource management and agroforestry systems may lead to improvements in livelihoods through the simultaneous production of food, fodder, and firewood, as well as the mitigation of the impact of climate change (Rabindranath and Hall, 1995).

Agroforestry systems may provide part of the answer to the challenge of sustainability, that is how to conserve forest ecosystems and farmland biodiversity, along with the services they provide, while simultaneously enhancing food production for an increasing population under conditions of land and water scarcity (Lambin and Meyfroidt, 2011; Godfray et al., 2010; Phalan et al., 2011). The villages in and around the Niyamgiri Hill Range derive their livelihoods from forest resources. The practice of traditional agriculture and the inter-dependency of the agro-ecosystem and the forest ecosystem have impacted both ecological and economic conditions in these ecosystems. Studies of ecosystem linkages and socio-cultural changes are essential to develop strategies to arrest further degradation of the ecosystem and suggest priority sectors for improvement.

Study objectives

The current study focuses on the energetics of the village agro-ecosystem surrounding Niyamgiri forests, aiming to propose strategies for achieving conservation objectives and ensuring the compatibility of the village ecosystem with ecological requirements. The sustainability of the agro-ecosystem, its dependency on the forest ecosystem, and the economic development of the community were examined in terms of resource and energy flow, with the following major objectives:

1. To investigate agricultural practices, animal husbandry and other economic activities in villages around the Niyamgiri Forest.
2. To assess the impact of various practices on society and the forest, considering changes in culture and tradition.
3. To compare energy dynamics between villages closer to urban areas and those farther away from urban centers.
4. To identify linkages between the human community and the forest ecosystem and propose a sustainable model.

MATERIALS AND METHODS

Study area overview

The Niyamgiri Hill Ranges extend across four blocks in the Rayagada District of Odisha, India. For this study, the Bissam Cuttack block was chosen due to the accessibility of villages. The Niyamgiri hill range is predominantly covered by Shorea robusta forest, and the practice of shifting (Podu) cultivation is widespread. The tribal population residing in the range belongs to the Kandha tribe, specifically the 'Dongria Kandha,' considered a primitive tribal group settled in high-altitude areas above 600 to 700 m elevation.

For the study of agro-ecosystems, four villages at higher elevations inside the Niyamgiri Forest and four villages situated at the foothills of Niyamgiri were selected. Among the foothill villages, two are closer to the market place (urban area), and two are a bit farther away. The villages inside Niyamgiri Hill Forest at higher altitudes include Patlamba, Rodanga, Khajuri and Gortali. The villages at the foothills away from the market place are Majhihalma and Bhaliabhatta. The villages on the foothills located nearer to the market place are D. Kumbharbadi and Papikhunti. In total, eight villages were selected for the study. The physical location map of the study area is depicted in Figure 1.

Methodology

The tropical monsoon in the region contributes an annual rainfall of 1100 to 1500 mm, primarily concentrated during the rainy season from July to September. Temperature variations in the district ranged from 6.5 to 30°C between 2009 and 2013, with relative humidity fluctuating between 40% (March) and 85% (July). The Niyamgiri forest is of the tropical dry deciduous type, predominantly featuring Sal and its associates.

Comprehensive information on the selected villages was collected through a questionnaire-cum-schedule (Annexure A). The questionnaire design drew inspiration from methods employed by Reddy (1982), Nisanka and Mishra (1989, 1990), Singh and Singh (1992), Nayak et al. (1993), and Sahoo (1993). Socio-economic data and ecological parameters of the villages were gathered during the period 2010 to 2015. Regular visits were made to the sampled villages to collect data, primarily through interviews with the family heads. Data collection began in 2010 to 2011, with individual family information recorded in the village through participatory rural appraisal (PRA) exercises. A comprehensive inventory was created, covering various aspects such as area under different crops, cropping patterns, yields, area under irrigated and rainfed crops, labor input in terms of animals and human beings, fertilizer input in terms of manure and chemicals, seed input, crop production, crop by-products, fodder requirement of livestock population, sources and supply of fodder.

An estimate of animate energy input into different crop entities was done separately. The hours spent per unit area (ha) of crops were determined by counting the total number of working men, women, children and draught animal pairs (DAP), and calculating the total hours spent by each for various agricultural operations. Total hours spent for each crop were then calculated based on the respective crop area. Energy efficiency of each system was calculated as the output-input ratio. Output was determined as the agronomic yield of the crop (grain, tuber and other edible plant parts) and the yield of crop by-products (fodder output) following Mitchell (1979). Energy equivalents were based on data from Gopalan et al. (1978) and Pimentel and Pimentel (1979), expressed on a fresh weight basis. The energy budget was calculated separately for each crop.

The study of energy flow through the village ecosystems considered both animate (human and animal) and inanimate (food, fodder, fuel and thatching material) energy sources. The energy content of imported and exported materials was expressed to estimate the inflows and outflows of energy.

RESULTS AND DISCUSSION

The human population in the uphill villages ranges from 83 to 312, while foothill villages have populations between 76 and 150. The total human population across all villages is 800, comprising approximately 500 males and 300 females, with an age distribution of 200, 500 and 100 for the age groups <1-15, 16-59 and 60+ years, respectively. The animal population consists of 90 cows, 150 buffaloes, 148 bullocks, 234 goats and 30 horses. The cultivated area represents 3.37 to 18.85% of the total geographical area of the village, with per capita cultivated area varying from 0.117 to 0.329 ha (Table 1).

Despite the limited cultivation area, families actively engage in agriculture, supporting each other in the practice. The remaining time is often dedicated to the collection of Minor Forest Products (MFP) for livelihood support. Primarily, women and children gather various leafy vegetables, tubers, mango (green and ripe), siali leaf and mahua flowers. During the rainy season, when agricultural work is less intense, the collection and marketing of firewood in headloads become common. Firewood plays a significant role in the energy flow, contributing 53.02 to 69.52% of the total energy flow of the villages (Table 2).

This energy flow underscores the village community's dependence on the forest ecosystem. Other MFP, bamboo and small timber/poles collected from the forest further enhance the participation of forest products in the total energy flow of the village ecosystem. The total human energy spent on the collection of MFP, bamboo and firewood was 101.65 GJ in Patlamba, 171.21 GJ in Rodanga, 178.09 GJ in Khajuri, 102.69 GJ in Gortali, 92.739 GJ in Majhihalma, 36.41 GJ in Bhaliabhatta,

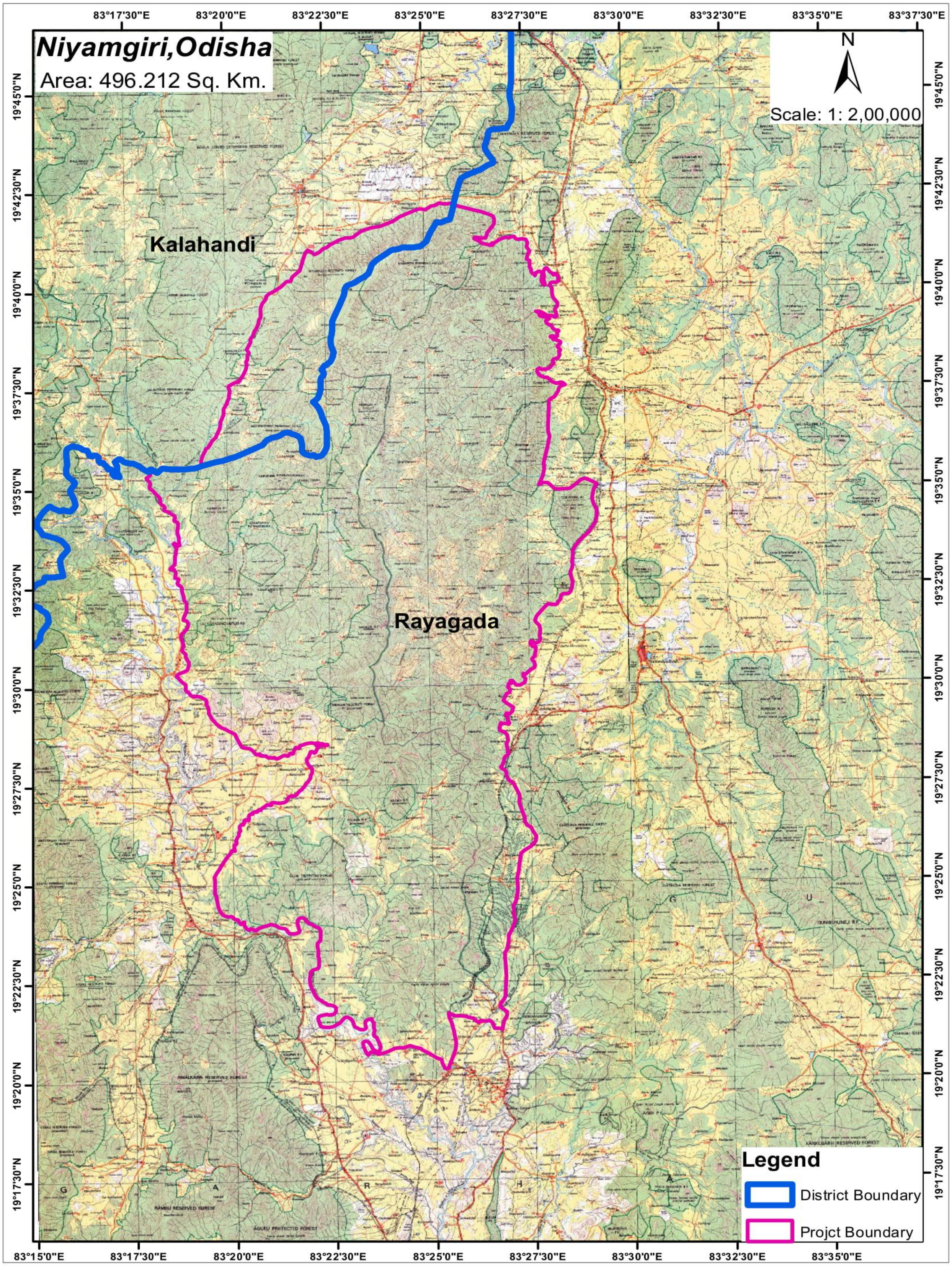

Figure 1. Topo-map of study area in Rayagada and Kalahandi districts.

Table 1. Structural analysis of village ecosystem.

Village data	Village							
	P	R	K	G	M	B	D	H
Total household	22	60	61	39	36	18	26	16
Total human population	83	279	312	201	150	90	100	76
Total male	32	129	140	87	72	44	47	45
Total female	51	150	172	114	78	46	53	31
Male:female	1:1.59	1:1.16	1:1.22	1:1.31	1:1.08	1:1.04	1:1.12	1:0.68
Average family size	3.8	4.65	5.1	5.2	4.2	5.0	3.8	4.8
Literacy rate (%)	4.8	21.86	39.4	13.9	48.0	21.1	72.0	50.0
Total livestock population	200	218	334	383	341	112	131	176
Cow	4	16	22	25	39	0	29	21
Bullock	0	6	0	0	0	19	0	6
Buffalo	0	7	0	0	0	7	0	16
Goat	83	51	67	86	78	13	42	26
Sheep	0	33	0	0	0	0	0	2
Poultry	90	90	77	173	140	73	37	99
Pig	23	15	168	99	84	0	23	6
Land use pattern								
Total land area (ha)	157.97	297.75	307.66	259.23	624.17	60.61	250.16	173.72
Aquatic	0	0	1.15	0	0	0.52	2.12	0
Housing	0.06	0.29	0.36	0.36	0.33	0.40	0.17	0.16
Uphill shifting cultivation	5.46	13.52	19.14	14.21	9.028	4.129	7.854	7.328
Mid hill (orchard)	3.1	27.83	36.68	20.43	0.1	0.04	0.1	0.06
Home-garden (Vegetables)	0.61	5.18	3.24	3.04	8.06	3.40	7.11	15.20
Valley paddy	0	7.22	0	0	10.84	3.46	13.07	0.00
Valley maize	0.566	1.235	10.809	9.514	8.016	4.574	4.777	0.554
Per capita agricultural land orchard (in Ha)	0.117	0.197	0.223	0.234	0.240	0.173	0.329	0.304

P, Patlamba; R, Rodanga; K, Khajuri; G, Gortali; M, Majhihalma; B, Bhaliabhatta; D, D. kumbharbadi; H, Papikhunti.

Table 2. Share of firewood in village energy flow (GJ).

Village	Total energy flow	Share of firewood energy	Percentage of firewood energy
Patlamba	6000.37	3798	63.29
Rodanga	9852.59	6285	63.79
Khajuri	10249.25	6390	62.34
Gortali	6407.36	3397.50	53.02
Majhihalma	5585.05	3885	69.52
Bhaliabhatta	2407.70	1597.5	66.34
D. Kumbharbadi	4380.24	2955	67.46
Papikhunti	2591.59	1522.50	58.74

72.96 GJ in D. Kumbharbadi, and 37.96 GJ in Papikhunti (Tables 4 to 11). The forest cover in Rayagada district has been subject to various biotic interferences, leading to qualitative changes according to reports from the forest survey of India. While the area of forest cover has not been significantly affected, the quality of the forest has undergone changes (Table 3). This indicates the need for appropriate measures to restore the forest and enhance its productivity.

All the villages under study rely on rain-fed agriculture, with no developed irrigation facilities. However, natural stream water is available to paddy fields through gravity

Table 3. Change dynamics of forest cover of Rayagada district in sq.km (FSI, 2021).

Year of FSI report	1999	2013	2013	2017	2021
District geographical area (DGA)	7580	7580	7580	7580	7073
Very dense forest	-	13	428	422.	373
Dense forest	972	-	-	-	-
Moderately dense forest	-	1,085	860	853	1145
Open forest	1728	1,963	1845	1851	1622
Scrub forest	806.	3,061	279	349	357
Percent of DGA	35.62	43.28	44.3	44.2	33.5

Table 4. Human energy input in agriculture (GJ ha^{-1}).

Village	Cultivated area	Total human energy	Human energy per hectare
Patlamba	12.36	27.64	2.23
Rodanga	56.14	161.19	2.87
Khajuri	57.37	197.39	3.44
Gortali	37.25	124.79	3.35
Majhihalma	21.07	50.92	2.41
Bhaliabhatta	9.93	22.73	2.28
D. Kumbharbadi	24.72	44.02	1.78
Papikhunti	21.73	38.70	1.78

flow. Four categories of agriculture practices are prevalent in the villages: (i) Podu cultivation in high hill areas, (ii) mid-hill orchards below the podu area, (iii) home gardens adjoining habitation, and (iv) valley cultivation near Nala beds, typically at lower heights of habitations. Podu cultivation involves mixed cropping of cereals, pulses and oilseeds, demonstrating a sustainable approach with optimal space and time utilization. Mid-hill orchards, featuring horticultural trees such as mango, orange and pineapple yield good annual returns. Home garden cultivation is less common in uphill villages, relying on forest collection for domestic vegetable needs, while foothill villages emphasize vegetable production and sale. Among all villages, Papikhunti stands out for its robust home garden products like brinjal, tomato, lady's finger, and simba. Rice production is practiced in one uphill village (Rodanga) and three foothill villages.

The human energy invested in agriculture in uphill villages ranged from 2.23 to 3.44 GJ ha^{-1}, while in foothill villages, it varied from 1.78 to 2.41 GJ ha^{-1} (Table 4). The analysis of material flow related to the food component considered the export-import ratio (Table 5). The import-export ratio of food energy flow in different villages indicates the self-sufficiency of the village ecosystem in food production. The village D. Kumbharbadi, closest to the urban area, has the highest export-import ratio (55.29), followed by Gortali (1.105) and Khajuri (1.09).

This suggests that the village nearest to the urban area has the ability to produce the highest food energy compared to other villages under study. Villages away from urban areas have lower export-import ratios (Majhihalma- 0.03, Bhaliabhatta- 0.04), indicating the impact of the urban area on village economic activities. These villagers are required to import more food commodities from outside the village ecosystem compared to others.

The animal husbandry sub-system is poorly developed in these villages, with no milk produced in uphill villages. Buffalo milk production was recorded from foothill villages: Majhihalma at 14 L/day, Bhaliabhatta 15 L/day, D. Kumbharbadi 18 L/day and Papikhunti 25 L/day. In the energy flow of the village, the export of minor forest products (MFP) is a major component (mainly siali leaf, hill broom, mango, tamarind etc.) and highlights the importance and role of the forest in the village economy. The production of agricultural and animal components was mostly utilized inside the village as food, fodder, fuel, etc. Some agricultural products like cereals and pulses were sold, treated as exports of the village. Some food items like rice, vegetables, kerosene, dry fish, etc. were purchased from the local market, treated as imports to the village ecosystem. Similarly, items like firewood and bamboo sold outside were treated as export value. Village-wise data on production, consumption, import, and export are given in Tables 6 to 13 for each village to assess the energy flow.

Table 5. Export-import of food energy values in GJ and ratio in study villages.

Uphill villages	**Patlamba**	**Rodanga**	**Khajuri**	**Gortali**
Export	31.70	306.02	419.87	269.68
Import	138.59	484.29	381.86	243.89
Ratio	0.23	0.63	1.09	1.105
Foot hill villages	**Majhihalma**	**Bhaliabhatta**	**D. Kumbharbadi**	**Papikhunti**
Export	7.15	4.67	167.29	17.17
Import	224.90	112.85	3.03	100.44
Ratio	0.03	0.04	55.29	0.17

The millennium ecosystem assessment (MA) (2005) suggests that in the next 50 to 100 years, major agricultural decisions will involve trade-offs, especially between agricultural production and water quality, land use and biodiversity, water use and aquatic biodiversity (Nelson, 2005). Brooker et al. (2014) point out that with growing demand for food production and water use, demands on ecosystem services could surpass the capacity of certain ecosystems to supply these services. So, a balance between the production of various services in the ecosystem and the social and economic benefits and risks of using technology is crucial (Brooker et al., 2014).

Traditional agricultural systems have evolved into diverse agro-ecosystems, some of which are rich in biodiversity and provide ecosystem services in addition to food production. Examples include wet rice-poultry farming systems and the practice of increased diversity of crop varieties within farmers' fields, which have been shown to reduce the risk of crop loss to pest diseases (Jarvis et al., 2007; Mulumba et al., 2012).

Agro-forestry systems may provide part of the answer to the challenge of sustainability by conserving forest ecosystems and farmland biodiversity, as well as the services they provide, while simultaneously enhancing food production for an increasing population under conditions of land and water scarcity (Lambin and Meyfroidt, 2011; Godfray et al., 2010; Phalan et al., 2011). Research is needed to explore alternative agricultural strategies and understand how more biologically complex systems may present short and long-term environmental and socio-economic benefits, such as enhanced food security, ecosystem service provisioning, and agricultural resilience to environmental change (Altieri, 1980; Tomich et al., 2011). These benefits are often assessed by comparing complex agricultural systems to intensified monocultures, which are widely associated with reduced biodiversity (Tscharntke et al., 2005), disruption of biogeochemical processes (Drinkwater and Snapp, 2007), and large contributions to local and global climate change (Robertson et al., 2000).

Taking major components into account, such as food, minor forest products (MFP), fodder and fuel production, the highest energy production was recorded for the village Khajuri (10,249.25 GJ year-1), followed by Rodanga (9,852.59 GJ year^{-1}), Gortali (6,407.36 GJ year^{-1}) and Patlamba (6,000.37 GJ year^{-1}) in the uphill villages. Among foothill villages, Majhihalma recorded the highest energy output of 5,795.33 GJ year^{-1}, followed by D. Kumbharbadi, Bhaliabhatta and Papikhunti. Rice contributes higher energy production than other agricultural products in foothill villages, while Koshala (Barnyard millet) occupies the highest position in energy production among uphill villages. The composition of production and consumption energy indicates higher energy savings in the uphill villages over the foothill villages (Table 14).

The village ecosystem comprises three major sub-systems: Agriculture, animal husbandry and the domestic sub-system. All these are interrelated among themselves and with the forest ecosystem. The relationship can be described through the quantity of energy flow and its sustainability. The deficit of the village ecosystem is met by procuring materials from outside these systems. The production of the agriculture sub-system is not sufficient to meet the food requirements of the village's ecosystem. The input-output ratio of MFP collection varies from 1:38.47 (Gortali) to 1:50.46 (Bhaliabhatta), which is much higher than the agriculture production sub-system. In the agriculture sub-system, the input-output ratio varies from 1:11.63 (Rodanga) to 1:23.32 (Bhaliabhatta). In Gortali, the input of MFP collection was 102.70 GJ, and the output was 3,951.19 GJ. The highest ratio in the village Bhaliabhatta has the input value of 36.411 GJ and output value 1,830.17 GJ (Tables 6 to 13). This indicates the comparative benefit between the forest ecosystem and agriculture ecosystem. MFP collection is a "no investment" practice for the low-income group, which dominates in tribal pockets. It is mainly collected by female workers and children, and in effect, for family sustenance, the education of boys and girls is neglected. The contribution of MFP to energy production is very

Table 6. Energy flow in Patlamba village ecosystem (GJ year^{-1}).

Source	Item	Production	Consumption	Export	Import	Waste
	Rice	0	130.491	0	130.491	0
	Maize	2.108	2.108	0	0	0
	Finger millets (Mandia)	52.356	52.356	0	0	0
	Pearl millets (Ghantia)	9.105	9.105	0	0	0
	Common millets (Kangu)	29.464	29.464	0	0	0
	Barnyard millets (Koshala)	48.99	48.99	0	0	0
	Redgram Legumes (Kandul)	17.25	13.78	3.47	0	0
	Jhudanga	0.302	0.302	0	0	0
	Kating	10.173	10.173	0	0	0
	Vegetables	0.214	2.296	0	2.082	0
	Turmeric	8.006	1.168	6.838	0	0
Food	Ginger	0.336	0.14	0.196	0	0
	Banana	0	0	0	0	0
	Jack fruit	9.638	0.319	8.52	0	0.799
	Mango	3.321	0	3.321	0	0
	Pine apple	10.162	1.933	8.229	0	0
	Papaya	1.519	0.389	1.13	0	0
	Dry food (flour, etc.)	0	2.639	0	2.639	0
	Others (potato, etc.)	0	0.763	0	0.763	0
	Meat	1.78	1.78	0	0	0
	Dry fish (marine)	0	2.039	0	2.039	0
	Sugar	0	0.249	0	0.249	0
	Molasses	0	0.333	0	0.333	0
Sub total		204.724	310.817	31.704	138.596	0.799
	Fruits and miscellaneous	0.55	0.55	0	0	0
	Mohua flowers	1.305	0.435	0.87	0	0
	Tamarind fruits	1.906	0.492	1.414	0	0
	Bamboo(weight)	691.12	35.86	655.26	0	0
	Wild tubers	2.802	2.802	0	0	0
Minor forest products	Mango	82.43	7.728	74.702	0	0
	Salapa rasa (Wild shap) (in L)	0.494	0.494	0	0	0
	Leafy vegetables	0.897	0.457	0.44	0	0
	Small timber/poles (in weight)	522.7	28.177	494.523	0	0
	Amla	0.462	0	0.462	0	0
	Broom grass	3.116	0.656	2.46	0	0
Sub total		1307.782	77.651	1230.131	0	0
	Other straw	379.74	304.778	0	0	74.962
Fodder	Crop residues	132.301	25.787	0	0	106.514
	Bran/ husk					
Sub total		512.041	330.565	0	0	181.476
	Firewood/fuelwood (tons)	3798	1344	2454	0	0
	Kerosene (tons)	0	36.96	0	36.96	0
Fuel	Dung (tons/year)	128.53	103.3	0	0	25.23
	Agriculture residue	49.296	45.346	0	0	3.95
Sub total		3975.826	1529.606	2454	36.96	29.09
Grand total		6000.37	2248.64	3715.84	175.56	211.37

Table 7. Production, consumption, export, import and waste of energy in Rodanga village ecosystem (GJ $year^{-1}$).

Source	Item	Production	Consumption	Export	Import	Waste
Food	Rice	102.089	568.503	-	466.41	-
	Maize	7.085	7.085	-	-	-
	Finger millets (Mandia)	139.98	139.98	-	-	-
	Pearl millets (Ghantia)	11.513	11.513	-	-	-
	Common millets (Kangu)	38.862	38.227	0.635	-	-
	Barnyard millets (Koshala)	150.006	147.246	2.76	-	-
	Redgram legumes (Kandul)	53.719	19.039	34.68	-	-
	Jhudanga	2.106	1.998	0.108	-	-
	Kating	23.302	21.563	1.739	-	-
	Vegetables	2.242	2.899	1.43	2.087	-
	Turmeric	150.921	3.652	147.269	-	-
	Ginger	72.324	0.336	71.988	-	-
	Banana	6.351	-	6.351	-	-
	Jack fruit	19.489	0.532	17.04	-	1.917
	Orange	0.226	0.0338	0.1922	-	-
	Mango	6.67	-	6.67	-	-
	Pine apple	12.871	1.096	11.775	-	-
	Papaya	6.328	2.938	3.39	-	-
	Dry food (flour)	-	7.789	-	7.789	-
	Others (Potato, etc.)	-	1.388	-	1.388	-
	Meat	5.367	5.367			
	Dry fish (marine)	-	4.58	-	4.58	-
	Sugar	-	0.832	-	0.832	-
	Molasses	-	1.2	-	1.2	-
Sub total		811.451	987.7968	306.027	484.29	1.917
Oil Seed	Castor	6.708	1.538	5.17	-	-
	Niger	1.611	1.611	-	-	-
Sub total		8.319	3.149	5.17	0	0
Minor Forest products	Tamarind fruits	4.305	0.615	3.69	-	-
	Bamboo (weight)	563.98	495.52	68.46	-	-
	Wild tubers	7.226	7.226	0	-	-
	Mango	88.872	13.211	75.66	-	-
	Salapa rasa (Wild shap) (in L)	7.6	7.6	-	-	-
	Leafy vegetables	1.355	0.704	0.651	-	-
	Small timber/poles (in weight)	296.021	251.69	44.331	-	-
	Siali leaf (in weight)	2.962	-	2.962	-	-
	Broom grass	6.232	0.984	5.248	-	-
Sub total		978.553	777.55	201.002	0	0
Fodder	Paddy straw	81.219	79.98	-	-	1.239
	Other straw	913.67	725.22	-	-	188.45
	Bran/husk (legumes and millets)	48.688	48.688	-	-	-
	Crop residues	342.347	65.036	-	-	277.31
Sub total		1385.924	918.924	0	0	467.00
Fuel	Firewood/ fuelwood (tons)	6285	2795.253	3489.75	-	-

Table 7. Contd.

	Kerosene (tons)	0	100.8	-	100.8	-
	Dung (tons/year)	238.6	190.26	-	-	48.34
	Agriculture residue	144.74	137.776	-	-	6.964
Sub total		6668.34	3224.089	3489.75	100.8	55.304
Grand total		9852.59	5911.51	4001.95	585.09	524.22

Table 8. Energy flow in Khajuri village ecosystem (GJ year^{-1}).

Source	Item	Production	Consumption	Export	Import	Waste
Food	Rice	0.00	373.54	0	373.54	0
	Maize	37.11	37.11	0	0	0
	Finger millets (Mandia)	242.92	242.92	0	0	0
	Pearl millets (Ghantia)	19.19	19.19	0	0	0
	Common millets (Kangu)	21.37	21.37	0	0	0
	Barnyard millets (Koshala)	175.19	119.99	55.2	0	0
	Redgram legumes (Kandul)	78.34	26.32	52.02	0	0
	Jhudanga	3.13	3.13	0	0	0
	Kating	41.63	41.63	0	0	0
	Vegetables	3.70	2.16	2.7885	1.2519	0
	Turmeric	88.71	3.51	85.21	0	0
	Ginger	77.67	0.42	77.25	0	0
	Banana	7.84	0.00	7.839	0	0
	Jack fruit	16.34	0.26	14.91	0	1.1715
	Orange	0.11	0.02	0.094	0	0
	Mango	43.79	0.00	43.792	0	0
	Pine apple	91.93	14.55	77.38	0	0
	Papaya	7.01	3.62	3.39	0	0
	Dry food (flour)	0.00	2.03	0	2.03	0
	Others (potato, etc.)	0.00	0.39	0	0.39	0
	Meat	6.35	6.35	0	0	0
	Dry fish (marine)	0.00	2.51	0	2.51	0
	Sugar	0.00	0.67	0	0.666	0
	Molasses	0.00	1.47	0	1.4674	0
Sub total		962.34	923.15	419.87	381.86	1.17
Oil seed	Castor	27.43	1.53	25.9	0	0
	Niger	0.93	0.93	0	0	0
Sub total		28.36	2.46	25.90	0.00	0.00
Minor Forest products	Tamarind fruits	3.94	0.74	3.198	0	0
	Bamboo (weight)	502.04	489.00	13.04	0	0
	Wild tubers	8.20	8.20	0	0	0
	Mango	104.73	18.33	86.39	0	0
	Salapa rasa (Wild shap) (ton)	9.60	9.60	0	0	0
	Leafy vegetables	1.32	0.44	0.88	0	0
	Small timber/poles (weight)	265.15	265.15	0	0	0

Table 8. Contd.

	Siali leaf (weight)	3.24	0.00	3.2384	0	0
	Broom grass	7.38	1.15	6.232	0	0
Sub total		905.59	792.60	112.98	0.00	0.00
Fodder	Other straw	1111.08	913.21	0	0	197.870
	Crop residues	454.77	100.04	0	0	354.730
sub total		1565.85	1013.25	0.00	0.00	552.60
Fuel	Firewood/ fuelwood (tons)	6390.00	5190.00	1200	0	0
	Kerosene (tons)	0.00	102.48	0	102.48	0
	Dung (tons/year)	179.69	132.65	0	0	47.04
	Agriculture residue	217.42	199.90	0	0	17.52
Sub total		6787.11	5625.03	1200.00	102.48	64.56
Grand total		10249.25	8356.48	1758.75	484.34	618.33

Table 9. Energy flow in Gortali village ecosystem (GJ $year^{-1}$).

Source	Item	Production	Consumption	Export	Import	Waste
Food	Rice	0.00	238.82	0.00	238.82	0.00
	Maize	29.69	29.69	0.00	0.00	0.00
	Finger millets (Mandia)	186.73	186.73	0.00	0.00	0.00
	Pearl millets (Ghantia)	19.34	19.34	0.00	0.00	0.00
	Common millets (Kangu)	24.96	24.96	0.00	0.00	0.00
	Barnyard millets (Koshala)	132.49	91.09	41.40	0.00	0.00
	Redgram legumes (Kandul)	67.02	32.34	34.68	0.00	0.00
	Jhudanga	3.73	3.73	0.00	0.00	0.00
	Kating	34.26	16.87	17.39	0.00	0.00
	Vegetables	3.03	1.70	2.14	0.81	0.00
	Turmeric	49.97	2.92	47.04	0.00	0.00
	Ginger	49.92	0.36	49.56	0.00	0.00
	Banana	4.19	0.00	4.19	0.00	0.00
	Jack fruit	9.12	0.70	6.39	0.00	2.03
	Orange	0.08	0.01	0.07	0.00	0.00
	Mango	32.40	0.00	32.40	0.00	0.00
	Pine apple	38.17	7.16	31.01	0.00	0.00
	Papaya	4.24	0.85	3.39	0.00	0.00
	Dry food	0.00	1.14	0.00	1.14	0.00
	Others (potato, etc.)	0.00	0.24	0.00	0.24	0.00
	Meat	4.53	4.53	0.00	0.00	0.00
	Dry fish (marine)	0.00	1.49	0.00	1.49	0.00
	Sugar	0.00	0.58	0.00	0.58	0.00
	Molasses	0.00	0.80	0.00	0.80	0.00
Sub total		693.87	666.06	269.68	243.89	2.03
Oil seed	Castor	11.81	1.30	10.51	0.00	0.00
Sub total		11.81	1.30	10.51	0.00	0.00

Table 9. Contd.

	Tamarind fruits	3.08	0.62	2.46	0.00	0.00
	Bamboo (weight)	281.99	281.99	0.00	0.00	0.00
	Wild tubers	4.73	4.73	0.00	0.00	0.00
	Mango	49.22	7.82	41.40	0.00	0.00
Minor forest products	*Salapa rasa* (Wild sap) (ton)	6.27	6.27	0.00	0.00	0.00
	Leafy vegetables	0.99	0.46	0.53	0.00	0.00
	Small timber/poles (weight)	185.21	185.21	0.00	0.00	0.00
	Siali leaf (weight)	15.73	0.00	15.73	0.00	0.00
	Broom grass	6.56	0.98	5.58	0.00	0.00
Sub total		553.77	488.07	65.70	0.00	0.00
Fodder	Other straw	955.31	702.83	0.00	0.00	252.48
	Crop residues	387.80	387.80	0.00	0.00	0.00
Sub total		1343.11	1090.63	0.00	0.00	252.48
	Firewood/ fuelwood (tons)	3397.50	2662.50	735.00	0.00	0.00
Fuel	Kerosene (tons)	0.00	65.52	0.00	65.52	0.00
	Dung (tons/year)	215.76	174.77	0.00	0.00	40.99
	Agriculture residue	191.53	170.81	0.00	0.00	20.72
Sub total		3804.79	3073.61	735.00	65.52	61.71
Grand total		6407.36	5319.67	1080.88	309.41	316.22

distinct in all villages. Since the only input was human labor, the rate of return was found to be very high. Pandey and Singh (1984), while studying Kumaun Himalayan villages, observed that the agro-ecosystem of the hills is surrounded by the forest ecosystem, and a considerable amount of subsidy energy is available for the operation of hill agro-ecosystems in the form of animal fodder, wood fuel and free irrigation water from spring-fed ponds. The surrounding forest ecosystem provides 76% of the fodder requirement, the crop land ecosystem only 22%; crop residues, 11%, and the remaining 2% imported from the market. Unlike the agro-ecosystems of hills, Niyamgiri villages do not use dung as energy in terms of dung (manure). Dung can be used as manure to reduce pressure for fuel wood from the forest ecosystems. The villages in the hills, such as the one studied, are therefore centers of massive energy consumption. These systems are viable as long as the energy subsidy from the surrounding forest ecosystem is available. But the cost of it is tremendous. There are ever-increasing concentric circles of forest destruction around the villages.

The highest per capita food energy consumption in the village Khajuri is due to higher paddy cultivation in the valley and being nearest to the market for easy access to urban facilities. The other village Papikhunti concentrates on vegetable production, and there is no scope for paddy cultivation in the valley Nala sides. Access to the public distribution system (PDS) is better in these two villages compared to other villages. Food energy consumption in all villages is less than the average requirement of 11.7 MJ cap^{-1} day^{-1} as suggested by the National Expert Group of the Indian Council of Medical Research (Gopalan et al., 1978). The highest value of Khajuri village (11.54 MJ cap^{-1} day^{-1}) is at par with the value of 10.7 MJ cap^{-1} day^{-1} (Sahoo, 1993) but higher than the value of 9.3 MJ cap^{-1} day^{-1} for a tribal village on Mahendragiri foothills, Odisha (Nayak et al., 1993). The uphill villages depend on the variety of minor millets produced in Podu areas. In general, all villages suffer malnutrition due to insufficient food consumption. Illiteracy and addiction to low-cost liquor among tribals create health problems, which are also responsible for the deterioration of the economy.

The villagers use a traditional cooking system with "challah" where firewood (biomass) is used, and kerosene is used for lighting. Due to easy availability, stem wood and branch wood are used. Firewood collection by cutting immature trees is responsible for the deterioration of forest crops. The per capita per day consumption varies from 1.855 kg day^{-1} (Rodanga) to 3.080 kg day^{-1} (Khajuri) in uphill villages and from 2.577 kg day^{-1} (Bhaliabhatta) to 4.402 kg day^{-1} (D. Kumbharbadi) in foothill villages. The average per day consumption is lower in uphill villages compared to foothill

Table 10. Energy flow in Majhihalma village ecosystem (GJ $year^{-1}$).

Production, consumption, export, import and waste of energy in Majhihalma village ecosystem (GJ $year^{-1}$)						
Source	**Item**	**Production**	**Consumption**	**Export**	**Import**	**Waste**
Food	Rice	196.54	416.99	0.00	220.45	0.00
	Maize	26.15	26.15	0.00	0.00	0.00
	Finger millets (Mandia)	98.01	98.01	0.00	0.00	0.00
	Redgram legumes (Kandul)	26.41	26.41	0.00	0.00	0.00
	Jhudanga	1.24	1.24	0.00	0.00	0.00
	Kating	0.00	0.00	0.00	0.00	0.00
	Vegetables	4.17	1.88	3.04	0.75	0.00
	Banana	3.04	0.00	3.04	0.00	0.00
	Jack fruit	2.94	0.38	1.07	0.00	1.49
	Papaya	0.40	0.40	0.00	0.00	0.00
	Dry food	0.00	1.03	0.00	1.03	0.00
	Others (potato, etc.)	0.00	0.24	0.00	0.24	0.00
	Meat	1.89	1.89	0.00	0.00	0.00
	Dry fish (marine)	0.00	1.46	0.00	1.46	0.00
	Sugar	0.00	0.50	0.00	0.50	0.00
	Molasses	0.00	0.47	0.00	0.47	0.00
	Tobacco	0.63	0.63	0.00	0.00	0.00
Sub total		361.42	577.68	7.15	224.90	1.49
Oil seed	Niger	17.64	17.64	0.00	0.00	0.00
Sub total		17.64	17.64	0.00	0.00	0.00
Minor Forest products	Tamarind fruits	0.62	0.62	0.00	0.00	0.00
	Bamboo (weight)	298.29	285.25	13.04	0.00	0.00
	Leafy vegetables	0.37	0.09	0.28	0.00	0.00
	Small timber/poles (in weight)	159.09	159.09	0.00	0.00	0.00
	Broom grass	4.92	0.98	3.94	0.00	0.00
Sub total		463.29	446.03	17.26	0.00	0.00
Fodder	Paddy straw	156.63	147.68	0.00	0.00	8.94
	Other straw	150.86	128.23	0.00	0.00	22.63
	Bran/husk (legumes and millets)	94.23	94.23	0.00	0.00	0.00
	Crop residues	107.72	107.72	0.00	0.00	0.00
Sub total		509.43	477.86	0.00	0.00	31.57
Fuel	Firewood/ fuelwood (tons)	3885.00	3127.50	757.50	0.00	0.00
	Kerosene (tons)	0.00	60.48	0.00	60.48	0.00
	Dung (tons/year)	281.09	233.31	0.00	0.00	47.78
	Agriculture residue	70.18	49.61	0.00	0.00	20.57
Sub total		4236.27	3470.91	757.50	60.48	68.35
Grand total		5588.05	4990.12	781.91	285.38	101.41

villages. The annual per capita fuelwood consumption varies from 0.667 tons $year^{-1}$ (Rodanga) to 1.585 tons $year^{-1}$ (Khajuri), which is higher than the consumption rate reported for many Indian villages such as Haripur complex of Odisha (Sahoo, 1993), Bhogibunda tribal village (Nayak et al., 1993), and Bhabinara-Yampur, Odisha (Nisanka and Mishra, 1990), Uchangi, Karnataka (Mishra et al., 1983). The average fuelwood consumption

Table 11. Energy flow in Bhaliabhatta village ecosystem (GJ year^{-1}).

Production, consumption, export, import and waste of energy in Bhaliabhatta village ecosystem (GJ year^{-1})						
Sources	**Items**	**Production**	**Consumption**	**Export**	**Import**	**Waste**
Food	Rice	84.27	194.50	0.00	110.22	0.00
	Maize	14.68	14.68	0.00	0.00	0.00
	Finger millets (Mandia)	37.32	37.32	0.00	0.00	0.00
	Redgram legumes (Kandul)	13.09	11.36	1.73	0.00	0.00
	Jhudanga	0.78	0.78	0.00	0.00	0.00
	Vegetables	2.04	1.25	1.19	0.40	0.00
	Banana	1.74	0.00	1.74	0.00	0.00
	Jack fruit	0.96	0.21	0.00	0.00	0.75
	Papaya	0.34	0.34	0.00	0.00	0.00
	Dry food	0.00	0.56	0.00	0.56	0.00
	Others (potato, etc.)	0.00	0.16	0.00	0.16	0.00
	Meat	0.79	0.79	0.00	0.00	0.00
	Dry fish (marine)	0.00	0.85	0.00	0.85	0.00
	Sugar	0.00	0.33	0.00	0.33	0.00
	Molasses	0.00	0.33	0.00	0.33	0.00
	Tobacco	0.16	0.16	0.00	0.00	0.00
Sub total		156.17	263.62	4.67	112.85	0.75
Oil seed	Niger	8.88	8.88	0.00	0.00	0.00
Sub total		8.88	8.88	0.00	0.00	0.00
Minor forest products	Tamarind fruits	0.37	0.37	0.00	0.00	0.00
	Bamboo (weight)	138.55	138.55	0.00	0.00	0.00
	Leafy vegetables	0.21	0.05	0.16	0.00	0.00
	Small timber/poles (weight)	89.44	89.44	0.00	0.00	0.00
	Broom grass	4.10	0.82	3.28	0.00	0.00
Sub total		232.67	229.23	3.44	0.00	0.00
Fodder	Paddy straw	44.92	42.12	0.00	0.00	2.80
	Other straw	66.95	59.08	0.00	0.00	7.87
	Bran/husk (legumes and millets)	27.06	27.06	0.00	0.00	0.00
	Crop residues	56.36	54.53	0.00	0.00	1.83
Sub total		195.29	182.80	0.00	0.00	12.50
Fuel	Firewood/ fuelwood (tons)	1597.50	1252.50	345.00	0.00	0.00
	Kerosene (tons)	0.00	30.24	0.00	30.24	0.00
	Dung (tons/year)	180.03	145.79	0.00	0.00	34.24
	Agriculture residue	37.16	29.89	0.00	0.00	7.27
Sub total		1814.69	1458.43	345.00	30.24	41.51
Grand total		2407.70	2142.95	353.10	143.09	54.75

per household (family) obtained in the study is within the range reported for many Indian villages. The value is comparable to the value reported for six villages of Karnataka (Reddy, 1982) and nearly similar to the value reported for Himalayan foothill villages (Pandey and Singh, 1984; Moench, 1989) but less than the tribal villages in Odisha (Mohapatra, 1992). Per capita biomass energy consumption observed in these villages is higher than the value reported by Goodman (1987), Williams (1985), and Scurlock and Hall (1990) for the rural

Table 12. Energy flow in D. Kumbharbadi village ecosystem (GJ year^{-1}).

Production, consumption, export, import and waste of energy in D. Kumbharbadi village ecosystem (GJ year-1)						
Sources	**Items**	**Production**	**Consumption**	**Export**	**Import**	**Waste**
Food	Rice	243.56	402.77	159.21	0.00	0.00
	Maize	14.85	14.85	0.00	0.00	0.00
	Finger millets (Mandia)	60.42	60.42	0.00	0.00	0.00
	Redgram legumes (Kandul)	12.40	12.40	0.00	0.00	0.00
	Jhudanga	0.85	0.85	0.00	0.00	0.00
	Vegetables	3.26	1.84	1.89	0.47	0.00
	Banana	4.69	0.00	4.69	0.00	0.00
	Jack fruit	3.37	0.34	1.49	0.00	1.54
	Papaya	1.02	1.02	0.00	0.00	0.00
	Dry food	0.00	0.61	0.00	0.61	0.00
	Others (potato, etc.)	0.00	0.13	0.00	0.13	0.00
	Meat	1.87	1.87	0.00	0.00	0.00
	Dry fish (marine)	0.00	0.81	0.00	0.81	0.00
	Sugar	0.00	0.67	0.00	0.67	0.00
	Molasses	0.00	0.33	0.00	0.33	0.00
	Tobacco	0.95	0.95	0.00	0.00	0.00
Sub total		347.21	499.85	167.29	3.03	1.54
Oil seed	Niger	11.88	11.88	0.00	0.00	0.00
Sub total		11.88	11.88	0.00	0.00	0.00
Minor Forest products	Tamarind fruits	0.62	0.62	0.00	0.00	0.00
	Bamboo (weight)	224.94	211.90	13.04	0.00	0.00
	Leafy vegetables	0.19	0.19	0.00	0.00	0.00
	Small timber/poles (in weight)	101.31	101.31	0.00	0.00	0.00
	Broom grass	3.28	0.82	2.46	0.00	0.00
Sub total		330.34	314.84	15.50	0.00	0.00
Fodder	Paddy straw	193.68	181.55	0.00	0.00	12.13
	Other straw	102.45	95.36	0.00	0.00	7.09
	Bran/husk (legumes and millets)	116.12	116.12	0.00	0.00	0.00
	Crop residues	92.09	15.21	0.00	0.00	76.88
Sub total		504.35	408.24	0.00	0.00	96.10
Fuel	Firewood/ fuelwood (tons)	2955.00	2377.50	577.50	0.00	0.00
	Kerosene (tons)	0.00	43.68	0.00	43.68	0.00
	Dung (tons/year)	193.81	181.70	0.00	0.00	12.11
	Agriculture residue	37.65	32.11	0.00	0.00	5.54
Sub total		3186.46	2634.98	577.50	43.68	17.65
Grand total		4380.24	3869.79	760.29	46.71	115.29

population of developing countries.

Firewood is used as fuel energy in all villages and meets the family income for those selling firewood. This is in agreement with the data reported for many Indian villages of Tyviang (Gangwar and Ramakrishnan, 1987). Easy access to firewood and a subsistence village economy is responsible for 100% dependency on biomass energy. Traditional mud stoves for cooking require high consumption of firewood as the heat utilization efficiency of mud challah (stoves) is only

Table 13. Energy flow in Papikhunti village ecosystem (GJ year^{-1}).

Production, consumption, export, import and waste of energy in Papikhunti village ecosystem (GJ yr^{-1})						
Sources	**Items**	**Production**	**Consumption**	**Export**	**Import**	**Waste**
Food	Rice	0.00	97.98	0.00	97.98	0.00
	Maize	10.97	10.97	0.00	0.00	0.00
	Finger millets (Mandia)	56.05	56.05	0.00	0.00	0.00
	Barnyard millets (Koshala)	73.14	73.14	0.00	0.00	0.00
	Redgram legumes (Kandul)	46.90	38.23	8.67	0.00	0.00
	Vegetables	8.42	2.32	6.47	0.37	0.00
	Banana	0.96	0.00	0.96	0.00	0.00
	Jack fruit	1.51	0.17	1.07	0.00	0.27
	Papaya	0.57	0.57	0.00	0.00	0.00
	Dry food	0.00	0.58	0.00	0.58	0.00
	Others (potato, etc.)	0.00	0.15	0.00	0.15	0.00
	Meat	0.77	0.77	0.00	0.00	0.00
	Dry fish (marine)	0.00	0.76	0.00	0.76	0.00
	Sugar	0.00	0.33	0.00	0.33	0.00
	Molasses	0.00	0.27	0.00	0.27	0.00
	Tobacco	0.32	0.32	0.00	0.00	0.00
Sub total		199.60	282.60	17.17	100.44	0.27
Oil seed	Niger	71.42	13.66	57.76	0.00	0.00
	Rasi	29.49	7.32	22.17	0.00	0.00
Sub total		100.90	20.97	79.93	0.00	0.00
Minor forest products	Tamarind fruits	0.37	0.37	0.00	0.00	0.00
	Bamboo (weight)	122.25	122.25	0.00	0.00	0.00
	Leafy vegetables	0.26	0.07	0.19	0.00	0.00
	Small timber/poles (in weight)	79.15	79.15	0.00	0.00	0.00
	Broom grass	2.46	0.82	1.64	0.00	0.00
Sub total		204.49	202.66	1.83	0.00	0.00
Fodder	Other straw	64.65	49.78	0.00	0.00	14.87
	Crop residues	139.63	139.63	0.00	0.00	0.00
Sub total		204.28	189.41	0.00	0.00	14.87
Fuel	Firewood/ fuelwood (tons)	1522.50	1222.50	300.00	0.00	0.00
	Kerosene (tons)	0.00	26.88	0.00	26.88	0.00
	Dung (tons/year)	242.29	211.22	0.00	0.00	31.07
	Agriculture residue	117.52	114.25	0.00	0.00	3.27
Sub total		1882.31	1574.85	300.00	26.88	34.34
Grand total		2591.59	2270.49	398.93	127.32	49.48

around 20.35% for firewood (Nisanka et al., 1992). PDS rice received from government schemes (imported) meets the gap. On the other hand, the uphill villages sell a good quantity of minor millets, horticulture products (jackfruit, pineapple, banana, orange and mango), which can be recorded as high energy value. The material flow table presenting the production, consumption, import, export, and waste part of major items under food, minor forest products, fodder, fuel indicates that the import is very less compared to the export (Tables 6 to 13). The import and export data of all villages detailed in Table 15 in terms of energy help to understand the level of dependence of villages on food, minor forest products, fodder and fuelwood.

Table 14. Total production and consumption of energy in villages (GJ year^{-1}).

Uphill village	Patlamba	Rodanga	Khajuri	Gortali
Production	6000.37	9852.59	10249.25	6407.36
Consumption	2248.64	5911.51	8356.48	5319.67
Savings	3751.73	3941.08	1892.77	1087.69
Foothill village	Majhihalma	Bhaliabhatta	D.Kumbharbadi	Papikhunti
Production	5795.33	2722.74	4380.24	2591.59
Consumption	5168.72	2438.60	3869.79	2270.49
Savings	626.61	284.14	510.45	321.10

Table 15. Export-import of energy for food, minor forest products, fodder, fuel and ratio in villages.

	Energy value in GJ			
Uphill village	Patlamba	Rodanga	Khajuri	Gortali
Export	3715.84	4001.95	1758.75	1080.8
Import	175.56	585.09	484.34	309.41
Ratio	21.16	6.83	3.63	3.49
Foothill village	Majhihalma	Bhaliabhatta	D. Kumbharbadi	Papikhunti
Export	781.91	353.10	760.2	398.93
Import	285.38	143.09	46.71	127.32
Ratio	2.73	2.46	16.27	3.13

Analysis of variance (ANOVA) for the energy production, consumption of different sources such as food, minor forest products (MFP), fodder and fuel in different villages showed that there is a significant difference between these values. The differences in energy production and consumption in food, minor forest products (MFP), fodder and fuel among different villages are also significant. ANOVA for the energy export and import of different energy types such as food, MFP, fodder and fuel at the 8 villages reveals that there is a significant difference in different sources while there is no significant difference between these sources among the villages. ANOVA for the waste of different categories of energy at 8 villages shows that there is a significant difference in waste of energy among food, MFP, fodder and fuel at the 8 different villages while there is no significant difference in waste energy among the villages (Table 16). The 3-way ANOVA data for cultivation type (podu, mid hill, home garden and valley cultivation), site and category (grains, straw and residue) showed F values for these three factors that show a highly significant difference (Table 17). This indicates that there is a distinct difference in the cultivation types, segregation of energy content and among villages of the Niyamgiri hill ecosystem.

Conclusion

The data on energy dynamics in these villages highlight the significant role of biomass from the forest in the material flow of the village ecosystem. This is evident through the participation of minor forest products, firewood, small timber (poles) and bamboo. The village ecosystems are heavily dependent on biomass fuel and fodder from the nearby forest. The import and export figures for different items suggest that the tribal village ecosystem is open and partially independent. The Niyamgiri forest, covering a vast area of 496.59 km^2, is undulating with hills, stream sides and located far away from each other. Although man-animal conflicts are not frequent, the presence of herbivores and occasional wild elephants can lead to crop damage. However, these issues are managed by the tribal community, and compensation is provided for damages as per government provisions.

Recommendations

On the basis of the studies on subsistence economy and interaction between agriculture and ecology of villages, it

Table 16. F and p- values of analysis of variance (ANOVA) for different energy sources (food, MFP, fodder, fuel) at study villages.

Energy parameter	Source of variation	F	P-value
Energy production (GJ/year)	Energy sources	34.49	0.001
	Villages (sites)	2.72	0.05
Energy consumption (GJ/year)	Energy sources	38.948	0.001
	Villages (sites)	2.457	0.05
Energy export (GJ/year)	Energy sources	7.887	0.001
	Villages (sites)	1.57	NS
Energy import (GJ/year)	Energy sources	13.338	0.001
	Villages (sites)	1.279	NS
Waste (GJ/year)	Energy sources	7.478	0.001
	Villages (sites)	1.119	NS

Table 17. Three-way analysis of variance (ANOVA) between cultivation type (Podu, mid hill, home garden and valley cultivation), site and category (grains, straw residue).

Source	DF	SS	MS	F	P
Total	95	38961.8			
Treatment	54	36277.2	671.8	10.26	0.001
Cultivation type	3	24084.6	8028	122.64	0.001
Site (village)	7	3840.3	548.61	8.38	0.001
Category	2	3974.6	1987.3	30.36	0.001
Interaction	42	4377.7	104.23	1.6	0.005
Error	41	2684.6	65.46		

was observed that the village community of Niyamgiri hills depend on nature assets intensely. One of the conservation priorities should be to improve the economic conditions of tribal society in order to protect structural and functional characters of the Niyamgiri forest for sustainable productivity. Food being the basic necessity of the society needs inter-disciplinary approach for sustainable production. Agriculture, horticulture and forest department must work with convergence to ensure sustainability of these traditional villages. Improvement of animal resources has great potential to meet socio-economic needs. Storage and value addition of agriculture and horticulture products will boost up village economy while reducing dependency on natural resources from forests for human livelihood.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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ANNEXURE A
Questionaire for the study

Name of family head---
1. Village----------------------g p-----------------------------------block------------------------------
2. Age---------------------------sex----------religion---------------------caste----------------------
3. Occupation----------------farmer-------- wage labour-------trader-------invalid------------
service holder------------others-------------------------------------
4. Name of the informer---
5. Relation of informer to family head ---
6. Family ---------------nuclear -----------joint------------
7. Total member of family ----------male -----------female -------children-------------------
(put tick mark in correct place)

Preliminary information (family type, education, economic status).

S/N	Name of household member	Relation to the head of household	Marital status (m/sp/d/wi/rm	Present age	Sex	Education at present	Main occupation	Seasonal occupation	Age at which started earning
1									
2									
3									
4									
5									
6									
6									
8									
9									
10									

Residence / housing

a. Residence: Own ---------- Rented -------Separated ------Nucleated -----Others-------
b. Type of Residence: Pucca ------Kucha ----- Semi-Pucca -------Others --------------------------
c. Wall type: Mud ---------Brick ---------Brushwood ----------Others ---------------------
d. Roof type: RCC ------------A C Sheet ------G I Sheet ----Straw -----Others -------------
e. Floor type: Kucha --------Cement --------Mixed ----------Others -------------------------
f. Door/Window: Iron ----------Wood ----------Bamboo ---------Others ------------------------
g. Furniture-Cot/Chair: Wood --------Iron ------------Nil ---------------Others **----------------------**

Occupation

Have you changed your occupation – Yes ---------No --------
If yes why --------------------------------- Voluntarily ------Forced --------Others ----------------
What are cottage industries of your village: ---
Which of these is practised in your household: ---
How many of family members join in this work**: --**

Male	Female	Children	Total

What is your monthly income from this source: ---Rs---
What is your difficulties**: ---**

Land utilisation

Name of local land area unit.: ----------
Conversion in acre**: -----------------------**

Type of land	Locality (upland/low land/others	Area in acre
Own land		
Lease land		
Land leased out		
Orchard land		

Total annual income from agriculture: -------------------------------------

Land area (acre).

Irrigated land	Non-irrigated land			Total land
Cultivable land	Up-land cultivable	Waste land-(Hill/Jhola)	Other shallow land	

Water source of agriculture.

Stream (%)	Well (%)	Rain (%)	Lift/ bore	Canal (%)	Pond (%)

Self-cultivation land (area in acre).

S/N	INPUT	Number	Rate	Amount
1	Human labour (person days)			
2	Animal labour (no. of days)			
3	FYM/ compost (cart load)			
4	Seed (kg)			
5	Others like insecticide etc.			

Rabi crop.

S/N	Out put	Area (Acre)	Quantity produced	Quantity self-use	Sale	
					Qty	Price
1	Maize					
2	Ragi					
3	Vegetable					
4	Others					

Kharif crop.

S/N	Out put	Area (Acre)	Quantity produced	Qty. for self-use	Sale	
					Qty	Price
1	Paddy					
2	Vegetable					
3	Maize					
4	Others					

Fruit crops.

S/N	Output	Area (acre)	Quantity produced	Qty. self for use	Sale	
					Qty	Price
1	Mango					
2	Banana					
3	Papaya					
4	Pine apple					
5	Others					

Crop by-product.

S/N	Product	Area	Qty produced	Qty. self-use	Sale	
					Qty	Price
1	Leaf powder					
2	Green grass					
3	Compost					
4	Straw					
5	Others					

Animal husbandry: Annual production.

S/N	Cattle	Number initial	Number at end of year	Increase of numbers	Price	Milk/price	Total price
1	Cow						
2	Buffalo						
3	Bullock						
4	Goat						
5	Sheep						
6	Poultry						
7	Pig						
8	Others						
9							
10							

Total income: ---

Local vegetation and forest plant food.

S/N	Food products	Period of collection	Quantity collected (kg)	Quantity used (kg)	Quantity sold (kg)	Price (Rs)
	Wild leafy vegetables					
1						
2						
3						
4						
5						
	Wild seed					
1						
2						
3						
4						
5						

	Wild Sap
1	
2	
3	
4	
5	
	Wild fruits and dry fruits
1	
2	
3	
4	
5	
	Wild tubers etc.
1	
2	
3	
4	
5	
	Wild herbs
1	
2	
3	
4	
5	
	Wild flowers
1	
2	
3	
4	
5	
	Gum and resin
1	
2	
3	
4	
5	
	OTHERS
1	Small timber
2	Fire wood
3	Bamboo
4	Grass and fodder
5	Leaf (Sal/ Siali)

Fuel wood requirement:

1. From where do you get firewood --
2. What is daily requirement of fire wood ---
3. Do you sell fire wood --------------------(yes/no) --
4. If yes, please give the rate and quantity sold by you in a week ----------------------------
5. What distance you have to trav
6.
7. el for collecting firewood ----------------------------------
8. Do women also collect fire wood ---
9. At what rate do get the kerosene from P D S ---
10. Do you use kerosene as fuel or just for lighting --

Other purchases.

S/N	Material of purchase	Quantity of annual purchase	Price
1	Kerosene oil		
2	Rice/ wheat		
3	Vegetables		
4	Dry fish		
5	Dry food		
6	Others		

Forest dweller's economy.

S/N	Name of minor forest produce	Period of collection	Total quantity collected	Qty. for self-use	Qty. for sale	Rate at which sold	Distance travelled to collect	Total money earned
1	Mahua seeds							
2	Mahua flowers							
3	Sal seed							
4	Arrowroot							
5	Honey							
6	Resin							
7	Siali leaf							
8	Kenduleaf							
9	Amla							
10	Harida							
11	Bahada							
12	Others							

Related Journals: