# Assessment of Spatio-Temporal Changes of Land Use and Land Cover over South-Western African Basins and Their Relations with Variations of Discharges

Salomon Obahoundje
*Université Félix Houphouët Boigny*

Arona Diedhiou
*Université Félix Houphouët Boigny, University Grenoble Alpes*

Eric Antwi Ofosu
*University of Energy and Natural Resources*

Sandrine Anquetin
*University Grenoble Alpes*

Baptiste François
*University of Massachusetts Amherst*

*See next page for additional authors*

## Authors

Salomon Obahoundje, Arona Diedhiou, Eric Antwi Ofosu, Sandrine Anquetin, Baptiste François, Julien Adounkpe, Ernest Amoussou, Yao Morton Kouame, Kouakou Lazare Kouassi, Vami Hermann Nguessan Bi, and Marc Youan Ta

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**Salomon Obahoundje [1,*], Arona Diedhiou [1,2], Eric Antwi Ofosu [3], Sandrine Anquetin [2], Baptiste François [4], Julien Adounkpe [5], Ernest Amoussou [6], Yao Morton Kouame [7], Kouakou Lazare Kouassi [8], Vami Hermann Nguessan Bi [9] and Marc Youan Ta [9]**

1 LAPAMF-African Centre of Excellence on Climate Change, Biodiversity and Sustainable Development, Université Félix Houphouët Boigny, 22 B.P. 582 Abidjan 22, Abidjan, Ivory Coast; arona.diedhiou@ird.fr
2 IRD, CNRS, Grenoble INP, IGE, University Grenoble Alpes, F-38000 Grenoble, France; sandrine.anquetin@univ-grenoble-alpes.fr
3 Department of Energy and Environmental Engineering, University of Energy and Natural Resources, P.O. Box 214 Sunyani, Ghana; ericofosuantwi@gmail.com
4 Department of Civil and Environmental Engineering, University of Massachusetts Amherst, Amherst, MA 01003, USA; bfrancois@umass.edu
5 WASCAL Climate Change and Water Resource Doctoral Programme-School of Environment Planning and Management, University of Abomey-Calavi, P.O. Box 526 Cotonou, Benin; julvictoire@yahoo.com
6 Département de Géographie et Aménagement de Territoire (DGAT/FLASH), Université de Parakou, BP 123 Parakou, Parakou, Benin; ajernest@yahoo.fr
7 Centre de Recherches Ecologiques, Université Nangui Abrogoua, 02 BP 801 Abidjan, Abidjan, Ivory Coast; mortonkouame@gmail.com
8 UFR-Environnement, Université Jean Lorougnon GUEDE, 12 BP V 25 DALOA 12, Daloa, Ivory Coast; k_lazare@yahoo.fr
9 CURAT (Centre Universitaire de Recherche et d'Application en Télédétection), Université Félix Houphouët Boigny, 22 BP 801 Abidjan 22, Abidjan, Ivory Coast; vami@outlook.com (V.H.N.B.); youanta@yahoo.fr (M.Y.T.)
* Correspondence: obahoundjes@yahoo.com; Tel.: +229-617-451-12 or +225-421-144-28

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**Abstract:** West African basins play a vital role in the socio-economic development of the region. They are mostly trans-boundary and sources of different land use practices. This work attempts to assess the spatio-temporal land use and land cover changes over three South Western African basins (Volta, Mono and Sassandra basins) and their influence on discharge. The land use and land cover maps of each basin were developed for 1988, 2002 and 2016. The results show that all the studied basins present an increase in water bodies, built-up, agricultural land and a decline in vegetative areas. These increases in water bodies and land use are as a result of an increase in small reservoirs, of dugouts and of dam constructions. However, the decline in some vegetative clusters could be attributed to the demographic and socio-economic growth as expressed by the expansion of agriculture and urbanization. The basic statistical analysis of precipitation and discharge data reveals that the mean annual discharge varies much more than the total annual precipitation at the three basins. For instance, in the entire Volta basin, the annual precipitation coefficient of variation (CV) is 10% while the annual discharge CV of Nawuni, Saboba and Bui are 43.6%, 36.51% and 47.43%, respectively. In Mono basin, the annual precipitation CV is 11.5% while the Nangbeto and Athieme annual discharge CV are 37.15% and 46.60%, respectively. The annual precipitation CV in Sassandra basin is 7.64% while the annual discharge CV of Soubre and Dakpadou are 29.41% and 37%, respectively. The discharge varies at least three times much more than the precipitation in the studied basins. The same conclusion was found for all months except the driest months (December and January). We showed that this great variation in discharge is mainly due to land use and land cover changes. Beside the hydrological modification of the land use and land cover changes, the climate of the region as well as the water quality and availability and the hydropower generation may be impacted by these changes in land surfaces conditions. Therefore, these impacts should be further assessed to implement appropriate climate services and measures for a sustainable land use and water management.

**Keywords:** land use; land cover; energy water nexus; climate change; West Africa

## 1. Introduction

Sub-Saharan Africa has experienced, over the past, some changes in land cover due to drought events [1,2]. After the drought of the 1980s the region has recovered from this loss. Apart from the climatic factors, other drivers of change are biological and socio-political [3] as well as demographical [4] and socio-economical [5] factors. In order to meet the need for food, fiber, water and shelter of an increasing population, the environment has seen a change in forest landscapes, farmlands, waterways and air quality. The cause of land use and land cover changes in West Africa basins was mainly attributed to rapid population growth rate [6,7]. However, this phenomenon consequently has some effects on hydrological dynamics [8,9]. The sustainability of water resources depends mainly on land use planning and management [8]. Some main West African basins, namely, Volta, Niger and Sassandra have already experienced these changes due to a rapid population growth rate and the transboundary condition of the basins.

The West African region has a high population growth rate associated with a high urbanization ratio [10,11]. Apart from urbanization, the West Africa population relies on rain-fed agriculture which requires more and more land to feed its growing population. All of these practices have consequently resulted in land use and land cover changes.

The Volta, Niger, Mono and Sassandra catchments are the main contributors to the socio-economic development of the region and are all shared between at least two countries. These basins are the main sources of the hydroelectricity production [12] of the sub-region. Despite the fact that all the riparian's countries have agriculture as their main activity, the policy for planning and management of land uses and practices may be different and this may vary within the same country. This may result in different land uses and practices within the same basin with impacts on the water availability of the river. For instance, in West Africa, the water consumption and withdrawals have increased [13] and created a strong competition between hydropower and upstream water withdrawal for agriculture [14], especially between Ghana and Burkina Faso [15,16]. Some communities and even governments tend to blame upstream countries for phenomena such as deficits in discharges or rivers, floods and water weeds [14]. Some hydropower facilities located downstream lack water because of too many withdrawals. In fact, in Volta basin, the upstream dams namely Bagre, Kompienga and Bui plants deprive Akosombo hydropower generation. Moreover, the Ghana "One village one dam" project which aims for the construction of at least 570 small reservoirs [17] for irrigation at the Northern part of Ghana of Akosombo dam could also be a real threat to Akosombo hydropower. However, the water losses caused by implementation of small reservoirs are marginal compared to the one due to climate change patterns especially evapotranspiration [18] but the implementation of large reservoirs and/or great number of small reservoirs at upstream of Akosombo could strongly affect Akosombo power generation [19].

The aim of this study is to assess the spatio-temporal changes of land use and land cover of Volta, Mono and Sassandra basins and the relation between these changes and the variations of precipitation and discharge.

## 2. Hydro Climatology of the Study Area

The studied basins are located in the southern part of West Africa (Figure 1). Sassandra catchment is located in Ivory Coast and covers an area of 75,479.79 km$^2$. Mono catchment spreads across Togo and Benin, and cover an area of 24,282.26 km$^2$. The Volta basin with an area of 413,520.15 km$^2$ is shared among Burkina Faso, Mali, Benin, Togo, Ivory Coast and Ghana. In these basins are constructed some of the largest hydropower plants which are the main sources of electricity generation of the region. The population living in these basins are mainly rural and agriculture is the main activity. The main land cover types in these basins are mainly shrubs, savanna, forest, barren land, agricultural land, built-up and water bodies. The agricultural land covers more than 20 percent of each basin area.

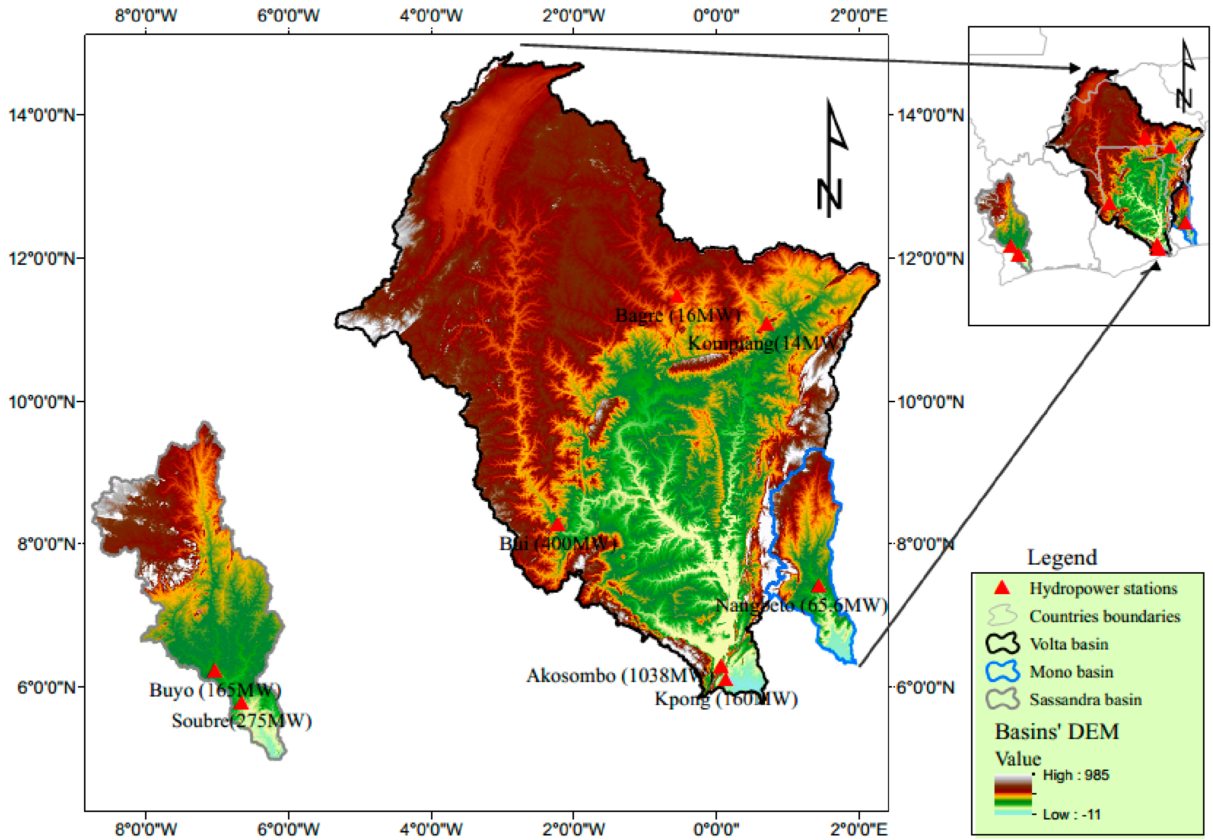


**Figure 1.** Study area map.

In the Sassandra basin, the Buyo and Soubre dams are constructed with a capacity of 165 Mega Watt (MW) and 275 MW, respectively. In the Mono basin is located the Nangbeto dam with a capacity of 65 MW. In the Volta Basin, there are five dams: the Bagre (16 MW), Kompienga (14 MW), Bui (400 MW), Akosombo (1038 MW) and Kpong (160 MW). The operation of these hydropower plants relies strongly on the hydro-climatic condition of the sub-regions.

The climate of West Africa is controlled by the movement of the Inter Tropical Convergence Zone (ITCZ) [20,21] and influenced by the Monsoon and Harmattan. Their hydroclimatic characteristics vary progressively along a north-south axis. In the southern zone or Guinean zone (transitional equatorial climate), the total annual precipitation is greater than 1100 mm shared in two rainy seasons (March–June and August–November) while the Northern part (transitional tropical climate mainly known as the Sahelian zone) is drier with a total annual rainfall variation ranging between 300 and 500 mm in one rainy season (July to September) [13]. The transitional sub-region between the Sahelian zone and the Guinea zone is called the Sudanian zone with annual precipitation increasing southward between 500–900 mm (in the Sudano-Sahelian area) and between 900 and 1100 mm (in the

Sudano-Guinean area) [13]. The pan evaporation is estimated at 2540 mm per year, and an average annual runoff coefficient of about 8.3% [22]. All these factors vary from basin to basin.

For instance, in the Volta basin, the mean monthly runoff in the sub-basin varies from 623 $m^3/s$ at the peak of the rainy season to about 2 $m^3/s$ in the dry season. During the rainy season, the rainfall is greater than evapotranspiration, and vice versa, during the dry season. The basin mean, highest and lowest temperatures are, respectively, 26 °C, 44 °C and 15 °C. The relative humidity varies between 20–30% during the Harmattan period in dry season and 70–80% in the rainy season [6].

The total annual precipitation in Mono basin is 1168 mm [23]. The mean monthly discharge at Athieme station varies from 261 $m^3/s$ (September) at the peak of the rainy season to about 0 $m^3/s$ in the dry season (February to April) [24]. During the rainy season, the rainfall is greater than evapotranspiration (which varies from 4.5 to 6 mm/day [25]), and vice versa, during the dry season. Mono basin present similar temperature and relative humidity as Volta basin.

The total annual precipitation of Sassandra basin varies from 1250 to 1700 mm (Southward). The mountainous area (Man region) record the highest depth of total annual precipitation which varies from 1600–2500 mm. The potential evapotranspiration varies from 1400 to 1500 mm/year. The mean annual discharge at Soubre station is estimated at 630 $m^3/s$ for wet year and 475 $m^3/s$ for dry year [26,27]. The relative humidity and temperature are similarly to the one of Volta basin.

In the three basins, the agricultural sector represents the main socio-economic activity of the riparian following by trading. This makes all the basins exposed to the rapid land use change as the practice remains traditional with an extensive and slash farming system on burned areas.

## 3. Data and Methods

### *3.1. Land Use and Land Cover (LULC) Data*

#### 3.1.1. LULC Data Sources

The data used in this study are from the United State Geological Surveys (USGS). Data of the Landsat Thematic Mapper (TM), the Enhanced Thematic Mapper (ETM) and of the Operational Land Imager (OLI) were assessed for the years 1988, 2002 and 2016 respectively to study the land use and land cover changes. To ensure the best quality, these data were extracted for the driest and cloudless months (January and February). Five (05) scenes are necessary to cover the entire Mono basin corresponding to the following paths/rows: 192/54; 192/55; 192/56; 193/54 and 193/55. To cover the entire Sassandra basin, eight (08) scenes were used corresponding to the following paths/rows: 197/55; 197/56; 198/53; 198/54; 198/55; 198/56; 199/54 and 199/55. The largest study basin used twenty-five (25) scenes to cover the entire Volta basin. These scenes belong to the paths from 192 to 197 with the row 52 of the 192th path, the rows from 52 to 56 of path 193, the rows from 52 to 55 of 194th path, the rows from 50 to 55 and 50 to 54 of 195th and 196th paths and finally, the row 51 to 53 of the 197th path. For a given year all these scenes were merged into a single map. The southern part of Mono basin which was cloudy was not considered. The Landsat data level 2 has been ordered for atmospheric correction. After the completion of the ordered data, it has been processing and classified using supervised classification method.

#### 3.1.2. LULC Data Analysis Method

There are mainly three approaches to perform a land cover classification, namely, pixel-based, subpixel-based and object-based approaches divided in different methods each with their advantages and limitations [28]. The state of the art of each approach is well described in [28]. The maximum likelihood pixel-based classification method, which was developed in the 1970s, is the most commonly used method on Landsat images. This method has been used to develop our land cover map.

The land cover types may vary within the same basin as well as from a catchment to another catchment. For instance, for Volta basin, we have nine (09) clusters of land cover namely water bodies, built-up, barren, agricultural land, shrubs, herbaceous savanna, savanna, forest and evergreen forest. Whilst, in Mono basin we have made only six (06) clusters of land cover namely water bodies, built-up, agricultural land, herbaceous savanna, Savanna, and forest. The Sassandra basin has the same number of clusters as Mono basin, but here we have the appearance of evergreen forest cluster and the absence of herbaceous savanna class.

Indeed, the "water bodies" cluster represents the stream line, small reservoirs, lakes and dams. The "built-up" cover type represents urbanized areas and roads as well as land covered by buildings and other man-made structures, residential areas, commercial services, industrial areas, mixed urban and built up lands. The "barren" cluster was defined as land with exposed soil, sand or rocks, desert area or bare land. The "agricultural land" represents the farmland areas or the lands covered with temporary crops followed by harvest period, crop fields and pastures. The "shrubs" cluster represents some woody plants, smaller than a tree, usually having multiple permanent stems branching from or near, the ground or woody plants of relatively low height, having several stems arising from the base and lacking a single trunk. The "savanna" represents grassland with scattered trees, grading into either open plain or woodland while the "herbaceous savanna" represents grassland. The "forest" cluster refers to growth of trees and other plants covering a large area while the "evergreen forests" are forest made up of rainforest trees in tropical zone or evergreen trees.

Land classification can be subjected to errors due to geometric errors, misclassifications, and undefined classes. To statistically quantify these errors, a random selection of pixels of the classified maps was performed to build a confusion matrix [6,7]. In order to calibrate and validate the land cover classification, an accuracy assessment was performed and the kappa coefficient was used as the statistical parameter. This approach consists of the reclassification of land cover data in another way by following the step described by Congalton [29]. The accuracy assessment can be defined as a comparison of a map produced from remotely-sensed data with another map from some other source. A determination is made of how closely the new map produced from the remotely-sensed data matches the source map. It is necessary to present the accuracy assessment as an error matrix as recommended by Congalton [29]. For these assessments, the most common way to represent the classification accuracy of remotely sensed data is in the form of an error matrix. An error matrix or confusion matrix is a square array of numbers set out in rows and columns which express the number of sample units (i.e., pixels, clusters of pixels, or polygons) assigned to a particular category relative to the actual category as verified on the ground. The columns usually represent the reference data while the rows indicate the classification generated from the remotely sensed data. Reference pixels for each category were selected in a stratified random fashion. Ten-pixel times the number of land cover category are randomly selected for each group.

The confusion matrix as presented in Table 1 and consists of:

(i) The Total Accuracy (overall accuracy) of the classification which is given as the sum of the truly classified pixel (Diagonal values) over the total number of the selected pixel. The total selected pixel is equal to ten times the number of land cover category. For instance, the total accuracy of Volta land cover of 1988 is calculated as follows:

$$Total\ Accuracy = \frac{Number\ of\ orrected\ pixel}{Total\ number\ of\ elected\ pixel} \times 100 \tag{1}$$

$$Total\ Accuracy = \frac{(87+90+48+90+89+65+87+87+89)}{(10\times 90)} \times 100 \tag{2}$$

Then the *Total Accuracy* is 90.37% for Volta land cover classified data of 1988, meaning that for the land cover classification 1988 in Volta basin, 90.37% are correctly classified (Table 1).

(ii) The Producer's Accuracy which is the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data. In other words, it is the probability of a reference pixel being correctly classified and the measure of omission error and is expressed as follow:

$$Producers' Accuracy f cluster_{cluster} = \frac{(Corrected\ classified\ pixel)}{(Total\ selected\ Pixel_{cluster})} \times 100 \quad (3)$$

For example, the Producer's Accuracy of water bodies (Table 1) is:

$$Producers' Accuracy f cluster_{water\ bodies} = \frac{(87)}{(80)} \times 100$$

This means that among 90 pixels of water bodies 96.67% are truly classified as water bodies by the model and the remainder are omissions.

(iii) The omission error in percentage which represents pixels that belong to the true class, but fail to be classified into the proper class. For the water bodies we have: (1 + 1 + 1) × 100/90 = 3.33%. Among the 90 pixels of water bodies 3 are omitted during the classification and regarded as built-up, agricultural land and forest.
(iv) The user's accuracy, here the total number of correct pixels in a category is divided by the total number of pixels that were classified in that category as derived from classified data. It is the probability that a pixel classified on the map/image actually represents that category on the ground. The user's accuracy of agricultural land (Table 1) is: (90 × 100)/104 = 86.54%. Meaning that among 104 pixels classified as agricultural land, it is only 90 pixels which are truly agricultural land. The additional pixels which belong to other classes is the omission error; and
(v) The commission error represents the pixels that belong to another class, but are labeled as belonging to the class. The commission error of agricultural land is: (1 + 9 + 1 + 3) × 100/104 = 13.46%. The technical explanation is that 1, 9, 1 and 3 pixels of water bodies, barren land, savanna and forest respectively are classified as agricultural land.

The Table 1 exhibits the confusion matrix of Volta basin 1988 land cover classification constituted of described above factors. The producers' accuracy and the omission errors are presented on the last two raw while the user's accuracy and the commission errors are on the last two columns. As we have nine maps we just presented only Volta basin 1988 confusion matrix and the results of the remains maps was summarized in Table 2.

The kappa coefficient $K$, a discrete multivariate proxy used in accuracy assessment of thematic maps, is an efficient method to derive information from an image via the confusion matrix. $K > 0.80$ represents strong agreement and good accuracy; $K$ between 0.40 and 0.80 means a middle accuracy, and $K < 0.40$ represents a poor accuracy [6,7]. The kappa coefficient is given by the Equation (4).

$$K = \frac{N \sum_{i=1}^{r} x_{ij} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})} \quad (4)$$

where $r$ is the number of rows in the matrix, $x_{ij}$ is the number of observations in row $i$ and column $i$, $x_{i+}$ and $x_{+i}$ are the marginal totals of row $i$ and column $i$, respectively, and $N$ is the total number of observations.

**Table 1.** Confusion Matrix of Volta basin land cover classification of 1988.

| Classes | Water Bodies | Built-Up | Barren | Agricultural Land | Shrubs | Herbaceous Savanna | Savanna | Forest | Evergreen Forest | Number of Classified Pixel | User Accuracy | Commission Error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Bodies | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 87 | 100 | 0 |
| Built-up | 1 | 90 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 93 | 96.77 | 3.23 |
| Barren | 0 | 0 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 48 | 100 | 0 |
| Agricultural Land | 1 | 0 | 9 | 90 | 0 | 0 | 1 | 3 | 0 | 104 | 86.54 | 13.46 |
| Shrubs | 0 | 0 | 8 | 0 | 89 | 0 | 0 | 0 | 0 | 97 | 91.75 | 8.25 |
| Herbaceous Savanna | 0 | 0 | 0 | 0 | 0 | 65 | 2 | 0 | 0 | 67 | 97.01 | 2.99 |
| Savanna | 0 | 0 | 14 | 0 | 0 | 25 | 87 | 0 | 0 | 126 | 69.05 | 30.95 |
| Forest | 1 | 0 | 10 | 0 | 1 | 0 | 0 | 87 | 0 | 99 | 87.88 | 12.12 |
| Evergreen Forest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 89 | 89 | 100 | 0 |
| Number of Ground Truth | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 810 | | |
| Producer's Accuracy | 96.67 | 100 | 53.33 | 100 | 98.89 | 72.22 | 96.67 | 96.67 | 98.89 | | **Total Accuracy** | **90.37** |
| Omission Error | 3.33 | 0 | 46.67 | 0 | 1.11 | 27.78 | 3.33 | 3.33 | 1.11 | | **kappa coefficient** | **89.17** |

For this study, the kappa coefficient and the accuracy assessment of the three catchments for the years 1988, 2002, and 2016 are summarized in the Table 2. These factors were obtained from confusion matrix of Volta, Mono and Sassandra basin for the years 1988, 2002 and 2016. Once should recall that the kappa coefficient $K > 0.80$ represents strong agreement and good accuracy; $K$ between 0.40 and 0.80 means a middle accuracy, and $K < 0.40$ represents a poor accuracy [6,7]. All the Kappa coefficients of this study are greater than 80% which means the results show strong agreement and good accuracy.

**Table 2.** Kappa Coefficient and Accuracy Assessment of the land cover classification.

| Basin | Parameters | 1988 | 2002 | 2016 | Qualification |
|---|---|---|---|---|---|
| Volta | Kappa Coefficient | 89.17% | 85.97% | 90% | Strong |
| | Accuracy Assessment | 90.37% | 87.53% | 89.84% | |
| Mono | Kappa Coefficient | 86.67% | 86.33% | 89.33% | strong |
| | Accuracy Assessment | 88.89% | 88.61% | 91.11% | |
| Sassandra | Kappa Coefficient | 88% | 87.33% | 86.67% | strong |
| | Accuracy Assessment | 90% | 82.46% | 88.89% | |

### *3.2. Precipitation and Discharge Data*

The Global Precipitation Climatology Project (GPCP) monthly data [30] was used to assess the precipitation variability in Mono, Volta and Sassandra basins due to lack of observed data. The GPCP products are merged data from rain gauge stations, satellites, and sounding observations to estimate monthly rainfall on a 2.5-degree global grid from 1979 to the present [31]. The GPCP data was used to validate some model outputs within African continent and specifically in West Africa region [32–37] and one of its weakness is that it gives earlier onset rainfall compare to rainfall product of Tropical Rainfall Measuring Mission (TRMM) satellite. The GPCP data is correlated to observed rainfall in Ghana [38]. The river discharge data was collected from Bui power Authority (Bui 1954–2015), from Volta River Authority (Nawuni and Saboba 1954–2008), from Mono River Authority (1954–2000) and from Sassandra River Authority (Soubre 1954–2004 and Dakpadou 1969–2004).

The temporal variation of some hydrological stations data at the downstream of the basins were analyzed following some literatures methods [39,40]. The daily data from the stations are described in Table 2.

These stations were chosen according to the continuity of their data (low missing data) and also base on the fact that there are mostly at the outlet of each basin or sub-basin.

However, some of these stations may be affected by the hydropower plants constructed at upstream. For instance, in the Sassandra basin, the Buyo (1980) was constructed in 1980 at upstream of Soubre with installed capacity of 165 MW. In the White Volta basin, the Bagre and Kompienga hydropower plants were constructed at the upstream of Nawuni and Saboba respectively. The dam construction could have affected the flow regime of the river and in the aim to not attribute any change in studied hydrological data only to the hydropower construction, we also choose some river stations which had not received any of this kind of activity during the considered period. It is in this view that Bui, Athieme and Dapkadou rivers were chosen respectively in Volta, Mono and Sassandra basins.

In order to have the same period study for our analysis, all the discharge data have been taken from 1969 to the end date of the data availability at each station. The consistency, the homogeneity and the stationarity of the data have been checked as well as the continuity in order to assess the missing values. There are several methods to cope with missing data. Each method has its own strengths and weaknesses [41]. The regression-based imputation derived from the single- imputation method and frequently used in hydrology for missing data correction was applied in this study [41,42]. The percentage of missing data is presented in Table 3.

The regression-based imputation method consists firstly of the estimation of regression equations that relates to the variable that contains missing data to a set of variables featuring complete information across all observations in the dataset. Secondly, the equation is used to predict the missing values [41]. This method does not have any bias problem with the mean values.

**Table 3.** Hydrological stations and basins.

| Stations (Basin) | Longitude | Latitude | Data Available Period | Missing Data (%) |
|---|---|---|---|---|
| Nangbeto (Mono) | 1.4333 | 7.433 | 1954–2000 | 6.48 |
| Athieme (Mono) | 1.6667 | 6.9167 | | 8.84 |
| Soubre (Sassandra) | −6.6131 | 5.7833 | 1954–2004 | 3.10 |
| Dakpadou (Sassandra) | −6.07 | 5.24 | 1969–2004 | 3.01 |
| Saboba (Oti Volta) | 0.3167 | 9.6 | 1954–2008 | 16.22 |
| Nawuni (White Volta) | −1.03 | 9.68 | | 8.18 |
| Bui (Black Volta) | −2.2333 | 8.2833 | 1954–2015 | 6.48 |

The consistency, the trend, the periodicity and the persistence of the data have also been assessed as recommended by Machiwal and Jha [39]. The trend variation of both data has been checked using Mann–Kendall [43] non-parametric test to determine the significance of the observed trends test, and the Sen's Slope [44] Estimator to assess the direction (upward or downward) of the trend. The trend in both variables (precipitation and discharge) was assessed based on the period of available data, i.e., 1979–2000 for Mono basin; 1979–2004 for Sassandra basin and 1979–2008 for Volta basin. The test was also performed for the whole period of data availability from 1969 to the end data for discharge and from 1979 to 2017 for precipitation data.

### 3.3. Trend Detection

Several methods exist for trend detection in hydrology, namely, (i) Spearman's rho which is a rank-based test for correlation between two variables and can be used to test for a correlation between time and the data series; (ii) another rank-based test called Kendall's tau/Mann–Kendall test which is similar to Spearman's rho, but using a different measure of correlation which has no parametric analogue; (iii) Seasonal Kendall test which is a version of the Mann–Kendall test that allows for seasonality in the data; (iv) The test statistic for linear regression or the regression gradient is one of the most common tests for trend and, in its basic form, assumes that data are normally distributed and (v) other robust regression tests that are a number of robust methods for estimating trend in series and could potentially be used as alternative measures of the change [45].

The non-parametric Mann–Kendall test which is a rank-based non-parametric test for assessing the significance of a trend [43] recommended by the World Meteorological Organization (WMO) for trend detection in hydro-meteorological time series [46] is used in this study. The description of the different factors guiding this test is given below.

The null hypothesis H0 is that a sample of chronologically ordered data is independent and identically distributed. The statistic $S$ is defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}\left(x_j - x_i\right) \tag{5}$$

where

$$\text{sgn}(x) = \begin{cases} 1 \; if \; x > 0 \\ 0 \; if \; x = 0 \\ -1 \; if \; x < 0 \end{cases} \tag{6}$$

When $n \geq 40$, the statistic $S$ is asymptotically normally distributed with mean 0 and variance given by the following equation:

$$\mathrm{var}(s) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{t} t(t-1)(2t+5)\right] \tag{7}$$

where $t$ is the size of a given tied group and $\sum_{t}$ is the summation over all tied groups in the data sample. The standardized test statistic $K$ is computed by using the following equation:

$$K = \begin{matrix} \frac{s-1}{\sqrt{\mathrm{var}(s)}} \\ 0 \\ \frac{s+1}{\sqrt{\mathrm{var}(s)}} \end{matrix} \begin{cases} if\ s > 0 \\ if\ s = 0 \\ if\ s < 0 \end{cases} \tag{8}$$

The standardized statistic $K$ follows the standard normal distribution with mean zero and variance of one. The probability value $p$ of the statistic $K$ of sample data can be estimated using the normal cumulative distribution function as:

$$p = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-t^2/2} dt \tag{9}$$

For independent sample data without trend, the $p$ value should be equal to 0.5. For sample data with large positive trend, the $p$ value should be close to 1.0, whereas a large negative trend should yield a $p$ value close to 0.0. If the sample data are serially correlated, then the data should be pre-whitened and a correction applied to calculate the variance

In order to determine the magnitude of the trend, the Sen's slope is performed. We compute at the same times both the slope (i.e., linear rate of change) and the intercept according to Sen's method. The slope of a trend is estimated as follows:

$$\beta = median\left(\frac{x_i - x_j}{i - j}\right),\ \forall j < i \tag{10}$$

where $\beta$ is the estimate of the slope of the trend and $x_j$ is the $j$th observation. An upward trend is represented by a positive value of $\beta$ and a downward trend is represented by a negative value of $\beta$.

These parameters are widely used in climatological and hydrological data trend analysis and the equations to compute them are also well known and well described [7,14,29,30].

In addition, the coefficient of variation of precipitation and discharge were computed in order to assess the relationship between them and land use and land cover changes.

## 4. Results and Discussion

### 4.1. Spatio-Temporal Changes of Land Use and Land Cover

The Figures 2–4 present the maps of land use and land cover changes over Volta, Mono and Sassandra basin, respectively. Each figure presents three maps for 1988, 2002 and 2016 periods.

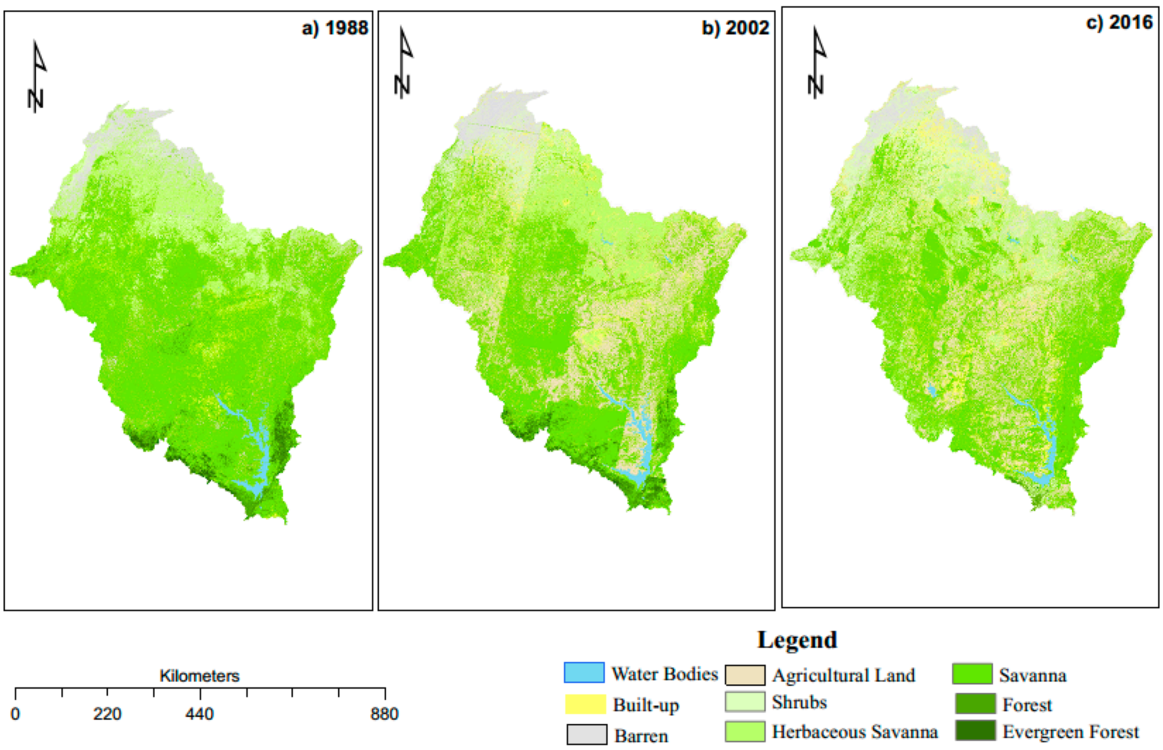


**Figure 2.** Volta basin land use and land cover maps in 1988, 2002 and 2016 (from left to right).

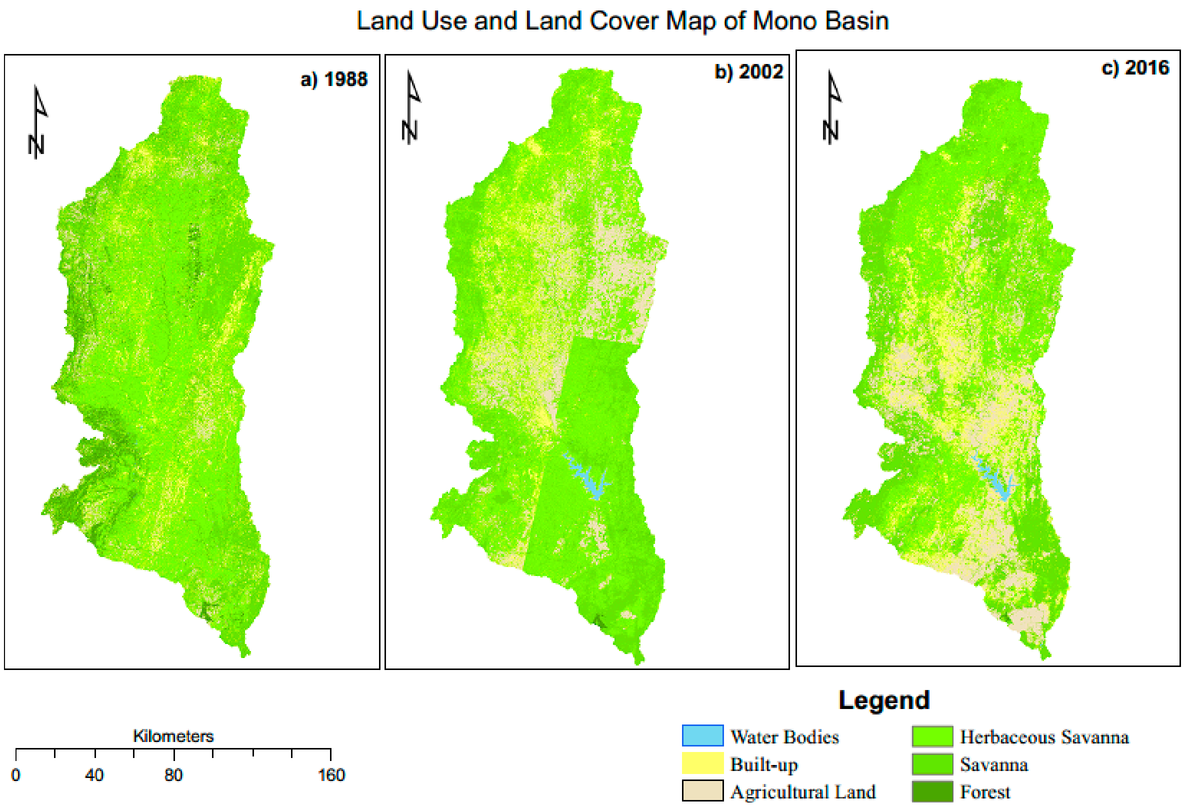


**Figure 3.** Mono basin land use and land cover maps in 1988, 2002 and 2016 (from left to right).

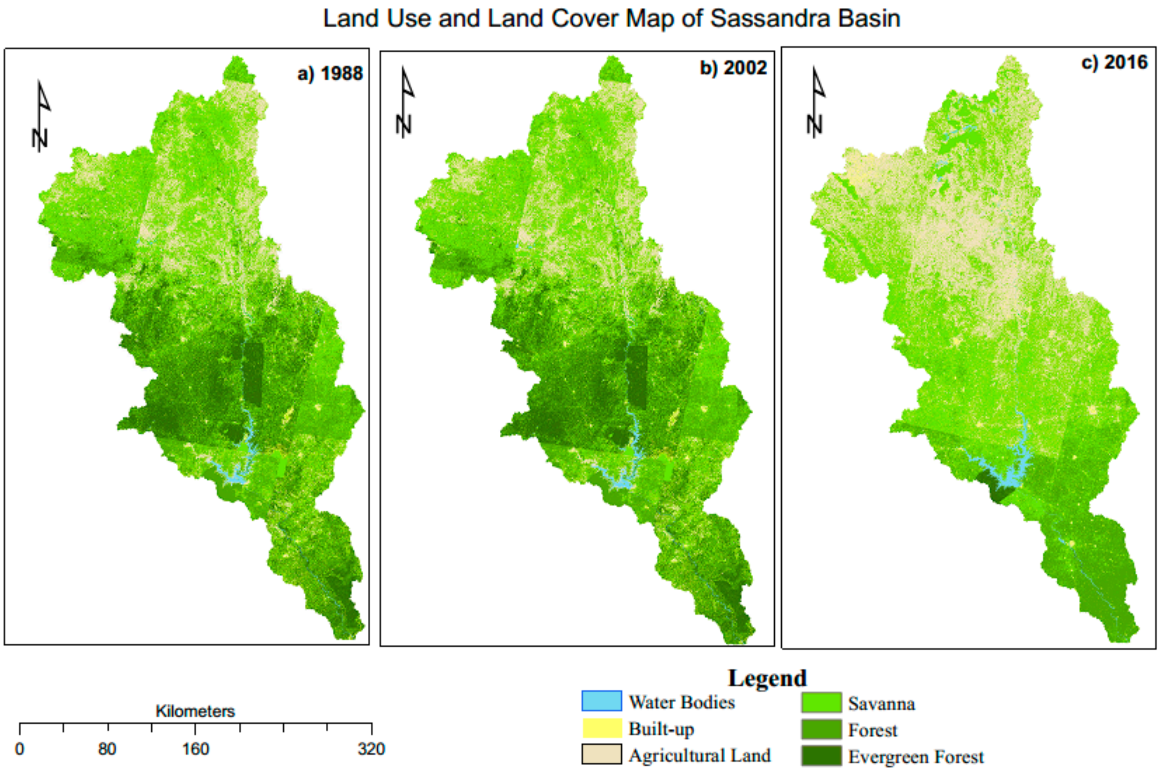


**Figure 4.** Sassandra basin land use and land cover maps in 1988, 2002 and 2016 (from left to right).

The evergreen forest and forest cover mainly the south-eastern and south-western part of Volta basin for the years 1988 and 2002. The savanna covers mainly the basin from the south to north while the barren land, shrubs and herbaceous savanna are mainly located in the northern part. The water bodies are also shown mainly at the reservoirs and streamlines locations. The agricultural land is mainly distributed in the central part (Figure 2).

Figure 3 shows that the western part of Mono basin is covered by forest, while the central part is covered by built-up, agricultural land and herbaceous savanna. The savanna covers the northern and eastern parts.

The southern and central parts of Sassandra basin present evergreen forest and forest cover while the agricultural land and built-up are in northern part (Figure 4). The savanna is mainly present in the northern part, central to the northern part for the years 1988 and 2002–2016 period, respectively. The water bodies are mainly show at Soubre reservoir, some small dam and stream lines within the basin.

Table 4 quantifies percentage of changes in land use and land cover (LULC) in the three basins which surfaces are 413,520.15 km$^2$ for Volta, 21,610.39 km$^2$ for Mono and 68,535.78 km$^2$ for Sassandra. The change in land cover varies according to the basin and the land use and practices.

For instance, in Volta basin (Table 4a) the land cover clusters such as water bodies, built-up, agricultural land and shrubs have increased between the three periods 1988–2002, 2002–2016 and 1988–2016. However, all the other land cover clusters, namely, the barren land, savanna, herbaceous savanna and evergreen forest have declined except the forest which has increased in the first period before declining in the last two periods. The decline of barren land areas could be associated with the increase of shrubs. In contrast, this could be some limitation of our model to perform the classification. It may consider some barren land as agricultural and/or built-up in the northern part of Volta basin. The increasing of shrubs for all the periods could be explained in one hand by the fact that the region has been recovered from the droughts of 1980s. In second hand, the increase in shrubs and generally some vegetative clusters could be attributed to the tree plantation resulting from agroforestry practice. The same conclusion was made by Vittek et al., in a previous study for the period 1975–1990 for West Africa overall [47].

The result reveals that the Mono basin (Table 4b) land cover presents an increase in built-up, agricultural land and water bodies while the vegetative clusters such as forest, savanna and herbaceous savanna have declined for the three study periods. Nevertheless, the herbaceous savanna and savanna clusters have increased in the 1988–2002 and 2002–2016 periods respectively.

The Sassandra basin (Table 4c) presents an increasing in water bodies, built-up and agricultural land while the evergreen forest has declined. However, some vegetative areas such as the savanna and the forest have decline in the first period and increased for the last two periods.

**Table 4.** Land use land cover change trend analysis: (**a**) Volta basin; (**b**) Mono Basin; (**c**) Sassandra basin.

| (a) Volta Basin | | | | | | |
|---|---|---|---|---|---|---|
| **Land Cover Types** | **Area (%) 1988** | **Area (%) 2002** | **Area (%) 2016** | **% Change (1988–2002)** | **% Change (2002–2016)** | **% Change (1988–2016)** |
| Water Bodies | 1.35 | 2.32 | 3.23 | 4.79 | 2.61 | 4.8 |
| Built-up | 2.09 | 6.21 | 10.18 | 13.15 | 4.26 | 13.35 |
| Barren | 5.76 | 5.02 | 4.98 | −0.85 | −0.06 | −0.47 |
| Agricultural Land | 3.39 | 19.85 | 23.32 | 32.36 | 1.17 | 20.27 |
| Shrubs | 4.65 | 5.88 | 16.52 | 1.76 | 12.07 | 8.8 |
| Herbaceous Savanna | 16.72 | 14.2 | 6.35 | −1 | −3.69 | −2.14 |
| Savanna | 62.28 | 43.58 | 35 | −2 | −1.31 | −1.51 |
| Forest | 1.66 | 1.73 | 0.42 | 0.29 | −5.05 | −2.58 |
| Evergreen Forest | 2.1 | 1.21 | - | −2.82 | −6.67 | −3.45 |
| **(b) Mono Basin** | | | | | | |
| **Land Cover Types** | **Area (%) 1988** | **Area (%) 2002** | **Area (%) 2016** | **% Change (1988–2002)** | **% Change (2002–2016)** | **% Change (1988–2016)** |
| Water Bodies | 0.14 | 0.49 | 0.47 | 16.67 | −0.23 | 8.2 |
| Built-up | 7.95 | 9.08 | 15.63 | 0.95 | 4.81 | 3.33 |
| Agricultural Land | 7.31 | 16.24 | 18.69 | 8.14 | 1.01 | 5.37 |
| Herbaceous Savanna | 47.98 | 55.63 | 38.97 | 1.06 | −2 | −0.65 |
| Savanna | 30.1 | 18.19 | 26.2 | −2.64 | 2.93 | −0.45 |
| Forest | 6.52 | 0.37 | 0.04 | −6.29 | −6.02 | −3.43 |
| **(c) Sassandra Basin** | | | | | | |
| **Land Cover Types** | **Area (%) 1988** | **Area (%) 2002** | **Area (%) 2016** | **% Change (1988–2002)** | **% Change (2002–2016)** | **% Change (1988–2016)** |
| Water Bodies | 1.05 | 2.31 | 2.64 | 8.02 | 0.95 | 5.23 |
| Built-up | 1.82 | 3.14 | 4.22 | 4.86 | 2.29 | 4.56 |
| Agricultural Land | 14.65 | 27.64 | 32.44 | 5.91 | 1.16 | 4.19 |
| Savanna | 46.55 | 43.36 | 46.87 | −0.46 | 0.54 | 0.02 |
| Forest | 12.24 | 10.88 | 13.24 | −0.74 | 1.45 | 0.28 |
| Evergreen Forest | 23.7 | 12.67 | 0.59 | −3.1 | −6.36 | −3.36 |

NB: The basins surfaces for land cover maps are: Mono: 21,610.39 $km^2$; Volta: 413,520.15 $km^2$ and Sassandra: 68,535.78 $km^2$.

Overall, the results from the LULC analysis show that water bodies, built-up and agricultural lands have increased rapidly for all studied basins. Such an increase in water bodies can be explained by the construction of small reservoirs, dugouts and dams within the basins. These basins have received more attention in term of small reservoirs and dugouts construction for irrigation, domestic water supplies and for livestock breeding as well as hydropower plants for electricity generation. Also, the observed increase in built-up and agricultural lands is associated with the increase in urbanized and cultivated areas respectively. In addition, the decline in vegetative areas (herbaceous savanna, savanna, forest and evergreen forest) can be explained by the expansion of agricultural and urbanized areas. In fact, the vegetative areas are being reduced to enlarge the land use areas or in another word, the vegetative areas are replaced by agricultural, built up and water bodies.

Over the world, and particularly in the tropics and subtropics areas, deforestation is attributed to large-scale commercial agriculture, local subsistence agriculture, infrastructure, urban expansion and mining [48]. During 2000–2010 period in Africa, 8000 $km^2$, 7000 $km^2$, 2500 $km^2$, 2000 $km^2$ and 500 $km^2$ of forest are converted per year respectively into commercial agriculture, local agriculture, infrastructure, mining and urban expansion [48]. According to Food and Agriculture Organization report [48], in Africa, fuelwood charcoal, timber logging, livestock grazing in forest and uncontrolled fires contribute respectively to 50%, 35%, 10% and 5% of forest degradation.

It was highlighted that the main drivers of land cover change are the excessive use of trees for timber, for biomass energy namely charcoal and wood fires as well as the uncontrolled bushfire phenomenon. Wood fuel accounts for 70% of the Sub-Saharan Africa total energy production [49] and is one of the main sources of forest and woodland degradation. Due to the increase in population growth rate, and relative price changes of alternate energy sources for cooking, it is expected that the consumption of charcoal will remain at very high levels or even increase in absolute terms over the next decade [50], thus, woodland and forest degradation could steadily increase. Uncontrolled bushfire, one of the major causes of soil erosion [51] and livestock pasture destruction could also affect seriously the land cover of each basin. Unfortunately, all the basins in West Africa are exposed to this phenomenon. It has also been highlighted that global croplands, pastures, plantations, and urban areas have expanded in recent decades, accompanied by large increases in energy, water, and fertilizer consumption, along with considerable losses of biodiversity [52]. West Africa basin is under vegetative area loss due to land use practices explained above. This is confirmed by Vittek et al., [47] in their study focus on dynamic land cover change in West Africa (1975–1990). They also found out the decreased in all the vegetative clusters.

Lastly, the change in land cover change found is in accord with some previous work in West Africa regions [51,53] and especially in Black Volta basin [6,7].

### 4.2. Statistical Analysis of Precipitation Data

The Mann–Kendall test was applied to assess the trend in the precipitation data variation of each location. The statistic indicators of Mann–Kendall test are the *p*-value, score (S) or Mann–Kendall statistic, the Z-score, the Kendall tau and their equations were given above. So, the Kendall tau is a measure of correlation; therefore, measures the strength of the relationship between the two variables base on the rank of the data. Whilst, the *p*-value measures the significance of the trend and the Z-score is an indicator of the statistical significance of the trend at 95% confidence level. Indeed, at the 2-sided *p*-value test the rejection region of a hypothesis is Z-score $\geq 1.96$ or Z-score $\leq -1.96$. Whilst, the score (S) expresses the magnitude change of the trend (increasing/upward; decreasing/downward). The periods 1979–2000 for Mono basin stations, 1979–2004 and 1979–2008 for Sassandra and Volta basin stations respectively corresponding to the available discharge data period in each basin are considered for the analysis of trends of precipitation (Table 5).

**Table 5.** Results of Mann–Kendall test of precipitation in the three basins (* represents the statistically significant trends at the 5% significance level (95% confidence level) and ** statistically significant trends at the 10% significance level (90% confidence level). BV: Black Volta sub-basin, WV: White Volta sub-basin, OV: Oti Volta sub-basin, MV: Main Volta sub-basin.).

| Basins and Stations | Long | Lat | Mann–Kendall Statistic (S) | Tau | Z-Score | 2-Sided *p*-Value |
|---|---|---|---|---|---|---|
| **Mono basin** | | | **(1979–2000)** | | | |
| Corre-Cope | 1.30 | 7.80 | 37 | 0.160 | 1.02 | 0.529 |
| Tetetou | 1.53 | 7.02 | −13 | −0.056 | −0.34 | 0.735 |
| Nangbeto | 1.43 | 7.43 | −13 | −0.056 | −0.34 | 0.735 |
| Athieme | 1.67 | 6.92 | −13 | −0.056 | −0.34 | 0.735 |
| **Sassandra basin** | | | **(1979–2004)** | | | |
| Odienne | −7.56 | 9.50 | 67 | 0.206 | 1.45 | 0.146 |
| Man | −7.51 | 7.38 | −75 | −0.231 | −1.63 | 0.103 |
| Soubre | −6.43 | 5.51 | −43 | −0.132 | −0.93 | 0.355 |
| Dakpadou | −6.07 | 5.24 | −43 | −0.132 | −0.93 | 0.355 |
| **Volta basin** | | | **(1979–2008)** | | | |
| Bui (BV) | −2.78 | 8.77 | −3 | −0.007 | −0.04 | 0.972 |
| Nwokuy (BV) | −4.20 | 11.84 | 33 | 0.076 | 0.57 | 0.568 |
| Goere * (BV) | −2.96 | 13.88 | 147 | 0.338 | 2.60 | **0.009** |
| Sunyani (BV) | −2.33 | 7.33 | −33 | −0.076 | −0.57 | 0.568 |
| Bagre Aval ** (WV) | −0.92 | 12.05 | 95 | 0.218 | 1.68 | **0.094** |
| Nawuni ** (WV) | −0.80 | 10.15 | 95 | 0.218 | 1.68 | **0.094** |
| Porga * (OV) | 1.10 | 11.57 | 123 | 0.283 | 2.18 | **0.030** |
| Saboba * (OV) | 0.38 | 10.30 | 123 | 0.283 | 2.18 | **0.030** |
| Lower Volta (MV) | −0.65 | 8.23 | 27 | 0.062 | 0.46 | 0.643 |
| Kpong (MV) | 0.09 | 6.19 | −3 | −0.007 | −0.04 | 0.972 |
| Yapei (WV) | −1.17 | 9.14 | 81 | 0.186 | 1.43 | 0.154 |

The locations of stations were chosen according to the basin size and available data. Among all the chosen locations, only three stations in the Volta basin (i.e., Goere, Porga and Saboba respectively at the northern part of Black Volta, Northern and southern part of Oti) show a significant upward trend at 95% level of confidence. The *p*-values of these stations are lower than the ($\alpha$ = 5%) at 95% level of confidence. This is also confirmed by the Z-score values greater than 1.96 which put them in the rejection zone. However, at the 90% level of confidence the Bagre Aval and Nawuni station (White Volta) show a significant upward trend. Though other locations in the Volta basin did not show any trend, the Northern to central locations indicate a positive Mann–Kendall score (S) contrarily to the southern locations (Bui, Kpong and Sunyani).

In the Mono and Sassandra basins, the results of Mann–Kendall test reveal no trend in precipitation. Nevertheless, between 1979 and 2000, the central (Nangbeto) and the southern (Athieme and Tetetou) parts of the Mono basin present a negative Mann–Kendall score (S) contrarily to the northern part (Corre-Cope) of this basin. The same conclusion can be made for Sassandra basin (1979–2004) where the northern part (Odienne) shows a positive Mann–Kendall score while the region from the central (Man) to the southern part (Soubre and Dakpadou) shows a negative one.

Overall the northern part of the three basins presents a positive Mann–Kendall score while the southern part shows the contrary, though they did not present any trend. The Sassandra and Mono basins have not experienced any trend, only Volta basin present a statistically significant trend.

Where data are available, the Mann–Kendall test of the precipitation for the extended period until 2017 (1979–2017) was performed (not shown). There is no major significant difference with results of the first period presented in Table 5 apart from the Odienne (upward), Man (downward) in Sassandra basin and Sunyani (downward) in Volta basin which present a statistically significant trend for 1979–2017 period. In addition, the Mono basins do not show again any trend during the 1979 to 2017 period.

### *4.3. Statistical Analysis of Hydrological Data*

Figure 5 displays the inter-annual variability of the streamflow within the three considered basins.

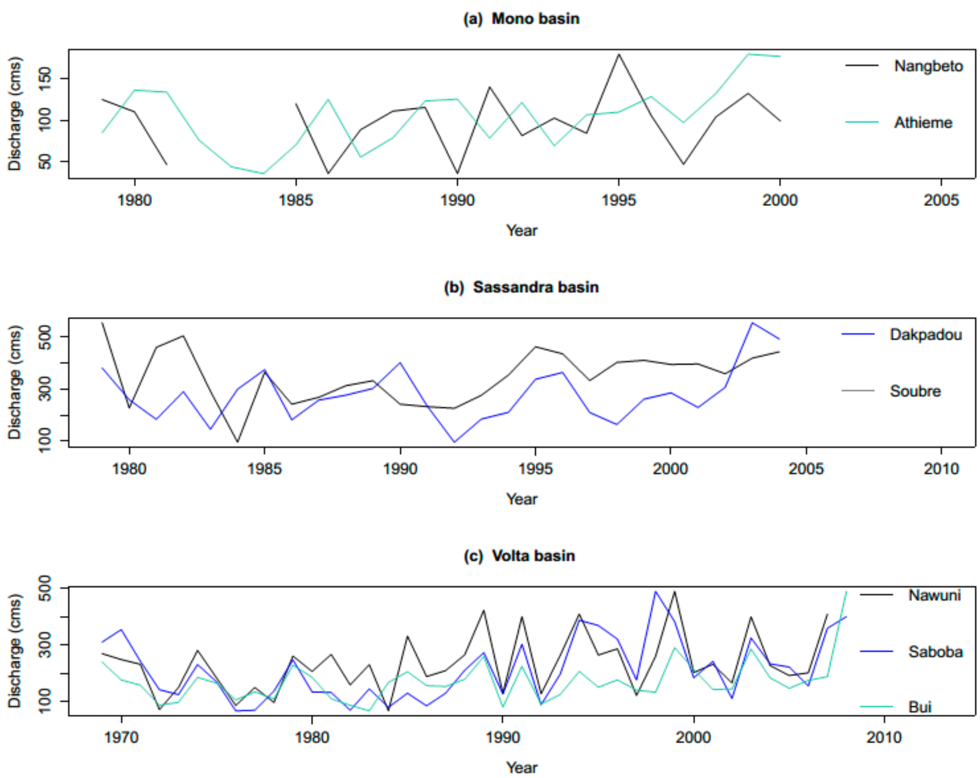


**Figure 5.** Annual mean discharge variability at the study stations; (**a**) Mono basin (1969–2000), (**b**) Sassandra basin (1969–2004) and (**c**) Volta basin (1969–2008).

The Mann–Kendall test was applied to assess the trend of the hydrological data variation of each station. The same process was followed. We analyzed our data in two times. The first time starts from 1979 (corresponding the start date of precipitation data) to end date of each station and the second time considers the data from 1969 to the end date. For both periods, all the selected hydrological stations of the basin present an increased trend in the discharge. This is confirmed by the positive Mann–Kendall tau and Z-score.

The analysis shows that at 95% confidence level ($\alpha = 5\%$) only Saboba station's (* in Tables 6 and 7) trend is found to be statistically significant and this is confirmed by the Z-score (2.10884 > 1.96 for in Table 6 and 2.60479 > 1.96 in Table 7) that belong to the rejection region of 2-sided *p*-value test. This trend is an upward one. However, Nangbeto and Athieme trend (upward) were statistically significant at 90% confidence level for the first period (** in Table 6) and the second period (** in Table 7), respectively.

**Table 6.** Result of discharge data Mann–Kendall test for studied basins (Mono basin (1979–2000), Sassandra basin (1979–2004) and Volta basin (1979–2008)). NB: * the statistically significant trends at the 5% significance level (95% confidence level) and ** statistically significant trends at the 10% significance level (90% confidence level).

| Stations (Basin) | Period | Mann–Kendall Statistic (S) | Tau | Z-Score | 2-Sided *p*-Value | Slope | Intercept (b) |
|---|---|---|---|---|---|---|---|
| Nangbeto ** (Mono) | 1979–2000 | 96 | 0.236 | 1.78202 | **0.074747** | 1.422 | −2734.2 |
| Athieme (Mono) | | 96 | 0.194 | 1.54056 | 0.12342 | 1.299 | −2469.4 |
| Dapkadou (Sassandra) | 1979–2004 | 4 | 0.00635 | 0.04086 | 0.96741 | 0.108 | −182.72 |
| Soubre (Sassandra) | | 76 | 0.121 | 1.02157 | 0.30699 | 1.138 | −1914.5 |
| Nawuni (White Volta) | 1979–2008 | 115 | 0.155 | 1.37904 | 0.16788 | 2.987 | −5702.19 |
| Saboba * (Oti Volta) | | 182 | 0.233 | 2.10884 | **0.034959** | 3.187 | −6059.99 |
| Bui (Black Volta) | | 142 | 0.182 | 1.6428 | 0.10043 | 2.896 | −5555 |

**Table 7.** Result of discharge data Mann–Kendall test for Mono basin (1969–2000), Sassandra basin (1969–2004) and Volta basin (1969–2008). NB: * the statistically significant trends at the 5% significance level (95% confidence level) and ** statistically significant trends at the 10% significance level (90% confidence level).

| Stations | Period | Mann–Kendall Statistic (S) | Tau | Z-Score | 2-Sided *p*-Value | Slope | Intercept (b) |
|---|---|---|---|---|---|---|---|
| Nangbeto (Mono) | 1969–2000 | 5 | 0.0292 | 0.13994 | 0.88871 | 0.821 | −1535.3 |
| Athieme ** (Mono) | | 65 | 0.281 | 1.80467 | **0.071127** | 4.103 | −8050 |
| Dakpadou (Sassandra) | 1969–2004 | 41 | 0.126 | 0.88166 | 0.37796 | 0.409 | −782.93 |
| Soubre (Sassandra) | | 67 | 0.206 | 1.45474 | 0.14574 | 2.796 | −5220.6 |
| Nawuni (White Volta) | 1969–2008 | 20 | 0.0493 | 0.3564 | 0.72154 | 2.309 | −4347.67 |
| Saboba * (Oti Volta) | | 147 | 0.338 | 2.60479 | **0.009193** | 6.028 | −11731.9 |
| Bui (Black Volta) | | 77 | 0.177 | 1.35592 | 0.17513 | 4.379 | −8514.4 |

Overall, all the downstream hydrological stations of the basins show an increase trend (non-statistically significant) in discharge during all the two analysis periods except the Saboba station which present statistically significant trend at 95% level of confidence and the Nangbeto and Athieme hydrological stations which show a statistically significant trend of 90% confidence level for the first period (1979–2000) and the second period (1969–2000). The increase in discharge of all selected stations and the statistically significant upward trend of Saboba could be caused by the increase in spatio-temporal distribution of precipitation and/or another non-climatic factor. The spatial distribution trend of precipitation and discharge for considered period in Table 6 of test are presented in Figure 6.

Despite the non-statistically significant trend in precipitation observed in Mono basin (1979–2000), the Nangbeto hydrological station shows a statistically significant upward trend at 90% confidence level. Though, the large part of Sassandra basin (1979–2004) presents a downward (non-statistically significant) trend, the Soubre station at the downstream shows an upward trend (non-statistically significant) discharge. This could be due to land cover and land use change.

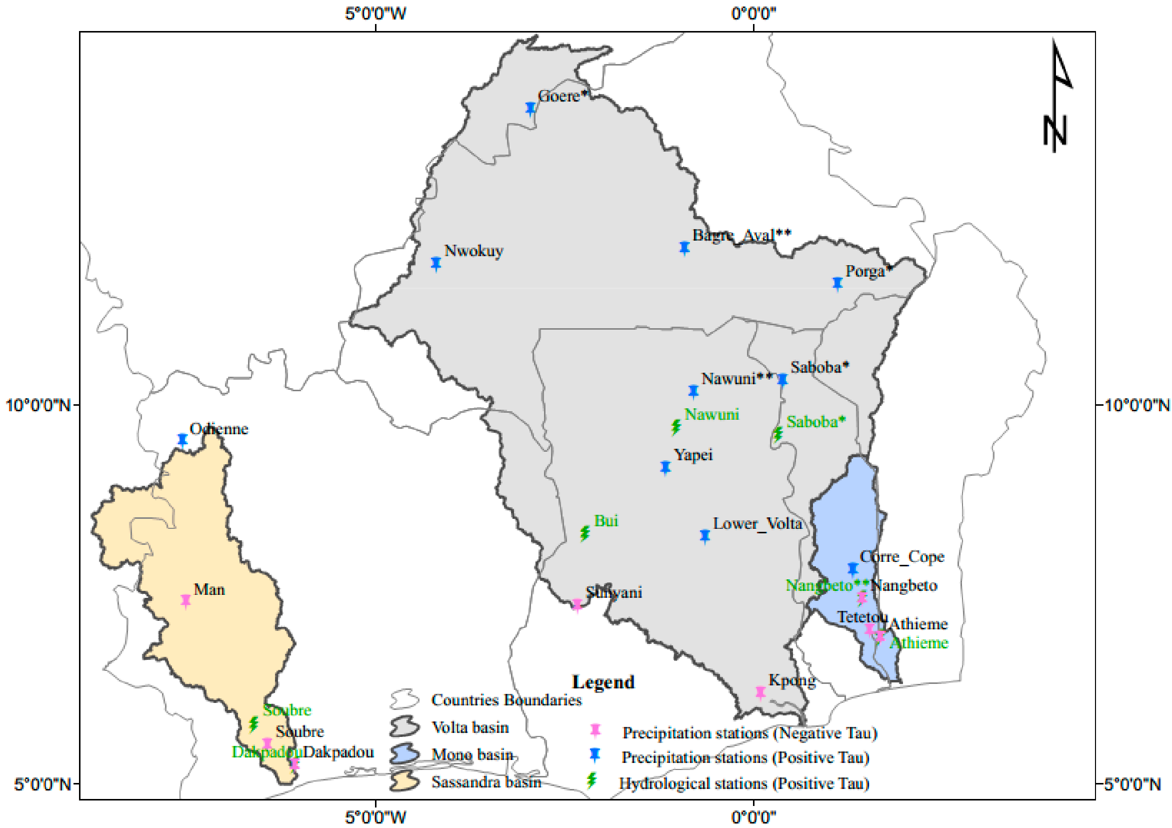


**Figure 6.** Map of spatio-temporal distribution of Precipitation and Discharge trend analysis (1979–2000 in Mono, 1979–2004 in Sassandra and 1979–2008 in Volta). NB: * the statistically significant trends at the 5% significance level (95% confidence level) and ** statistically significant trends at the 10% significance level (90% confidence level).

The present work shows an increased (non-statistically significant) trend in precipitation at the upstream of Bui and Nawuni hydrological stations of Black and White Volta basins respectively. This leads to an increase in trend of discharge at Bui and Nawuni stations. Even though the results reveal an upward trend in both variables (precipitation and discharge), the magnitude of increased in discharge is greater than in precipitation. For instance, the slope of the regression line is lower for rainfall compare to the discharge. In the Oti Volta sub-basin, the Porga and Saboba stations (upstream) show an upward trend in precipitation and discharge, but the two variables are statistically significant only at Saboba station. Also, the magnitude of change upward trend in discharge (slope of 3.187) is greater the one for precipitation (slope 0.18) in Saboba station (1979–2008). This difference in trend and magnitude of precipitation and discharge could be due to land use and land cover change.

These present results confirm previous studies that found out the same trend in discharge at Akosombo station (Lower Volta basin) and at Bui station (Black Volta) for the period of 1970–2011 [7] [54]. In the Lower Volta basin (Ghana part), most of the rainfall stations data analyzed has experienced an increased trend as well as Akosombo discharge [54] but while in the Black Volta basin [7], several rain-gauges stations present a downward trend in precipitation (except Boura station) while the Bui discharge show an upward trend. Their results also conclude that the land use and land cover change were the probable cause of this difference in trend of precipitation and discharge [7,55]. In order to understand the influence of land use and land cover changes, a basic statistical analysis was further processed.

### 4.4. Basic Statistical Analysis of Precipitation and Discharge

The Table 8 presents the basic statistic namely the standard deviation (SD), the mean and the coefficient of variation (CV) expressed in percentage of precipitation (P in mm) or of discharge (Q in $m^3/s$) at monthly and annually scale. The analysis of Table 8 shows that the discharges have a larger variability (greater CV) than the precipitation at annual and monthly level except some driest months namely December and January in all the basins. The annual precipitation coefficient of variation is lower (10%) in Volta basin while the three hydrological station present a greater coefficient of variation (>35%) 43.6%; 36.51% and 47.43% for Nawuni, Saboba and Bui respectively. In Mono basin, the annual precipitation coefficient of variation is lower (11.5%) while the Nangbeto and Athieme annual discharge coefficient of variation are 37.15 and 46.60% respectively. The annual precipitation coefficient of variation in Sassandra basin is 7.64% and the annual discharge coefficient of variation of Soubre and Dakpadou are respectively 29.41% and 37%. In summary, the annual discharge varies at least three times greatly than the annual precipitation. The same conclusion can also be made for all the month from February to November.

Previous studies confirmed that this large variation in discharge despite the lowest variation in precipitation is mainly due to land use and land cover change. Andreini et al. [56] showed that the coefficient of variation of runoff from the Volta sub-watersheds is much more variable than rainfall, due to land use. This has been confirmed recently in Black Volta basin with the same statistical analysis [6] and using Soil and Water Assessment Tool (SWAT) model [7]. The same conclusion has also been made in Chemoga watershed of Blue Nile basin in Ethiopia [57] using the coefficient of variation method. It is apparent from the Volta water balance that land use and land cover changes in the uplands of the basin play a pivotal role in determining the future of the basin water resources. The relative hydrological effects of forest changes and climatic variability are largely dependent on the change magnitudes and watershed characteristics [58]. Some previous work on West Africa basins showed an increase in runoff generation coefficient despite the increase in the number of dams in the basin [59] due to land use practice [60]. It has been demonstrated that such basin has loss their soil water hold capacity [60] and caused of the Sahelian paradox [61,62] which consequently result in an increase of flow of the river.

The analysis of land use and land cover change presented above reveals mostly a decrease in vegetative areas and an increase built-up areas, agricultural land, and water bodies. This change in land cover and land use also will affect the water holding capacity of the soil by decreasing the infiltration rate and increasing the runoff generation capacity of the basin. In the Black Volta basin, this increase in land use and land cover changes leads to an increase the discharge at Bui [6]. This effect combined with climate change can also reduce the underground recharge water capacity as it has been confirmed the decline in underground water recharge of Bandama basin [63]. Water availability could be at risk with changes of land use and land cover.

However, the land use and land cover changes have an important effect on the catchment runoff generation [55,64–70] and potential evapotranspiration [6,71,72]. Any change in runoff generation coefficient could affect the hydrodynamic of the river. So, the land use and land cover change could affect the hydrodynamic of the river. This has been found in different basins of the region namely Bandama [63], Senegal [55,64], Mono [25,65], Sahelo-Sudanian [61] and elsewhere [66,67]. The land use practices as the construction of large dams could have an influence on surrounding climate [67] and can lead to microclimatic changes [68]. It has been proved to have high impact on the rainfall [69] and on climate system [73,74] of a given region. The study of Mara river in East Africa region exhibits that the conversion of forests to agriculture and grassland in the basin headwaters is likely to reduce dry season flows and increase peak flows, leading to greater water scarcity at critical times of the year and exacerbating erosion on hillslopes [75]. The influence of land use and land cover on hydrological dynamic of the river is well documented [25,76–80].

**Table 8.** Basic statistics on Precipitation (P in mm) and discharge (Q in $m^3/s$).

| Variables | Stations | Factors | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q ($m^3/s$) 1979–2008 (Volta basin) | NAWUNI | SD | 20.37 | 21.57 | 24.84 | 26.20 | 35.25 | 79.23 | 108.22 | 325.38 | 530.56 | 387.28 | 52.63 | 23.06 | 107.15 |
| | | Mean | 34.93 | 28.47 | 28.47 | 31.80 | 48.13 | 107.25 | 202.26 | 661.43 | 1191.86 | 591.08 | 90.67 | 46.09 | 248.29 |
| | | **CV (%)** | **58.33** | **75.75** | **87.23** | **82.40** | **73.24** | **73.88** | **53.50** | **49.19** | **44.52** | **65.52** | **58.04** | **50.03** | **43.16** |
| | SABOBA | SD | 13.91 | 20.08 | 31.13 | 20.33 | 22.19 | 55.20 | 174.41 | 276.88 | 586.01 | 413.11 | 74.29 | 20.86 | 104.21 |
| | | Mean | 19.85 | 22.80 | 24.00 | 25.35 | 34.13 | 71.32 | 226.63 | 736.52 | 1382.93 | 732.18 | 119.63 | 39.22 | 285.43 |
| | | **CV (%)** | **70.08** | **88.07** | **129.73** | **80.20** | **65.00** | **77.40** | **76.96** | **37.59** | **42.37** | **56.42** | **62.10** | **53.20** | **36.51** |
| | BUI | SD | 20.36 | 13.05 | 10.31 | 9.28 | 27.21 | 79.09 | 122.33 | 272.54 | 464.59 | 353.12 | 86.99 | 37.20 | 101.90 |
| | | Mean | 23.31 | 12.30 | 8.61 | 11.07 | 36.99 | 101.97 | 216.41 | 493.31 | 909.84 | 566.05 | 145.36 | 53.13 | 214.86 |
| | | **CV (%)** | **87.36** | **106.13** | **119.74** | **83.84** | **73.56** | **77.56** | **56.53** | **55.25** | **51.06** | **62.38** | **59.84** | **70.02** | **47.43** |
| P (mm) 1979–2008 (Volta basin) | entire Volta basin | SD | 4.08 | 8.22 | 14.31 | 17.41 | 24.72 | 20.14 | 28.65 | 38.58 | 26.06 | 22.91 | 8.18 | 7.59 | 98.59 |
| | | Mean | 4.53 | 12.05 | 36.81 | 68.47 | 104.84 | 143.78 | 167.74 | 186.05 | 160.99 | 78.08 | 14.91 | 6.08 | 984.69 |
| | | **CV (%)** | **90.20** | **68.20** | **38.87** | **25.42** | **23.58** | **14.01** | **17.08** | **20.74** | **16.19** | **29.34** | **54.86** | **124.78** | **10.01** |
| Q ($m^3/s$) 1979–2000 (Mono basin) | NANGBETO | SD | 0.46 | 2.40 | 2.18 | 2.62 | 11.13 | 14.42 | 89.32 | 192.91 | 172.40 | 114.80 | 16.25 | 1.65 | 36.58 |
| | | Mean | 0.25 | 1.38 | 1.51 | 1.84 | 5.92 | 17.87 | 131.13 | 369.50 | 456.27 | 177.93 | 17.13 | 1.00 | 98.48 |
| | | **CV (%)** | **182.65** | **174.21** | **144.21** | **142.16** | **188.16** | **80.71** | **68.11** | **52.21** | **37.78** | **64.52** | **94.82** | **164.45** | **37.15** |
| | ATHIEME | SD | 36.66 | 45.36 | 37.35 | 35.00 | 35.65 | 28.93 | 103.91 | 154.52 | 167.05 | 182.29 | 49.32 | 40.21 | 52.57 |
| | | Mean | 37.11 | 41.27 | 33.65 | 36.07 | 38.00 | 53.95 | 147.23 | 239.06 | 345.22 | 261.49 | 73.53 | 47.12 | 112.81 |
| | | **CV (%)** | **98.78** | **109.91** | **110.98** | **97.04** | **93.80** | **53.62** | **70.57** | **64.64** | **48.39** | **69.71** | **67.07** | **85.33** | **46.60** |
| P (mm) 1979–2000 (Mono basin) | entire Mono basin | SD | 5.26 | 16.44 | 27.28 | 25.09 | 32.01 | 29.34 | 43.50 | 53.32 | 34.74 | 32.06 | 11.26 | 16.34 | 141.66 |
| | | Mean | 7.33 | 23.51 | 68.60 | 110.87 | 148.46 | 179.78 | 176.12 | 171.88 | 183.06 | 123.82 | 25.70 | 12.64 | 1231.77 |
| | | **CV (%)** | **71.70** | **69.91** | **39.77** | **22.63** | **21.56** | **16.32** | **24.70** | **31.02** | **18.98** | **25.89** | **43.79** | **129.26** | **11.50** |
| Q ($m^3/s$) 1979–2004 (Sassandra basin) | SOUBRE | SD | 116.03 | 113.67 | 131.33 | 106.72 | 124.00 | 113.50 | 160.51 | 260.87 | 379.71 | 323.73 | 148.17 | 87.72 | 102.47 |
| | | Mean | 292.17 | 286.88 | 275.46 | 294.43 | 288.32 | 291.39 | 297.06 | 345.49 | 502.72 | 581.56 | 415.32 | 310.21 | 348.42 |
| | | **CV (%)** | **39.71** | **39.62** | **47.68** | **36.25** | **43.01** | **38.95** | **54.04** | **75.51** | **75.53** | **55.67** | **35.67** | **28.28** | **29.41** |
| | DAKPADOU | SD | 5.67 | 2.75 | 3.80 | 14.00 | 15.56 | 40.99 | 34.22 | 21.81 | 31.09 | 42.88 | 25.89 | 19.71 | 11.72 |
| | | Mean | 4.94 | 2.90 | 5.73 | 17.25 | 28.86 | 70.69 | 55.62 | 27.55 | 37.97 | 62.70 | 44.46 | 21.54 | 31.68 |
| | | **CV (%)** | **114.77** | **94.83** | **66.24** | **81.16** | **53.91** | **57.98** | **61.52** | **79.17** | **81.88** | **68.38** | **58.23** | **91.52** | **37.00** |
| P (mm) 1979–2004 (Sassandra basin) | entiere Sassandra basin | SD | 15.30 | 15.17 | 22.97 | 23.03 | 26.66 | 35.13 | 42.93 | 53.13 | 44.26 | 37.90 | 25.24 | 13.15 | 123.58 |
| | | Mean | 15.57 | 39.47 | 92.26 | 141.12 | 170.90 | 210.95 | 191.95 | 240.02 | 242.11 | 171.64 | 77.94 | 24.32 | 1618.25 |
| | | **CV (%)** | **98.28** | **38.43** | **24.90** | **16.32** | **15.60** | **16.65** | **22.36** | **22.13** | **18.28** | **22.08** | **32.38** | **54.06** | **7.64** |

In addition, it is also found that land use and land cover practice in the same basin could be favorable to Bui hydropower plant production under climatic uncertainties [7]. But the resultant effect of this phenomenon in other regional hydropower plants is not known and need to be investigated. So there is a nexus between land use–climate change–energy productions [73].

Beside the hydrological dynamic modification of land use [81,82], it can also be responsible of global carbon cycle and climate changes; can affect regional climate, water and air quality as well as cause biodiversity decline [52] and cause some infectious diseases. The land use change can also impact the global and regional climate [80] through the surface energy budget as well as the carbon cycle [77,83].

The land use and land cover change have strong influence on regional hydroclimate [78], ecosystem and society [77]. The land use/cover classification over Greater Horn of Africa between 1986–2000 exhibits increased conversion of large portions of forests to agriculture, particularly in Kenya, with land (acreage) under crops increasing from 6.55% in 1986 to almost 18% by the year 2000 [84]. This change in land use/cover has resulted into a modest reduction in monthly rainfall totals and also may be contributing to notable shifts in moisture convergence zones and centers of rainfall maxima. A decrease in precipitation and an increase in surface temperature around the lake region was shown when surface vegetation cover is converted to agricultural land cover type [83]. The land use/cover plays important role in climate system of the region.

The changes in land use and land cover vary according to the basin and the land use category. This has a greater impact on the streamflow generation [81], and thus on water availability for different sectors as well as hydropower plant within the basin and could vary from plant to plant within the same region. Therefore, there is a need of some careful scientific study combining the resultant effect of land use and land cover change on hydrological dynamics of each basin as well as its impacts on each hydropower plant of all the basins in West Africa under climatic uncertainties. Due to the divergent impacts of land use on the environment, it is very important to model how this factor is going to change in the future and what are the plausible effects on all the environmental aspects [82]. This factor is also very important to be taking into account while simulating climate change [85].

## 5. Conclusions

The West Africa region's basins are under different land use practices due to their trans-boundary feature. All the studied basins are subject to more intense usage of land (built-up and agricultural land) due to population growth rate and socio-economic drivers. Between 1988 and 2016, the annual water bodies (built-up) has increased by 4.8% (13.4%); 8.2% (3.33%) and 5.23% (4.56%) for Volta, Mono and Sassandra basins, respectively, while the agricultural land has increase by 20.27%, 5.57% and 4.19%. The expansion land use area (built-up and agricultural land) has led to the reduction in vegetative areas namely forests and savannas. The savanna (herbaceous savanna) has decreased by 1.51% (2.14%), 0.43% (0.65%) per year for Volta and Mono basins respectively while an increase (0.02%/year) has been observed in savanna within Sassandra basin. The forest has decreased by 2.58% and 3.43% per year for Volta and Mono basin respectively while it has increased by 0.28% per year in Sassandra basin. The evergreen forest has also decreased by 3.45% and 3.36% per year in Volta and Sassandra basins respectively. Nevertheless, the shrubs cluster has increased over time within Volta basin and this could be attributed to the agroforestry practice in the basin. This change could be attributed to the cause of different trend and magnitude in precipitation and discharge observed in the study basin. Thus, the change in land use and land cover could have an influence on runoff generation coefficient of the basin as well as the hydrological dynamic modification. It has been responsible of the decline of the underground water recharge of the basin in West Africa [7,78]. This can also influence surrounding regions [54]. The analysis of the discharge in all selected hydrological stations of the basins reveals an upward trend and this can be due to the spatio-temporal precipitation variability in the basins or the change in land use or land cover.

However, the spatio-temporal variation of the precipitation presents a downward trend (non-statistically significant) from the southern to central part of Mono and Sassandra basins and in southern part of Volta basin. Whilst, the Northern part of Mono and Sassandra basins as well from the North to central part of Volta basin present an upward trend (non-statistically significant). Few of the precipitation sites shows a statistically significant trend and this is observed only in Volta basin. Despite this trend all the hydrological station presents an upward trend, only Saboba present a statistically significant at 95% level of confidence and Nangbeto and Athieme stations (Mono basin) at 90% level of confidence for 1979–2000 and 1969–2000 periods respectively. The magnitude of upward trend in discharge is greater than the precipitation one within the same period.

In addition, the coefficient of variation of precipitation and discharge analysis for the three basin reveals that the discharge varies much more (at least three times) than the annual precipitation at the three basins. The same conclusion was made for all the month except the driest months (December and January). This difference in coefficient of variation as well as in trend and magnitude is mainly due to land use and land cover change.

Although the change in land use (conversion of vegetative land into agricultural land) has led to increase in discharge, its resultant effects such as sedimentation and siltation could affect the water quality and availability for all water users' sectors. Thus, all the water user sectors could be affected by this phenomenon under this climatic uncertainty. For instance, it has been demonstrated in Black Volta basin that this change will be favorable for Bui hydroelectric production in the short and medium terms. This impact in the long term is not known and its resultant effects on the existing West Africa hydropower plant needs to be investigated for water-energy security nexus issues.

Finally, there should be a common land use planning and management for each basin for sustainable land use, agricultural practice and energy production.

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