Quantifying Recent Floodplain Vegetation Change along the White Volta River in the Northern Region of Ghana

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Abstract

Floodplains are among the most productive and highly diverse ecosystems that serve as a source of feed, shelter and breeding ground for wildlife, as well as protect neighbouring settlements from flush floods. Nonetheless, they are among the most threatened habitats on earth. The study quantified factors that accounted for floodplain vegetation change of the White Volta River, in the Northern Region of Ghana. We used Landsat images, extracted population and climate data and undertook vegetation and soil assessment. Our results showed that agricultural expansion, population growth and climate change, were the main factors that transformed the vegetation over the 26 –year period. Air temperature significantly increased from 34 ºC in 1989 to 36.1 ºC in 2010, with +0.2ºC decadal rate of change. Extreme temperatures coincided with a drop in rainfall from 1,427.3 mm to 695.5 mm/year. Agriculture expansion from 10.33% to 58.84% (1989 – 2015), led to increase in bare surface/sediment deposits (9.52% to 20.7%), while simultaneously reduced surface area of water bodies (7.61% to 3.5%) and riparian vegetation (72.53% to 16.96%). These findings highlight the current impact of climate change and human-led activities on the vegetation of the White Volta river floodplains, and suggest the need for strict conservation measures to curb further depletion of the vegetation and restore its overall functional status.

Keyword: Volta River basin, vegetation transformation, Landsat images, land use land cover, population growth, climate change

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Introduction

Floodplains are among the most productive and highly diverse species ecosystems that are naturally very dynamic physical environments because they receive annual or biannual floods (Brinson, 1981; Warren & French, 2001). They bear rich sediments (Spink et al., 1998) and support the growth of diverse plant species (Abraham et al., 2002). They also serve as sources of forage, shelter, breeding ground and transboundary corridor for wildlife from nearby national Parks/game reserves; at the same time, they protect neighbouring settlements from flooding. However, they have been subjected to disturbances in recent years and in the past, as some original floodplains are among the most threatened habitats on earth (Tockner & Stanford, 2002) or have completely disappeared. Human-led disturbances have led to an increase in physical processes like the alterations of accumulation and erosion bedloads (morphodynamics) (Müller & Scharm, 2001); alteration of flow and sediment regimes by river damming (e.g., Müller 1995a), fragmentation of river channels by dams and by water regulation resulting from reservoir operation, interbasin diversion and irrigation (Dynesius & Nilson, 1994) and logging, introduced disease, increased herbivory and invasive species (Naiman & Dècamps 1997, Tickner et al., 2001). Vegetation development in floodplains is greatly influenced by disturbance processes such as flooding, horizontal and vertical channel instability, erosion and sedimentation, on population dynamics and seed dispersal (Hanson et al., 1990; Malanson, 1993). This is considered at spatial (natural floodplains are a mosaic built up of habitats which are organized by variable, frequent and intensive physical disturbances) and temporal (expressed by the different stages of development of the singular elements of the mosaic) dimensions (Foeckler & Bohle, 1991). For instance, short-term arrangement of sediments though erosion transport and deposition processes, causes destruction of parts of floodplains, while simultaneously creating new sites suitable for regeneration of vegetation (Warren & French, 2001). The impact of these disturbance processes, have over time, influenced some species (known as *r*-selected species) to develop survival adaptive strategies and capitalize on regeneration opportunities (Warren, 1993). Landscape ecologists have often expressed varied opinions about the main cause of floodplain vegetation change. While some scientists attribute changes to mainly human-led disturbance (Naiman & Dècamps, 1997), others believe that natural causes such as flood pulses (Warren & French 2001; Thapa et al., 2016) triggered by climate change, are the reasons for observed changes in most floodplains.

Air temperature over the last 50 years (1960 – 2010) from Northern Region of Ghana have shown a 1°C per annum increase and a 2.4 percent per decade decrease in rainfall during the same period (De Pinto et al., 2012; Kabo-Bah et al., 2016). This historical trend is predicted to increase 2.1–2.4 °C by 2050 (World Bank, 2010). It is likely that floodplain vegetation may be responding to increase in thermal thresholds. Parry et al. (2007) indicated that new temperature and precipitation regimes expected, will occur much more quickly than historical climate shifts. Since many rivers are affected by infrastructure development, dams and water extractions, their ability to adjust to changes in the rate of water and sediment load may be impaired (Palmer et al., 2008). Thus, the amount of vegetation change along the White Volta River floodplain, may potentially depend on the rate of temperature and precipitation change at the local scale.

Scientific studies on the White Volta River have largely focused on predictive response of the river to climate change (Awotwi et al., 2015), competition of water resources (van de Giesen et al., 2001), land cover change on water balance (Awotwi et al., 2015), fish stock survey (Béné & Russell, 2007) and climate change on water resources (Oyebande & Odunuga, 2010). However, research on the combined effects of climate change and anthropogenic disturbances and human population pressure on the floodplain vegetation, over a long-term scale, is simply non-existent within the study area. There has been documentary evidence in some floodplains, which found hydrology of catchment such as discharge of river, maximum flood and its occurrence, minimum flow during dry season, ground water hydrology (e.g. Poff et al., 1997; Peñas et al., 2013) which threatened ecological processes of wetlands ecosystems (Poff and Zimmerman 2010) and the ecological, economic and cultural services they provide (Postel and Ritcher 2003).

The Water Resources Commission (2008) pointed out that a marked deterioration in the ecology of the White Volta River was realized within the past 10 - 20 years. Farmers and other indigenes along the floodplains of the catchment, have equally expressed concern about changes in the vegetation composition and distribution, especially the loss of *keystone* plants used as herbal extracts and the destruction of their properties in recent flood events (Stephen, *pers com*). Ouchley et al., (2000). Rood et al., (2003) argue that native biodiversity of disturbed floodplain ecosystems is set to increase in the future, if efforts are not put in place to restore them. In the last 10 - 20 years, some rural communities close to the floodplains of White Volta River, have suffered significant damage from flood events (Water Resources Commission, 2008), especially communities close to highly disturbed portions of the floodplains.

Given the vital role of the floodplain vegetation in flood attenuation and as a transboundary corridor for wildlife from Mole National Park, it is crucial to investigate whether climatic factors and the consequences of human disturbances such as farming, animal grazing and fuelwood extraction, have contributed in altering the vegetation structure over time and to propose appropriate conservation measures, that could contribute to minimize the vegetation transformation. In this study, we hypothesized that the floodplain vegetation of the White Volta River has not responded to the impacts of climate change impacts, human disturbances and population pressure, during the last 26 years (1989 and 2015).

Materials and Methods

Study area

The White Volta river basin in Ghana is located between latitudes 8°50'N - 11°05'N and longitudes 0°06'E - 2°50'W (Figure 1). It is bounded to the east by the Oti River Basin, to the west by the Black Volta River Basin and to the south by the Main/Lower Volta sub-basins. The drainage area of the Ghanaian part of the basin is about 50,000 km^2 (a good 20% of Ghana's total land area), and constitutes about 44% of the total area of the White Volta River Basin (named Nakanbé River in Burkina Faso) (Water Resources Commission, 2008). The basin is shared by six riparian nations, among which Ghana (40% of basin area) and Burkina Faso (43%) are the most important in terms of population, water use and economic activity (Rodgers et al., 2006). The entire White Volta River and its floodplains, constitute 106,000 km^2 (Sutherland et al., 2004) and drains much of northern and central Ghana Basin. More than 1,500 small natural aquifers and reservoirs dot the White Volta basin, collecting rainfall and runoff during the rainy season and storing it for use in the dry season. The storage and use of water underpins the important role that the river plays in livelihood support of hundreds of farmers, pastoralists and fishermen throughout the region. Rainfall is erratic and approximates 500 - 1,000 mm per year, with a steep south to north gradient, and less than 10%

becomes usable as runoff due to high evaporation rates (Rodgers et al., 2006). Temperature is on average 24° C minimum and 34° C maximum. Temperature and rainfall trends are inversely related from the steep south to north altitudinal gradient along the White Volta river basin. As temperatures increased from the south to north, altitudinal gradient rainfall simultaneously decreased in an equal time-scale. There is fairly low relief with few areas of moderate elevation in the north and east. The mean elevation is about 200m and the highest portion reaches 600m (Water Resources Commission, 2008). The geology of the White Volta Basin is composed of the Birimian rocks and its associated Granitic intrusives, isolated patches of Tarkwaian formations, and Voltaian systems (Junner and Hirst, 1946). The Obosum formation also known as the Upper Voltaian consists of dirty-yellow, fine-grained, thinly bedded, micaceous feldspathic quartz sandstones with subordinate argillite intercalations and whitish-yellow, massive, fine- to medium-grained, cross-bedded arkosic and quartzose sandstones (Junner, 1940). In Ghana, the formation occurs as scattered outcrops in the central part of the Voltaian Basin, with an average thickness of about 400m (Trompette, 1969). Recharge of the White Volta river basin is largely from infiltration of precipitation, with other indirect isolated sources like seepages from ephemeral streams and pools (Agyekum and Dapaah-Siakwan, 2008, Hydrological Assessment Project of Northern Ghana, 2006). Estimated groundwater hydrology recharge values are generally low - varying from 1.5% to 19% of annual rainfall, with a high spatio-temporal variability (Obuobie and Barry 2012; Forkuor et al. 2013).

The vegetation is moist Guinea savannah with a considerable forested broad-leaved canopied trees on the fringes of the River (e.g. *Salacia reticulata, Pterocarpus erinaceus, Vitex crysocarpa*) and shorter grasses/ fire resistant trees on other parts of the floodplain.

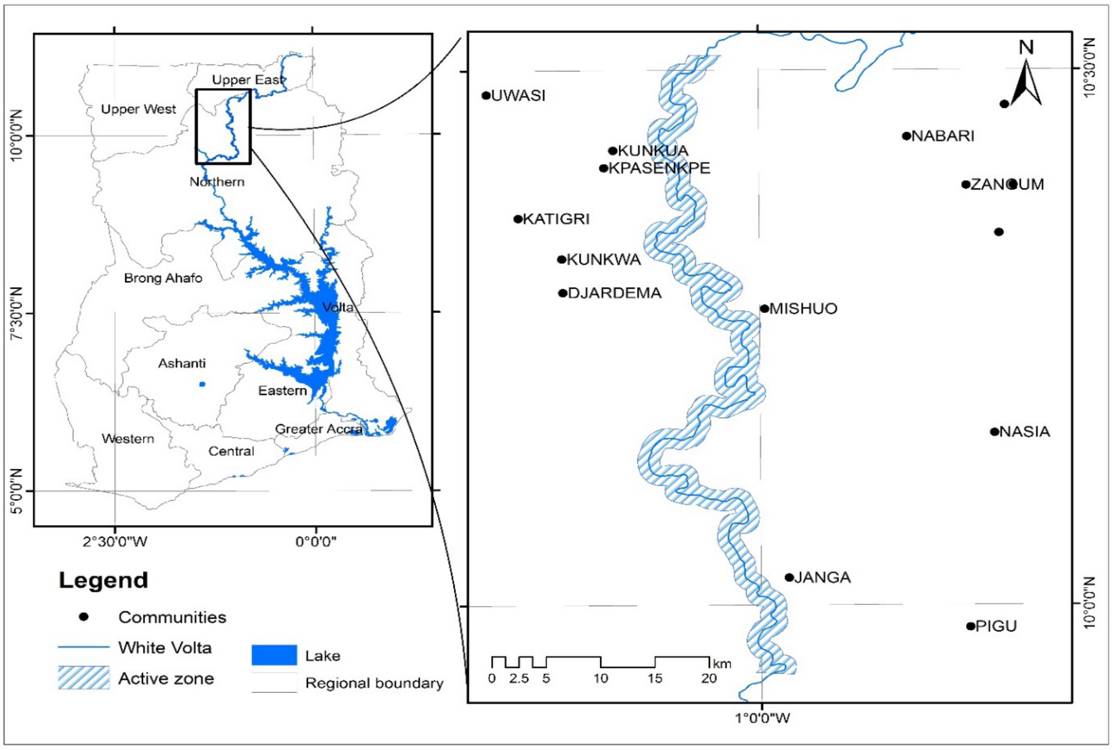

Figure 1: Map of Ghana, showing the floodplain along the White Volta River in Northern Region of Ghana, where the study was conducted

Source: Nsor et al., 2018

Procedure for the assessment of climate data, LULC Mapping and LULC Change detection

We acquired Landsat satellite images of project catchment area for two epochs; 1989 and 2015 from the USGS data resources (https://landsat.usgs.gov/landsat-data-access). Row and path numbers of the satellite images, as well as their spectral bands, used to discriminate land cover classes are presented in Table 1.

Table 1**:** Row and path numbers of the satellite images, as well as the spectral bands, used to discriminate land cover classes

Image	Row	Path	Spectral bands	Date of acquisition
TM Landsat 4	54 and 53 (mosaic)	194	4, 3, 2	1989-11-11
OLI Landsat 8	54 and 53 (mosaic)	194	5, 4, 3	2015-04-17

Source: Nsor et al., 2018

The longitudinal stretch of the study area, start from Kpasinkpe (i.e., north most part of the floodplain) and Janga (i.e. south most section of the floodplain). The lateral section covered 1 km of the delineated zone of the floodplain (the active zone). This active zone, constitute a distinct hydro geomorphic landscape or part of the alluvial plain, which naturally gets flooded in extreme flood events.

Based on prior knowledge of the study area and a brief reconnaissance survey, we developed a classification scheme for the study which gave a rather broad classification where the land uses land cover (here after referred to as LULC) and was identified by a single digit. Here, land cover is the physical material at the surface of the earth, while land use is a description of how people use the land (Fisher et al., 2005). Description of the various land covers were as follows: water bodies (rivers, marshes and streams); riparian vegetation (open woodland and shrubs along the banks of the main river, riparian systems and marsh wetlands); bare surface (sediment/bare ground alluvial deposits), rock surfaces and patchiness without ground cover and agricultural land use (farm lands for the cultivation of arable and cash crops). A total of 250 GPS points were collected using random stratified sampling technique for the classification (i.e. the division of sampling points into smaller groups based on shared attributes or characteristics). After collection, the data were divided randomly into two datasets: a classification dataset (76% of the original data or 190 points), and an accuracy assessment dataset (24% of the original data). Supervised classification technique with maximum likelihood classifier was used to create four cluster classes from the multispectral Landsat satellite imagery. Supervised classification technique is an image processing method where the image analyst defines clusters during a training process and subsequently determines how test pixels are assigned to the defined clusters using an appropriate classification algorithm (i.e maximum likelihood algorithm in this paper) (Richards & Richards,1999; Congalton et al., 2008; Lillesand et al., 2014). The fact that landscape structure and land cover dynamics are very complex made the Maximum Likelihood Classifier (MLC) an appropriate classification method (Adepoju et al., 2006). To assess the accuracy of the classified images, the classified image is compared to another data source that is considered to be accurate or ground truth data to generate the confusion matrix. Kappa coefficient, overall accuracy, user's accuracy and producer's accuracy were selected as measures to assess the accuracy of the classifications. The Kappa, a widely used measure of classification output, derived from the confusion matrix, is used to measure the agreement between two sets of categorizations of a dataset while correcting for chance agreements between the categories (Jenness & Wynne, 2007). The kappa coefficient is computed as:

$$k = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+}x_{+i}}{N^2 - \sum_{i=1}^{r} x_{i+}x_{+i}}$$ (Congalton et al., 2008).

Where:

$$x_{i+} = \sum_{j=1}^{r} x_{ij}$$

$$x_{+i} = \sum_{j=1}^{r} x_{ji}$$

x_{ij} lenotes the elements of the confusion matrix in row *i* and column *j* , *r* represents number of classes and N sum of all elements of the matrix. A Kappa value of one indicates perfect agreement of classification where as a kappa coefficient of zero means that the agreement is no better than would be expected by chance (Lillesand et al., 2014; Rwanga & Ndambuki, 2017). The Kappa coefficient was then computed using 60 accuracy assessment GPS points over the study area for the 2015 image. Accuracy assessment for the historical images (1989 image) was calculated using 30 identified GPS points for areas of 'no change' based on local community knowledge. The results indicate a total accuracy of 88.57% and a kappa index of 0.8103 for the 1989 image date and a total accuracy of 90 % and a Kappa index of 0.825 for the 2015 image (see appendix 1). The accuracies obtained showed maps have sufficient accuracy for post classification comparison approach.

Post-classification analysis method of change detection was used in this paper (Lu & Weng, 2007; Castellana et al. 2007). Land cover change is detected as a change in land cover between the two image dates based on the independent true land cover classification, which was achieved by supervised classification. The changes were measured between-class (conversion from one land cover class to another) and within-class (changes from one land use to another).

To ensure standardization, consistency and adequate record length among stations, we selected the 22-year period from 1989 to 2010, for the study duration. Secondly, due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends (Pachauri & Meyer, 2014). Time series of daily air temperature, precipitation and evapotranspiration from 1989 to 2010 covering 15 weather stations, were collectively obtained from the Ghana Meteorological Service. Monthly total rainfall values were obtained by summing the measured daily rainfall data, at the rainfall stations. Similarly, annual total rainfall data were computed by adding monthly total rainfall data.

To estimate missing monthly values, we used normal ratio method (Milly et al., 2001), to serially complete or fill in the dataset, below:

$$P_A = \frac{\sum_{i=1}^{n} \frac{NR_A}{NR_i}}{n} \times P_i \qquad (3)$$

Where *Pi* is the data at surrounding stations, NR_A is the normal monthly or seasonal data at station A, NR_i is the normal monthly or seasonal data at station i, and n is the number of surrounding stations whose data are used for estimation. This method has been widely used to reconstitute the climatological missing data (e.g. Eischeid et al., 2000). The method is applied to estimates missing climate data P_A at station A; which is a function of the normal monthly or annual data of the station where missing data was detected, and those of the neighboring stations for the period of missing data at the station under question. For evapotranspiration data computation, the combined method of FAO Penman-Monteith equation (Monteith, 1986) and resistance terms developed for the American Society of Civil Engineers (ASCE) Penman-Monteith equation (Allen et al., 1994; Jensen, 1990) were used and shown in the formula below:

$$ET_{\circ} = \frac{0.408\Delta(R_n - G + \gamma \frac{900}{T-273} U_2(e_a - e_d)}{\Delta + \gamma\ (1 + 0.34\ U_2 \square)} \text{ .... (1)}$$

Where $ET_{\circ}$ = is the grass reference evapotranspiration (mm d^{-1} or mm h^{-1}, = is the net radiation (MJ m^{-2} d^{-1} or MJ m^{-2} h^{-1}), G = is the soil heat flux density (MJ m^{-2} d^{-1} or MJ m^{-2} h^{-1}), T = is the mean daily temperature (ºC), γ and Δ = are the psychometric constant and slope of the saturation vapour pressure function (KPa ºC), U_2= is the average 24 – hour wind speed at 2 meters height (m s^{-1}), e_s = is the mean saturation vapour pressure of the air (KPa), e_a = is the saturation vapour pressure at dew point (KPa). Thus, the estimation of the FAO Penman-Monteith equation (FAO-PM) is similar to the ASCE Penman-Monteith equation. The assumption for using FAO Penman-Monteith equation is that one does not require local calibration or use of a localised wind function if wind speed is measured at a height of 2 m or is adjusted to this height (Allen et al., 1994). Computing equation on hourly or shorter time period generally gives better estimates than using 24 – hour time steps, especially in areas where substantial changes in in wind speed, dew point or cloudiness are a common feature during the day (Allen et al., 1994). The authors are of the view that drastic changes in weather can cause 24 - hour means to misrepresent evaporative power of the environment during parts of the day and may introduce inherent errors when calculating with equation (1). Secondary data on population growth and density between 1984 and 2010, for Northern Region of Ghana was sourced from the Ghana Statistical Services (www.statsghana.gov.gh).

Assessment of environmental factors

In order to ascertain the rationale for increasing rate of agricultural activities within the floodplains compared to other neighbouring areas, we randomly collected soil samples with a soil auger at a depth of 15cm, using the zigzag sampling method (Carter & Gregorich, 2006) on some agricultural fields. Three composite samples were taken from three different 25 cores in each farm, located in 10 farming communities. Samples were put in transparent polyethylene bags and labeled according to the code assigned to each plot and taken to the laboratory to analyze the presence of total Nitrogen, Phosphorus, Calcium and soil pH, using atomic absorption spectroscopy (AAS) techniques (van der Merwe et al., 1984). Organic matter was determined using the Walkley- Black method (Walkley & Black 1934). All analyses were carried out at the Savannah Agricultural Research Institute (SARI) at Nyankpala in the Northern Region.

Statistical analysis of climate data

Average for annual air temperature, total annual rainfall and potential evapotranspiration were initially subjected to Kolmogorov-Smirnov test, to determine if they were normally distributed, using PAST ver

2.17c. Time series analysis was further carried-out to determine the pattern of precipitation, air temperature and potential evapotranspiration, using Microsoft Excel package for Windows 10. Mann-Kendall test (a non-parametric test) was used to test for significant trends in climatic parameters, over time (Mann, 1945; Kendall, 1975). Mann-Kendall (MK) test makes no assumption for probability distribution of the variate and is not affected by missing values or outliers. Secondly, MK can be adopted in cases where data are not normally distributed or containing non-linear trends (Helsel & Hirsch, 2002). Therefore, this technique is the most robust for detecting trends in rainfall time-series data due to the influence of extremes and the fit of applications with skewed variables (Hamed, 2008).

The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model:

$$x_i = f(t_i) + \varepsilon_i \text{ .... } (4)$$

where f(t) is a continuous monotonic increasing or decreasing function of time and the residuals εi are assumed to be from the same distribution, comprising of zero mean value. It is therefore assumed that the variance of the distribution is constant in time *t*. In this test, the H_0 of no trend has been assumed, while the observations (x_i) are randomly ordered in time *t* against H_1, where there is an increasing or decreasing monotonic trend. In this test, *n* denotes the number of annual values in the studied data series. If '*n*' is at least 10, the normal approximation test is used. However, if the data values are less than 10, the Mann-Kendall test statistic S of the series x is computed using the formula:

$$S = \sum_{i=1}^{n-1} sgn(x_j - x_t) \quad \text{.......................(5)} \quad \text{(Mann, 1945; Kendall, 1975).}$$

Where x_j and x_k are the annual values in year's *j* and *k*, respectively, and is given as:

$$sgn(x_j - x_t) = \begin{pmatrix} 1 \; if \; x_j - x_k > 0 \\ 0 \; if \; x_j - x_k = 0 \\ -1 \; if \; x_j - x_k < 0 \end{pmatrix} \quad \text{..........(6)}$$

Where *sgn* is the signum function.

However, If n is 9 or less, the absolute value of S is directly compared to the theoretical distribution of S derived by Mann and Kendall (Mann, 1945; Kendall, 1975). Three different significance levels (α: 0.05, 0.01, and 0.001) were set to determine whether H_0 will be rejected, if the absolute value of S equals or exceeds a specified value Sa/2, where Sa/2 is the smallest S which has the probability less than α/2 to appear in case of no trend (Kabo-Bah et al., 2016). The significance level 0.001 means that there is a 0.1% probability that the values xi are from a random distribution and may lead to a wrong rejection of H_0 if normal trends are not observed. However, if there are several tied values (i.e., equal values) in the time series, it may reduce the validity of the normal approximation when the number of data values is close to 10 (Kabo-Bah et al., 2016). In this study, the desired value of α is taken as 0.05, for testing either an upward or downward monotone trend (a two-tailed test).

The variance associated with *S* is calculated from Mann (1945) & Kendall (1975):

$$v(s) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(t_k - 1)(2t_k + 5)}{18} \quad \text{.............(7)}$$

Where *m* is the number of tied groups and *tk* is the number of data points in group k. In cases where the sample size n > 10, the test statistic Z(*S*) is given as:

$$Z(s) = \begin{pmatrix} \frac{s-1}{\sqrt{v(s)}}, if\ s>0 \\ 0, \quad if\ s=0 \\ \frac{s-1}{\sqrt{v(s)}}, if\ s<0 \end{pmatrix} \quad \text{……………………….(8)}$$

Statistically significant trends are determined using the *Z* value and here the statistic *Z* has a normal distribution. Positive values of Z(S) indicate increasing trends, while negative Z(S) values reflect decreasing trends. Trends are considered significant if $|Z(S)|$ are greater than the standard normal deviate $Z1- \alpha /2$. The value for $Z\alpha/2$ is obtained from the standard normal cumulative distribution tables for the significance levels (Tabari et al., 2011). Finally, student t-test was employed to determine whether floodplain vegetation changed between the two epochs (1989 and 2015).

Results

Species composition along the floodplain

The floodplain vegetation type was manly perennial woodland and shrubland savannah communities, with isolated undergrowth made up of grasses and herbaceous cover. Dominant woody savannah species included: Mahogany- *Khaya senegalensis*, African Rosewood – *Pterocarpus erinaceus,* Dawadawa tree – *Parkia biglobosa* and shea-nut tree - *Vitellaria paradoxa*). The perennial shrub species comprised of *Mitragyna inermis, Syzygium guineense* and *Vitex crysocarpa,* with an average height of 4.5 - 5.5 m. The step-like form of the vegetation structure; beginning with tallest trees closer to the active river tract, to the shortest trees farther away, is related to the variation of the soil moisture level across the lateral zone of the floodplain. Less disturbed vegetation appeared dense and close canopied along a continuum, than areas that were heavily disturbed. Species farther away from the riparian zone, tend to wither in the dry season, while stands closer to the banks of the active river tract appear lush green all year round. The few interspersed undergrowth, were on average 0.5 – 1 m tall and included: *Chrysopogon zizanioides, Leersia hexandra, Scleria verrucosa, Schizachyrium sanguinum, Hyperhenia hirta, Ludwigia abyssinica and Ludwigia hyssopifolia.* These species*,* were characterized by tufted-bunch tussocks, fibrous rooting system, and lanceolate leaves.

Soil texture and nutrient composition along the floodplain

Soils in the floodplains were characteristically silty-loam to sandy-loam, with exceptionally high organic matter content (2.9 – 3.7%); total nitrogen (1.8 – 2.4 µg/g); available phosphorus (3.0 – 12.5 kg/ha) and pH (6.6 – 7.4). The high soil nutrients along the floodplains, typically favoured crop production, that are described as heavy feeders (e.g. maize, sorghum and millet), compared with the impoverished soils from neighbouring terrestrial systems, which exhibited low levels of organic carbon (0.5 – 1.9%), total nitrogen (0.04 – 0.06 µg/g) and percentage of available phosphorus (2.3 – 8.6 cmol(+)/g), and are characteristically reddish (from acrisols and luvisols soil orders). The soils hardly support major arable crop production like maize.

Table 2: Summary of the flood plain soil nutrient status from Kpasinkpe to Janga stretch of the White Volta River basin

Major soil elements	Range	Mean±S.E.
Organic matter (%) Organic matter (%) Total nitrogen (μg/g)	2.9 – 3.7 0.5 – 1.9 1.8 – 2.4	2.4±1.5 1.2±0.2 2.1±0.06
available P (cmol(+)/g)	2.3 – 8.6	6.9±0.1
Soil pH	6.6 – 7.4	7.1±0.09

Source: Nsor et al., 2018

Prominent changes in climate variability between 1989 and 2010 (22 years)

Initial test for normality on precipitation and temperature showed that data were normally distributed ($p < 0.001$, *Kolmogorov-Smirnov test*). Overall change in floodplain vegetation was significantly different (*t-test* = 7.4, $p<0.05$) over the 26-year period. Generally, temperature and precipitation followed similar patterns with marked fluctuations over the 22-year period (1989 – 2010). Air temperature showed significant increase ($p < 0.05$, *Mann-kendall test*) from 34 ºC in 1989 to 36.1 ºC in 2010, with a +0.2ºC decadal rate of change (Figure 2). These extreme temperature variations, correlated with a decrease in total rainfall from 1,427.3 mm in 1989 to 1101.4 mm, in 2010 and an increase in potential evapotranspiration (Figs. 3 & 4). The lowest rainfall recorded in the 22-year period was 695.5 mm/a in 1992 and 791.3 mm/year in 2001. Within this period, temperature increased from 34.4 ºC to 34.8 ºC, respectively (Figs. 2 and 3).

Variations in potential evapotranspiration (PET) (Fig. 4) appeared to follow a similar pattern as the one observed for total rainfall and temperature. For instance, as PET was highest in 1998 (2329.3 mm), total rainfall decreased to ~ 937 mm, in the same year. Similarly, lowest PET (2048.7 mm) in 1991, led to an appreciable increase in total rainfall to about 1579.8 mm, in the same year (Figs. 3 and 4). Air temperature directly influenced PET, over the 22- year period. This was evidenced between 1991 and 2010, when temperature increased from 34.1 ºC to an av. 36.1 ºC, alongside a corresponding increase in PET from 2048.7 mm to 2248.3 mm (Figs. 2 and 4). With the exception of an increase in air temperature, agricultural expansion from 10.33% to 58.84% and the simultaneous decrease in vegetation cover from 72.53% to 16.96%, from 1989 to 2015 (Table 3), equally contributed in evapotranspiration. Loss of water from 7.61% to 3.5%, over the same period, which was inextricably linked to agricultural expansion activities, also contributed to increased evapotranspiration.

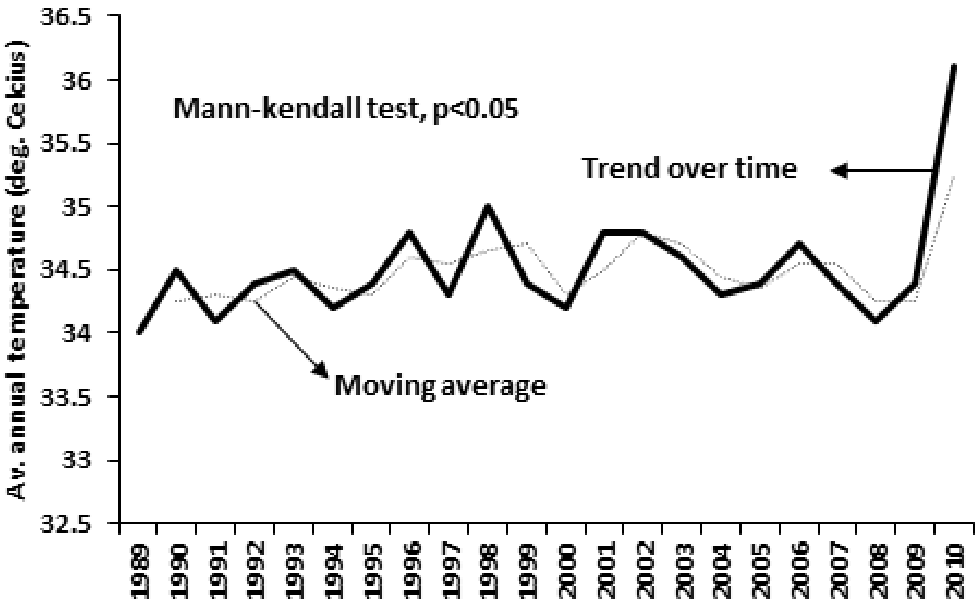

Figure 2. Variations in average annual temperature over 22 years' in Northern Region, Ghana.

Source: Tamale Met Station 07006TLE, 2017

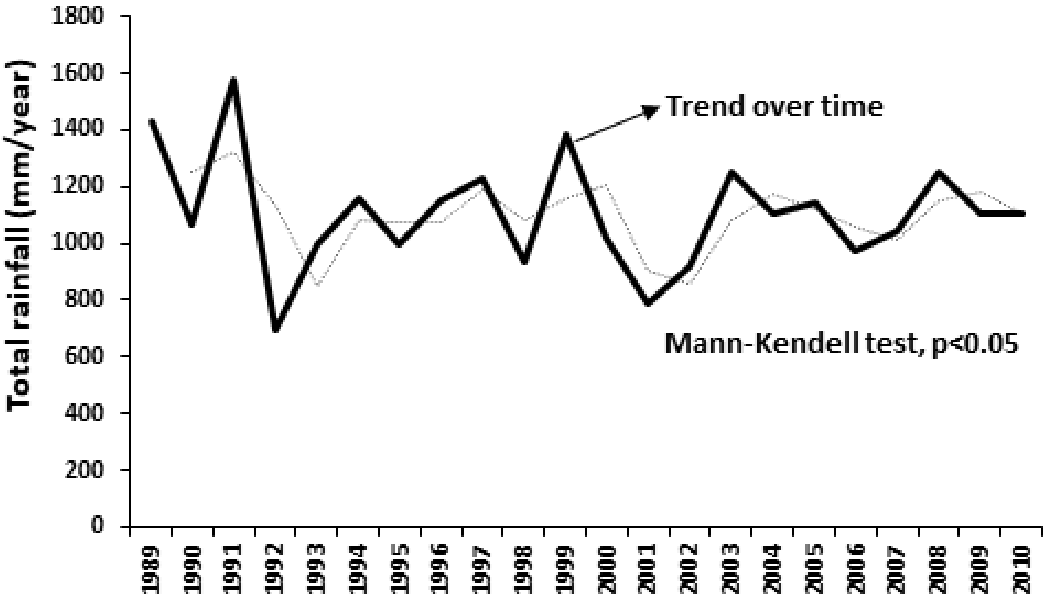

Figure 3. Precipitation trend over the last 22 years (1989 – 2010), showing a General steady decrease in Northern Region, Ghana.

Source: Tamale Met Station 07006TLE, 2017

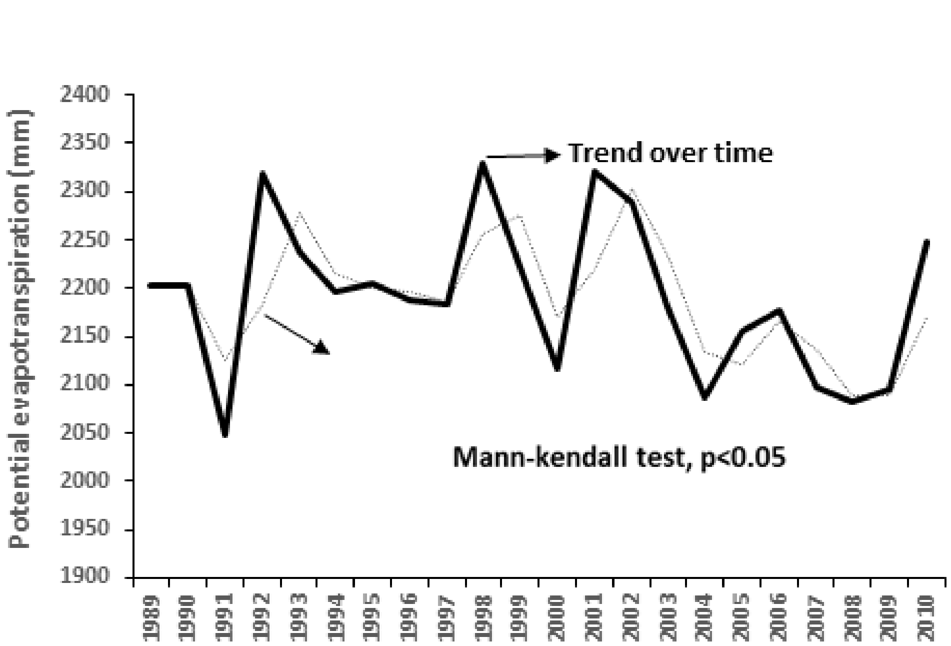

Figure 4. Variations in mean potential evapotranspiration over 22-year period (1989 – 2010) in Northern Region, Ghana.

Source: Tamale Met Station 07006TLE, 2017

Land cover and land uses dynamics (1989 and 2015) and population growth

Observed trends in land cover and land use dynamics of the floodplain between 1989 and 2015, showed a systematic transformation to a more variably disturbed system (Fig. 5). This transformation was largely linked to human-led activities, namely, expansion of agricultural activities - fundamentally driven by population pressure and changes in climate (Figs 2 – 5, Table 3). Areas occupied by water bodies decreased from 7.6% (in hectares) from 1989 to 3.5% in 2015, while bare surface, rather increased sharply from 9.52% to 20.7%, within the same time scale (Table 2). Bare surface including sediment deposits or alluvial fans, increased in areas where ground cover was less and flow discharge reduced. Most of the bare surface areas were characterized by erosional features or channel incision, closed to the banks of the riparian zone. This phenomenon was caused by increase in sediment deposit, during flooding. Expansion of farmlands, through slash and burn, sharply increased from 10.33% to 58.84%. This trend tended to affect the open woodland vegetation, leading to a 72.53% decrease of its original size to 16.96% (Table 3).

Agricultural activities, which is the mainstay occupation of most rural folks in the study area, have nearly doubled over the last two decades and this was consistent with increase in population growth and density, which far outstripped urban areas in the Region (Table 4). For instance, a 36.2% increase in population growth between 2000 (1,820,806) and 2010 (2,479,461) and population density between 1984 (17 pers/sq.km) and 2010 (35 pers./sq.km) (Table 3), reflected in an increase in labour force (i.e., 15 – 64 age range) in the agricultural sector (i.e., crop farming, forestry, fishing, pastoral farming and hunting), from 523,278 (2000) to 681,101 by the end of 2010. Observed increase in agricultural activities and population growth/density in rural communities close to the floodplains, occurred at the time that rainfall showed a steady decrease, while temperature had increased (Figs. 2 & 3).

The rapid increase in population growth, which did not reflect in equal increase in labour force, was so because not all inhabitants were directly involved in agricultural, forestry and water abstraction activities. The remaining populace, indirectly depended on these farming households for their farm produce supply, leading to increase in efficient work output among the active agricultural labour force.

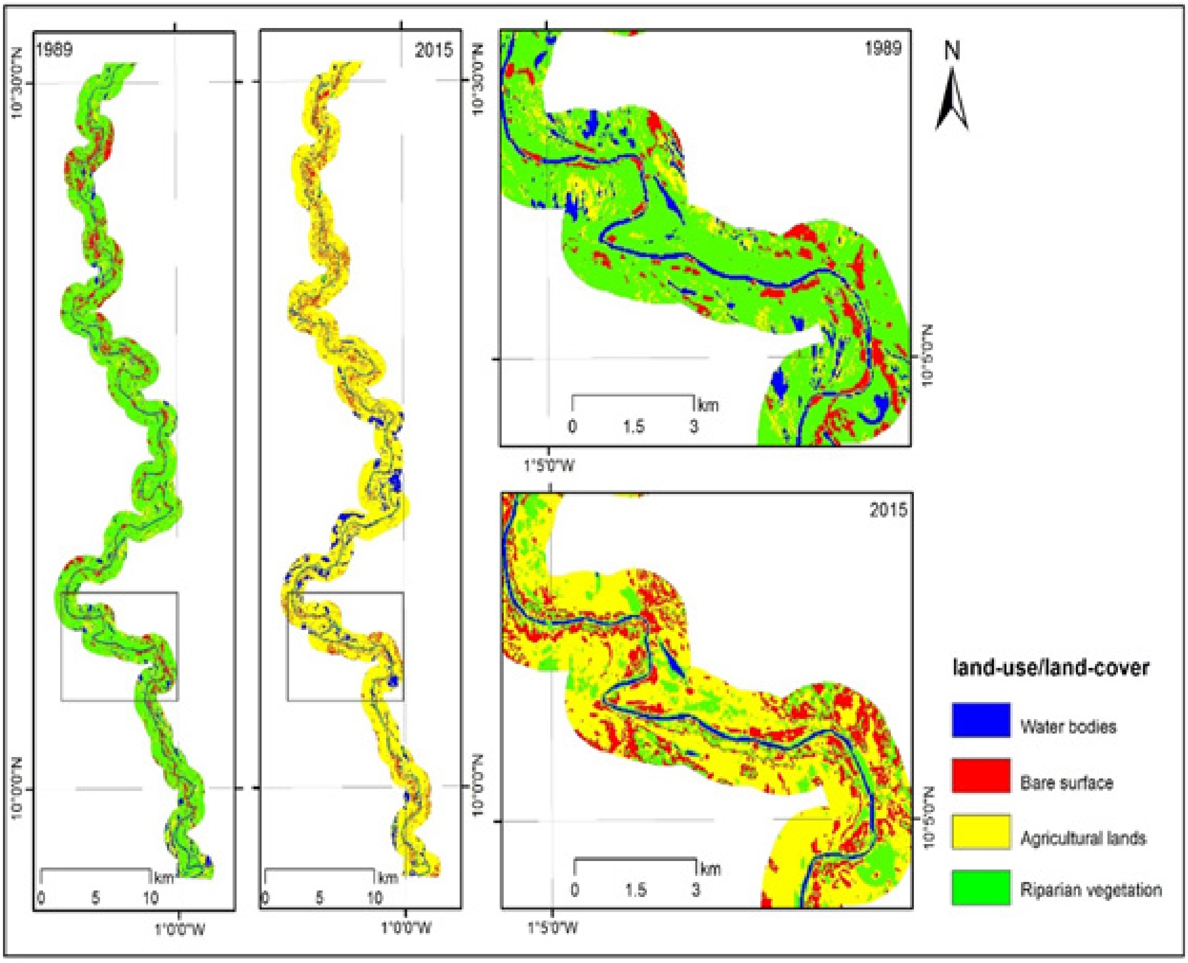

Figure 5. Changes in land use/land cover between Kpasinkpe and Janga section of the White Volta River floodplain, between 1989 and 2015. Notice the sharp transformation of the floodplain vegetation, largely mediated by agricultural activities over the 26-year period

Source: Authors' Field work, 2018

Table 3: Transition matrices for land use/land cover classes (in hectares) over a 26-year period (1989 – 2015), along the floodplains of the White Volta River

	2015					
Land use/land cover class	Water	Bare surface	Agricultural lands	Riparian vegetation/ Open woodland	*Total*	*Total (%)*
1989						
Water bodies	672.8	38.4	530.0	433	1674.3	7.61%
Bare surface	8.9	685.1	1050.5	350.8	2095.2	9.25%
Agricultural lands	62.3	255.8	1633.9	320.5	2272.5	10.33%
Riparian vegetation/open woodland	26.4	3573.5	9728.1	2627.2	15955.2	72.53%
Total	***770.4***	***4552.8***	***12942.5***	***3731.6***	**21997.3**	
% total	***3.5%***	***20.7%***	***58.84%***	***16.96%***		

Source: Authors' Field work, 2018

Table 4: Population growth and density in Northern Region of Ghana, for the period 2000 - 2010

Region	2000	2010	% increase	Intercensal growth rate
Ghana	18,912,079	24,658.823	30.4	2.5
Northern	1,820,806	2,479,461	36.2	2.9

Population density (1984 -2010)

Area (km^2)	1984	2000	2010
70,383	17	26	35

Source: Ghana Statistical Service (www. Statsghana.gov.gh), 2017

Discussion

Previous studies have largely linked floodplain vegetation dynamics to solely climate change impacts (Rivaes et al., 2013) or anthropogenic land use disturbances (Naiman & Dècamps 1997; Tickner et al., 2001; Shafroth et al., 2002). But the findings in this study, revealed multiple mediating factors; including, climate change impacts, agriculture expansion (due to increased population growth and density) and poor soils, as the key drivers of the floodplain vegetation change over the study period (1989 - 2010). Agricultural expansion on the fertile floodplains all year round, was so because, most farming communities farther away from the floodplains, are characterized by poor soils and erratic rainfall. This led to the influx of majority of farmers and their families from distant communities (including urban and peri-urban centres), to the remote catchment of the floodplains (to engage in farming activities). While we found low rainfall as one of the natural drivers of agricultural expansion on the floodplains, other studies showed that falling groundwater levels (Oboubie et al., 2012), in most areas of the North, as a factor that led to the migration of farmers to the floodplains. The cultivation of "*heavy feeder crops*" like maize, millet, rice, sorghum and legumes, as well as livestock farming, are only possible in areas with high fertile soils and availability of water all year round. This probably explains why the floodplains are the most favourable farming zones in Northern of Region of Ghana. Brinson (1981) and Warren & French (2001), revealed floodplains as part of the most productive and highly diverse species ecosystems, while Posthumus et al., (2010) gave an example of the importance of fertile floodplains in supporting agricultural production, as part of ecosystem services in England.

Although the fertile state of the floodplains have led to increasing use of land resources for agricultural and other economic related activities, population increase, the spread of settlement, these phenomenon have led to considerable changes in land cover along the catchment of White Volta River Basin between Ghana and Burkina Faso over the past four decades (Braimoh & Vlek, 2005; Ouedraogo et al., 2010). With the surge in population growth and density within communities close to the floodplain catchment, the possibility of future agricultural expansion is set to occur and this could further exacerbate the current disturbances of the floodplain vegetation. Our prediction of future worse case scenarios along the floodplains of the White Volta River has been confirmed by Rodgers et al., (2007), who reported of a likely increase in agricultural activities, given a 2.5% annual increase in population among communities along the White Volta River and erratic rainfall (as a result of unfavourable climatic conditions).

Effects of clearing of ground cover for agricultural activities led to increased sediment deposit and bare ground in the floodplains. Transformation of majority of the open woodland vegetation to grassland was an indication of long-term disturbance, largely due to agricultural activities and a reduction of river flow discharge. This phenomenon will not only promote the presence of ruderal species, but will affect both the abundance of species and diversity and consequently, lead to increase in flooding, sediment transport and erosion. Knox (2006) and Whohl (2006) found agricultural and grazing activities to be the main causes of increase in sediment deposits, while Akrasi (2005) also found widespread siltation in the Volta River basin. James et al., (2013) concluded that human activities that disrupt vegetation of river systems and destabilize soils, have the potential to decrease soil infiltration, suppress groundwater recharge, and amplify runoff generation and flood magnitude. The dominance of grassland succession over woodland has attracted grazing activities among Fulani pastoralists along the corridors of the floodplains, which could potentially lead to species loss, including *keystone* species. Awotwi et al. (2015) attributed the decrease in savannah woodland of the White Volta Basin, to increase in croplands. Other studies found impact of hydroelectric power plants on floodplain vegetation is well documented at the northern alpine rivers (Muller, 1995) and river regulations and (Tockner et al., 2002), on floodplain vegetation.

Hydrologic response to impact of agricultural expansion was also evidenced through a reduction in water surface area and an increase in bare surface area, brought about by clearing of vegetation. This phenomenon could lead to increase in surface run-off and the consequent effect of sediment deposition. Losses in vegetation cover of the Dutch Rhine River due to agricultural use and the consequent disappearance of other former river bed due to siltation (Jongman, 1992, Wolfert, 2001) attest to the impacts of LULC disturbances on floodplain vegetation. Awotwi et al., (2015) showed a similar link between a decrease in land cover and a corresponding decrease in surface water and base flow in the White Volta River Basin.

Effect of recent increase in air temperature and a simultaneous decrease in rainfall pattern, contributed in the floodplain vegetation change, through a reduction in the amount of river flow discharge. Hydrologic changes caused by changes in climatic events, tend to either shift species that are hydrophilic with a low thermal threshold tolerance, from their natural range or reduce cover abundance. Peak discharge alternations of the Drau River (Austria), linked to climate change impacts, revealed consistent variations in quantitative and spatio-temporal distribution of vegetation type (Politti et al., 2014). Using historical climate data, Mosner et al., (2015) showed how historical climate change will impact on future habitat availability for floodplain vegetation types, by observing current disturbance in the Rhine River. Thus, from the observed changes in the floodplain vegetation, alongside recent climatic trends in Northern Region, it is almost certain that future temperatures will increase; leaving in its wake much wider ramifications on the floodplain vegetation.

Conclusion

The impact of climate change, agricultural activities and population pressure on the floodplain vegetation, are obvious from the changes detected between 1989 and 2015 Landsat satellite images. Given the estimated increase of water demand from 40,779.79 million m^3 in 2010 to 42,969.22 million m^3 in 2020 (WRC, 2012), with agriculture as the main consumptive use, influx of farm families to the catchment of floodplains is set to increase. Secondly, the current erratic rainfall pattern and increase in air temperature in Northern Region of Ghana, could equally lead to increase in population drift to the floodplains for agricultural activities. This phenomenon may consequently result in overall impact on biodiversity, impair on water quality and total discharge. Considering the importance of the floodplain, one of the most productive and highly diverse ecosystem in Northern Region of Ghana, it is imperative to institute conservation measures that will curb the intensity of human activities. We prioritize firstly, a halt to farming activities, within the floodplain zone. These include: (a) construction of dams and dug-outs for dry season irrigation in the Districts, where farmers will be re-located; (b) introduction of organic composting, to re-vitalize all farmlands characterized by poor soil fertilities. This will help address the case of poor soil fertility, one of the reasons why farmers from Northern Region of Ghana, flock to these floodplain zones for their farming activities; (c) demarcation of range lands as fodder banks in the Districts, for grazing purposes and (d) introduction of alternative economic activities, that will support the livelihood of farmers and their families. Finally, reforestation of the depleted vegetation, using indigenous species. Martinet & Dubost (1992) and CIPRA (1992) proposed similar conservation measures and Development of Northern Alpine river landscapes, as a way of re-establishing the continuum of the floodplains along the whole river. Thus, restoration measures will only be successful if the essential factors of river ecosystems are restored (Muller et al., 1995). Considering the long lasting anthropogenic impact on floodplains, it is envisaged that the proposed conservation measures in this study, could contribute to restoring the functional status of the floodplain vegetation.

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Appendix 1

Table 1A: Accuracy assessment of land cover mapping for 1989 image. Results of accuracy assessment of land cover mapping for 1989 image and conditional Kappa for each category of land cover. Overall classification accuracy = 88.57%, while overall Kappa (κ) Statistics = 0.8103

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa
water bodies	3	3	3	100.00%	100.00%	1
Bare surface	7	9	6	85.71%	66.67%	0.583
Agricultural land use	5	3	2	40.00%	66.67%	0.611
Riparian vegetation	20	20	20	10.00%	100.00%	1
Total	35	35	31			

Table 1B: Results of accuracy assessment of land cover mapping for 2015 image and conditional Kappa for each category of land cover. Overall classification accuracy = 90%, while overall Kappa (κ) Statistics = 0.825

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa
Water bodies	2	2	2	100.00%	100.00%	1
Bare surface	13	12	10	76.92%	83.33%	0.787
Agricultural lands	26	26	33	91.67%	91.67%	0.792
Riparian vegetation	9	10	9	10.00%	90.00%	0.882
Total	60	60	54			