Article

Assessment of Current Land Use in the Oueme Basin and Preliminary Study of its Future for Hydrological Impacts

René Bodjrenou [1,2,*], Françoise Comandan [2] and Derrick Kwadwo Danso [3]

[1]   Doctoral School of Agricultural and Water Sciences (EDSAE - UAC); renebodjrenou@gmail.com
[2]   Laboratory of Hydraulics and Water Control (LHWC) of the National Water Institute; fcomandan@gmail.com
[3]   Department of Geological and Atmospheric Sciences, Iowa State University, Ames, USA; ddanso@iastate.edu
[*]   Correspondence: renebodjrenou@gmail.com; Tel.: +229 96-99-59-64

Abstract: The modification of land use is a crucial factor in the dysfunction of ecosystems. It considerably influences the hydrological cycle of basins. This study focused on the Oueme basin, which represents almost half of the total area of Benin, aims to describe the current and future evolution of its land cover using the maps of the Land Use Land Cover Dynamics project (1975, 2000 and 2013). A temporal analysis of the surface states has been performed with QGIS and the potential land cover in 2025, 2050 and 2085 was estimated using the Markov chain algorithm in the IDRISI software. The results show that the Oueme basin is predominantly savanna (77.70% in 1975, 66.29% in 2000 and 57.10% in 2013). Forest areas, which represented the second class in 1975 with a total proportion of 13.34%, have gradually decreased to 8.66% and 6.89% respectively in 2000 and 2013. Conversely, cultivated areas more than tripled in 2000 and quadrupled in 2013. Residential areas are increasing very strongly in the southern of the basin with an amplification in the recent period (6% between 2000-2013 against 2% between 1975-2000). This has probably led to a low stability rate in this zone (56%) compared to Oueme upper (74%). The recent period is more exposed to changes in surface condition and these changes are likely to be amplified in the future (probable total disappearance of forested areas in 2085). We recommend clarifying the impacts that each land use category generates/will generate on the hydrological cycle of this basin.

Keywords: land cover; Oueme basin; Oueme delta; forest areas; cultivated areas; residential areas

1. Introduction

The land, which is the support of all other elements of biodiversity, has undergone many changes in recent decades. This includes changes due to anthropogenic actions that are increasing with population growth, and modernization that aims to solve humanitarian problems in general and specially to cope with the global food and financial crisis (Orekan, 2021). Since the beginning of the 21st century, mapping studies have helped to identify environmental transformations on the planet. The consensus is that global forest loss has been significantly reduced.

However, this is not true everywhere. In Benin for instance, deforestation has increased (FAO, 2020). The evolution of land use categories in the country presents a worrying situation (Tappan *et al.* , 2016). For example, forest areas can be suddenly transformed into cultivated or residential areas with extensions in record time (Akognongbe *et al.* , 2014; Avakoudjo *et al.* , 2014).

The dynamics of land use in Benin have been studied on several occasions (e.g., Avakoudjo *et al* (2014); Oloukoi, *et al.* (2007); Tchibozo (2020)). However, it is still difficult to distinguish and characterize areas of strong change (e.g., between north and south). . This is partly due to differences in the methodology used to process and analyze primary data, usually satellite images, in most previous studies. In addition, the output images that result from post-processing of the primary data are of different spatial resolutions.

Moreover, the diversity of the spatial resolution of the maps produced previously, added to differences in analysis periods of previous studies, complicate their exploitation for long-term hydrological studies. These issues do not facilitate a critical analysis of the evolution of surface conditions in Benin. Additional studies are thus needed to highlight the environments that have undergone strong transformations.

The dynamic land cover map (LULCD) of West Africa provides a unique opportunity to address the challenge described above. It is produced with the care of several experts to present the surface states of West Africa as closely as possible to reality (Cotillon, 2017). This map has been used to show that West Africa's water cycle have significantly been altered over the last four decades due hunting, bushfires, agriculture, and urbanization (https://eros.usgs.gov/westafrica/atlas-overview). It is thus potentially suited for studies that contribute to a better understanding of the evolution of the surface states in the basins of Benin (Koubodana, 2019).

One of the major basins in Benin is the Oueme basin. To better present the causes of changes in the hydrological cycle in the Oueme basin, it will be necessary to understand its land use transformations. This could enable decision makers to develop effective plans for the development of the basin. Some previous studies have shown that the hydrological cycle in the basin have experienced disruptions (e.g., Sintondji et al., 2014; Houngue, 2020). However, these studies do not give any perspective on what might happen at the end of the century. This is likely due to the poor understanding of the future surface condition of this basin at the end of the century.

Therefore, the main aim of the present study is to provide a basis for hydrologists to explore the impact of land used changes on the hydrological cycle until the end of the century. This will be helpful in the use distributed models for hydrological impact studies in the Oueme basin. With the dynamic land cover map, we intend to critically analyze the current land used dynamics in the Oueme basin and determine potential transformations by the end of the century. We will also provide a comparison of the changes in the northern (upper Oueme) and southern (Oueme delta) parts of the basin.

In what follows, we present the working methodology, including the data and tools used, followed by the results and conclusion.

2. Materials and methods

2.1. Study region

The present study was carried out in the Oueme basin (Figure 1). Located in the Republic of Benin, this basin represents almost half of the total area of the country, which is about 114,000 km^2. It has a humid tropical climate characterized by two rainy seasons in the south and one in the north (Bodjrènou et al 2021). Benin is bordered to the south by the Atlantic Ocean, to the east by Nigeria, to the west by Togo, and to the north by Burkina Faso and Niger.
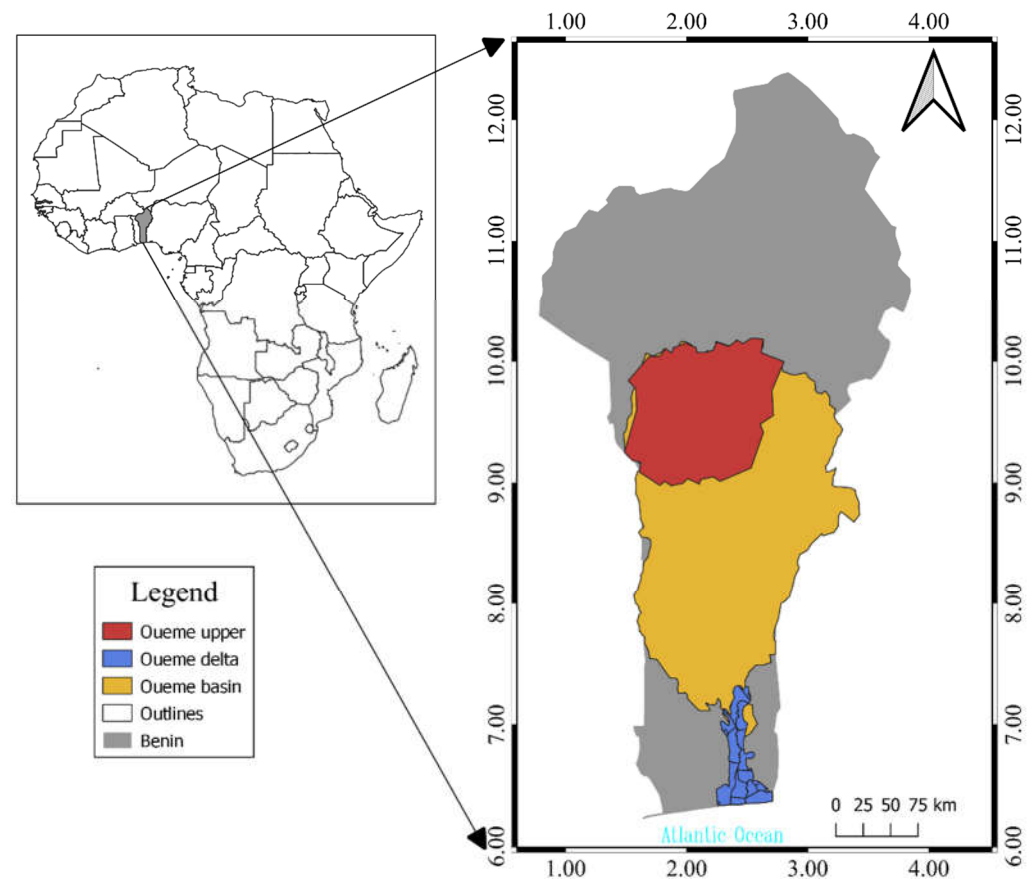
Figure 1. Study area.

2.2. Data

Land use maps from the years 1975, 2000, and 2013 are produced as part of the "Dynamics of Land Use in West Africa (Tappan *et al.*, 2016; Cotillon, 2017). These are maps already classified by the project team with the Rapid Land Cover Mapper (RLCM) tool. RLCM has been used by foresters since the 1970s to facilitate the selection and assignment of land cover classes (https://eros.usgs.gov/westafrica/mapping-land-use-land-cover). The team collected satellite imagery from orbits placed hundreds of kilometers from the earth (https://eros.usgs.gov/westafrica/). Geographical knowledge of the region, field experiments, and observations are then included to realize a 2km resolution precision for the maps. For this, the team considered the period of acquisition of the images and the bases of interpretation of the images (size, shape, color, pattern, tone, shadows, texture). Map interpretation relied primarily on the use of guidelines including written and illustrated definitions of all land cover and land use classes. Verification of the accuracy of the maps was performed using recent high-resolution satellite images (Landsat) viewed in Google Earth and several aerial photographs taken by the project team.

The project map shows several classes in the Oueme basin. Among these are: Forest (1), Savanna (2), Grassland (3), Plantation (6), Cultivated area, Mangrove (7), (8), Water bodies (9), Rocky land, Sandy surfaces (10), Rocky land (11), Dwelling (13), Irrigated crops (14), Gallery forest and riparian formation (15), Degraded forest (21), Open forest (25), Cultivation and fallow under oil palm (27), Swamp forest (28), Herbaceous savanna (31). The numbers in parentheses are those corresponding to each class.

In this study the classes are left unchanged, with no further reclassification. However, similar colors are assigned to similar classes. Note that similar classes can be merged into a single unit during hydrological simulations.

For more details on the map, see Table 2 in the article by (Koubodana *et al.*, 2019).

2.3. Software

QGIS 3.14 was used to extract and present the land cover characteristics of the study area over the last four decades (1975 to 2013) and to describe the evolution of land use using statistical analysis tools for raster layers. This software also allowed an analytic study of the temporal evolution of land use in the Oueme basin. Idrisi software, recognized and supported by National Scientifical Research Center has been used to describe tye future evolution oh the land use. Its ability to simulate surface states in Benin is also recognized (Koubodana et al., 2019; Sieza et al., 2019; Tchibozo, 2020). It integrates the Markov chain, which is a stochastic model based on the following four assumptions:

- The whole past of the system is summarized in its state at the last moment we know it. Otherwise, the classes that disappeared during the historical period have no chance of reappearing.
- This is a discrete process. Example: the cultivated areas extend within the boundaries of the model.
- This is a homogeneous process over time. Otherwise, the increase/decrease of each land use class evolves at the same rate in the future as in the past.
- The number of possible states of the system is finite.

In addition, the Markov chain uses constraints and factors to ensure the best description of surface states in the future. One of the constraints is that forests never gain space in agricultural areas or cities. As for the factors, one example is that areas near rivers or water bodies are more exposed to agricultural production in a context where farmers need water to irrigate their crops. It presents the random distribution of the different categories of land use (see more details in Ladet *et al.* (2005) ; Brooks (1998) ; Tierney (1994))

2.4. Data Analysis

The average annual change in km² /year as well as the conversion and stability rates of the different land use units were obtained by the following formulas respectively:

$$E_i = \frac{S_{yi} - S_{xi}}{(yi - xi)} \tag{1}$$

$$Ts = \frac{S_i}{S_{xi}} \tag{2}$$

$$Tc = 1 - Ts \tag{3}$$

With : E_i = Average annual change in unit i
S_{yi}= Area of unit i in the most recent year (y) ;
S_{xi}= Area of unit i in the least recent year (x) ;
S_i= The area of unit i remained stable (located on the diagonal).
Tc = Conversion rate; Ts = Stability rate;

Note that we can switch from a transition matrix presented in probability to a transition matrix presented on the surface. The following equation describes the relationship between these two matrices.

$$S_{ij} = P_{ij} * S_{yi}$$

With S_{ij} the area of row ième and column jème for year x ;
P_{ij} = the area of row ième and column jème for year x ;
S_{yi} = Total area of unit i, at date y.

3. Results

3.1. Spatial analysis of the dynamics of the current surface state

Figure 2 shows the surface condition in 1975, 2000 and 2013 for the entire Oueme basin (the first three) and the Oueme delta (the last three).

In the Oueme basin, we noted the installation and/or development of agricultural zones in some areas. Furthermore, a decrease of forests areas can be seen. This situation can be observed throughout the entire basin. In the upper Oueme, the residential areas (in yellow) are less developed and well dispersed. However, there is a remarkable development of agricultural areas. Forest areas (in green) are decreasing and being replaced by cultivated and planted areas (in red).

In the Oueme delta, there is strong urbanization pressure on the water bodies. Residential areas are being developed around the water bodies. Additionally, cultivated areas and plantations can been seen in unexpected environments, sometimes even within the water bodies (potentially on islands). In contrast, grasslands and water bodies (blue) occupy larges areas scattered throughout the delta.
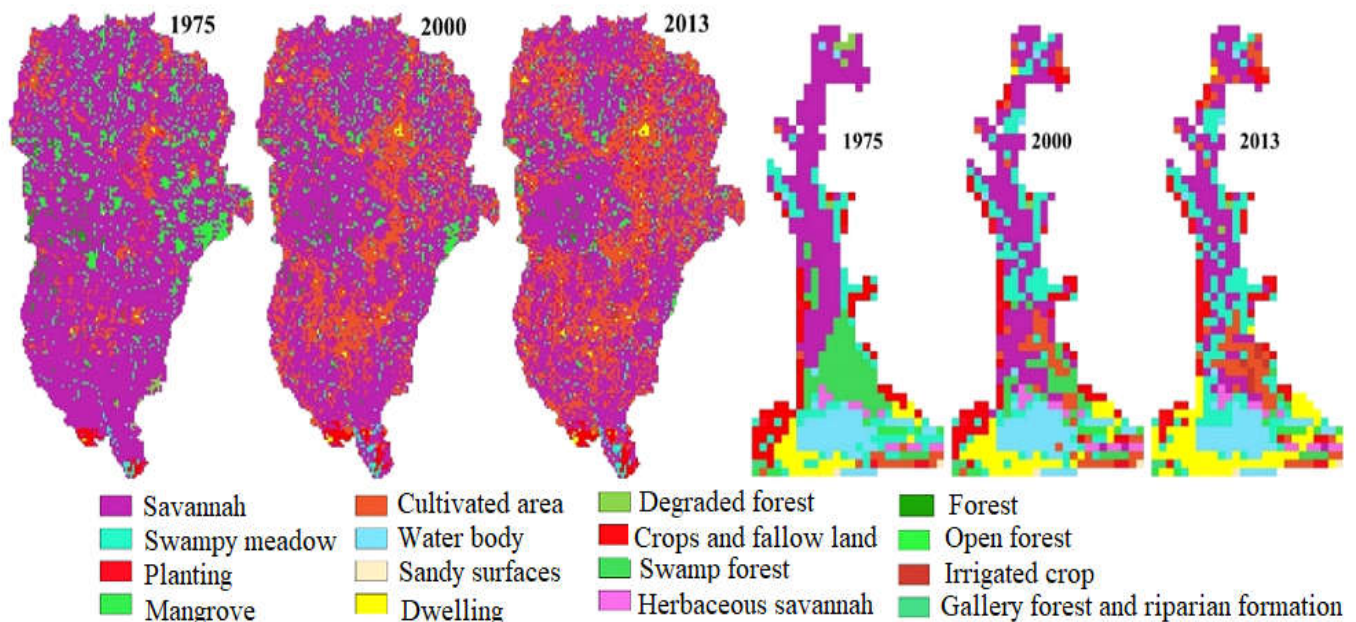
Figure 2. Land use dynamics in the Oueme basin.

The first three for the entire Oueme basin and the last three for its southern part

3.2. Analysis of the temporal evolution of the different land use classes

3.2.1. Average annual evolution of each class

Table 1 presents the evolution of each land use unit in the Oueme basin. Savanna occupied 77.7%, 66.29% and 57.10% respectively in 1975, 2000 and 2013 in the Oueme basin. Forest areas (forest, gallery forest and riparian formation, degraded forest, and open forest) which occupied the second place in 1975 with a total proportion of 13.34% have been replaced by cultivated areas. They now occupy only 8.66% and 6.89% of the total area in 2000 and 2013 respectively, while cultivated areas have increased from 7.50% in 1975 to 22.87% and 31.79% respectively in 2000 and 2013. These units, especially the Savanna and the cultivated areas, have experienced drastic changes. In the savanna, there is an average annual regression of more than 250 km^2 /year between 1975 and 2013.   However, the cultivated areas recorded an average annual increase of the same order (309.4 km^2 /year). There is a good correlation between the evolution of the savanna and that of the cultivated area. An increase of cultivated areas thus leads to a decrease of savanna. Over the sub-period 2000-2013, settlement areas had an average annual increase of 2.77%.

If the rate of regression of regression remains the same as the one observed between 2000 and 2013, forests will disappear in 2053, savanna in 2094, gallery forests and riparian formations in 2023, degraded forests in 2039, and open forest in 2059.

Analysis of the evolution of the upper Oueme (not shown) shows that savanna occupied 74.95% in 1975 in this zone. It however decreased to 69.77% in 2000 and 59.47% in 2013. If this rate, the upper Oueme savannah will completely disappear before 2085, compared to 2094 for the entire Oueme basin. We noted a regression of all forest/savanna surfaces in favor of cultivated surfaces, which increase from 9.85% in 1975 to 18.58 and 28.85% in 2000 and 2013, i.e., an average annual change of -49.9 km² /year and -111.1 km² /year for the 1975-2000 and 2000-2013 sub-periods respectively.

In the Oueme Delta (Table 2), housing areas have increased drastically. They increased from 2% between the 1975-2000 sub-period to 6% between 2000 and 2013. This increase respectively represents eight times (between 1975-2000) and sixteen times (between 2000-2013) of the observed change in the Oueme basin. Similarly, the change is ten (between 1975-2000) and twenty one (between 2000-2013) times as that observed in the upper Oueme.

The inhabitants of Oueme delta did not previously settle mainly in the wetlands. They have however exploited such areas for agricultural, construction, and domestic purposes in recent years. This is shown by the average annual progression (+10.2 Km² /year) of residential areas against the regression of the water bodies (-2.2 km² /year) over the period 2000-2013. Crop irrigation in the same area started in the second decade of the 21st century despite the high availability of water noted in 1975 and 2000 (more than 11%). There is a strong presence of water-stress resistant crops, such as oil palm (see next section for more details). The evolution of land use units in the upper Oueme is shown in the Appendix (table A1).

Table 1. Evolution of land use units in the Oueme basin in Bonou.

	Classes	Area in 1975		Area in 2000		Area in 2013		Evolution (km² /year)		
		(km²)	%	(km²)	%	(km²)	%	1975-2000	2000-2013	1975-2013
1	Forest	536	1,11	308	0,64	232	0,48	-9,1	-5,8	-8,0
2	Savannah	37616	77,70	32092	66,29	27644	57,10	-221,0	-342,2	-262,4
3	Prairie	144	0,30	220	0,45	308	0,64	3,0	6,8	4,3
6	Planting	100	0,21	68	0,14	688	1,42	-1,3	47,7	15,5
8	Growing area	3632	7,50	11072	22,87	15388	31,79	297,6	332,0	309,4
9	Water bodies	36	0,07	56	0,12	36	0,07	0,8	-1,5	0,0
11	Rocky terrain	24	0,05	24	0,05	24	0,05	0,0	0,0	0,0
13	Home	84	0,17	204	0,42	376	0,78	4,8	13,2	7,7
14	Irrigated crops	24	0,05	24	0,05	76	0,16	0,0	4,0	1,4
15	FGFR	2604	5,38	2380	4,92	984	2,03	-9,0	-107,4	-42,6
21	Degraded forest	132	0,27	28	0,06	56	0,12	-4,2	2,2	-2,0
25	Clear forest	3184	6,58	1472	3,04	2064	4,26	-68,5	45,5	-29,5
27	CFUP	296	0,61	464	0,96	536	1,11	6,7	5,5	6,3
	Total	48412	100	48412	100,0	48412	100,00	-	-	-

GFRF = gallery forest and riparian forest; CFUP = cultivation and fallow under oil palm.

Table 2. Evolution of land use units in the Oueme Delta.

	Classes	Area in 1975		Area in 2000		Area in 2013		Evolution (km^2/year)		
		(km^2)	%	(km^2)	%	(km^2)	1975-2000	2000-2013	1975-2013
2	Savannah	716	32,55	664	30,18	524	23,82	-2,1	-10,8	-5,1
3	Prairie	300	13,64	368	16,73	480	21,82	2,7	8,6	4,7
6	Planting	24	1,09	28	1,27	28	1,27	0,2	0,0	0,1
7	Mangrove	40	1,82	40	1,82	36	1,64	0,0	-0,3	-0,1
8	Growing area	60	2,73	192	8,73	224	10,18	5,3	2,5	4,3
9	Water bodies	256	11,64	264	12,00	236	10,73	0,3	-2,2	-0,5
10	Sandy surfaces	8	0,36	8	0,36	8	0,36	0,0	0,0	0,0
13	Home	140	6,36	184	8,36	316	14,36	1,8	10,2	4,6
14	Irrigated crops	-	-	-	-	28	1,27	-	-	-
15	GFRF	8	0,36	8	0,36	8	0,36	0,0	0,0	0,0
21	Degraded forest	24	1,09	4	0,18	8	0,36	-0,8	0,3	-0,4
27	CFUP	244	11,09	248	11,27	216	9,82	0,2	-2,5	-0,7
28	Swamp forest	324	14,73	136	6,18	32	1,45	-7,5	-8,0	-7,7
31	Herbaceous savannah	56	2,55	56	2,55	56	2,55	0,0	0,0	0,0
	Total	2200	100	2200	100	2200	100			

GFRF= gallery forest and riparian forest; CFUP = cultivation and fallow under oil palm.

3.2.2. In-depth analysis of dominant and sensitive categories

It is designated under the dominant and sensitive category, the land use unit that represents at least 2% of the total area studied and that has not remained stable.

In the Oueme basin, as well as in its upper part, there are four dominant and sensitive classes, namely: cultivated zone, savanna, open forest, gallery forest and riparian formation. In the south, there are two classes common to the others: cultivated area and savanna. In addition to these two classes, there are other classes such as water and habitat.

Our results (Figure 3) show that among the two common classes, the savanna has experienced a continuous regression over time. The regression has been very intense during the recent period (2000-2013). However, the cultivated areas have continuously progressed, although less pronounced in the recent period in Oueme delta (32.05% in the recent sub-period against 67.95% in the old sub-period). In contrast, cultivated areas in the upper Oueme has strongly regressed in recent years (69% between 2000-2013). The slight increase in the delta is likely related to the low transformation of wetlands for agricultural purposes. Residential areas have strongly increased in the Oueme delta, and is likely due to the wealth it contains. The increase of water bodies in this area over the recent period could be due to the recovery of rainfall.

Figure 3. Evolution of important categories in the study environment.

3.3. Diachronic and analytical studies of land use

The diachronic and analytical study makes it possible to determine the area or percentage of area that has remained unchanged and the causes of the transformation of certain units. The diagonal values match the areas that have remained stable when two maps are superimposed.

Our analytical results for the Oueme basin (Table 3) show that between 1975 and 2000, 76.48% of savanna (class 2) remained stable. Of the 23.52% converted to other land use units, crop and fallow areas (class 8) occupy 93.31%. For open forests (class 25), there is a stability rate of 40.3% and a conversion rate of 59.7%. These findings are similar in the basin over the period 2000-2013 (not shown). During this period, 78.36% of the savanna remained stable and 21.64% were converted to other land use units with a representation of 91.47% for crop and fallow areas. In gallery forests and riparian formations, there is a stability rate of 87.7%, while the rate of conversion to other units is 12.3% of which 25.30% is for cultivated areas. The open forests show a stability rate of 56.25% and 43.75% for conversion rate of which cultivated areas contributes 3.75%.

The analysis of the upper Oueme (not shown) shows a stability rate for the savanna of 82.97% between 1975-2000 and 79.06% between 2000-2013. Cultivated areas respectively contribute 97.59% and 95.40% to the conversion rates of the two periods. On the other hand, gallery forests and riparian formations have a stability rate of 89.31% and 87.18% for the two periods respectively, with a contribution of 14.29% and 23.33% of cultivated areas to their conversion rates.

The Oueme delta has a special status. During the first sub-period (Table 4), a slightly lower rate of stability is observed for the savanna (70.39%). 20.75% of the conversion rate

is used for cropping and fallow land under oil palm (class 27). while 18.87% is used the cultivation areas. In swamp forests (class 28), we noted a stability rate of 38.27% and 61.73% conversion to other units, with of 20% of that to grasslands and 40% to cultivated areas. Meanwhile we noted stability rates of 68%, 80%, 100%, 100% and 77% respectively for grasslands, cultivated areas, water bodies (class 9), housing areas (class 13) and crops and fallow land under oil palm. This trend is similar for the sub-period 2000-2013 (not shown). Over this sub-period, 69.28% of the savanna remained stable while 30.72% was converted to other land use units of which 47.06% was grasslands, 29.41% was cultivated areas, 7.84% was residential areas, and 13.73% was crops and fallow under oil palm. In swamp forests, there is a stability rate of 23.53% and 76.47% conversion to other units with a representation of 46.15% for grassland and 19.23% for cultivated areas.

Overall, the stability rate is 56% in Oueme delta compared to 74% in Oueme upper.

Table 3. Transition matrix of the Oueme basin in Bonou between 1975-2000.

The numerical values indicated in the table represent the surfaces in Km2

Classes	1	2	3	6	8	9	11	13	14	15	21	25	27	Total (2000)
Forest (1)	308	0	0	0	0	0	0	0	0	0	0	0	0	308
Savannah (2)	132	28768	24	40	1280	0	0	0	0	168	56	1548	76	32092
Prairie (3)	0	80	120	0	0	0	0	0	0	8	12	0	0	220
Planting (6)	0	28	0	28	8	0	0	0	0	0	0	4	0	68
Growing area (8)	68	8256	0	32	2284	0	0	0	0	40	44	348	0	11072
Water bodies (9)	0	20	0	0	0	36	0	0	0	0	0	0	0	56
Rocky terrain (11)	0	0	0	0	0	0	24	0	0	0	0	0	0	24
Home (13)	0	48	0	0	56	0	0	84	0	4	0	0	12	204
Irrigated crops (14)	0	0	0	0	0	0	0	0	24	0	0	0	0	24
FGFR (15)	8	0	0	0	0	0	0	0	0	2372	0	0	0	2380
Degraded forest (21)	4	4	0	0	0	0	0	0	0	0	20	0	0	28
Clear forest (25)	16	156	0	0	4	0	0	0	0	12	0	1284	0	1472
CFUP (27)	0	256	0	0	0	0	0	0	0	0	0	0	208	464
Total (1975)	536	37616	144	100	3632	36	24	84	24	2604	132	3184	296	48412

Table 4. Transition matrix of the Oueme Delta between 1975-2000.

The numerical values indicated in the table represent the surfaces in Km2

Classes	2	3	6	7	8	9	10	13	15	21	27	28	31	Total (2000)
Savannah (2)	504	36	0	0	4	0	0	0	0	4	36	80	0	664
Prairie (3)	108	204	0	0	0	0	0	0	0	16	0	40	0	368
Planting (6)	8	0	20	0	0	0	0	0	0	0	0	0	0	28
Mangrove (7)	0	0	0	40	0	0	0	0	0	0	0	0	0	40
Growing area (8)	40	24	0	0	48	0	0	0	0	0	0	80	0	192
Water bodies (9)	4	4	0	0	0	256	0	0	0	0	0	0	0	264
Sandy surfaces (10)	0	0	0	0	0	0	8	0	0	0	0	0	0	8
Home (13)	4	8	4	0	8	0	0	140	0	0	20	0	0	184
GFRF (15)	0	0	0	0	0	0	0	0	8	0	0	0	0	8
Degraded forest (21)	0	0	0	0	0	0	0	0	0	4	0	0	0	4
CFUP (27)	44	16	0	0	0	0	0	0	0	0	188	0	0	248
Swamp forest (28)	4	8	0	0	0	0	0	0	0	0	0	124	0	136
Herbaceous savannah (31)	0	0	0	0	0	0	0	0	0	0	0	0	56	56
Total (1975)	716	300	24	40	60	256	8	140	8	24	244	324	56	2200

GFRF = gallery forest and riparian forest; CFUP = cultivation and fallow under oil palm.

3.4. Predictive evolution of the different land use units

3.4.1. Ability of the IDRIS model to predict Land use

To test the validity of the IDRISI software, it was used to simulated the 2013 land use map and compared to observations (Figure 4). The correlation between the observed areas per class and those simulated is 99.3%, 99.6% and 95.3% for the Oueme basin, the upper Oueme, and the Oueme delta respectively.
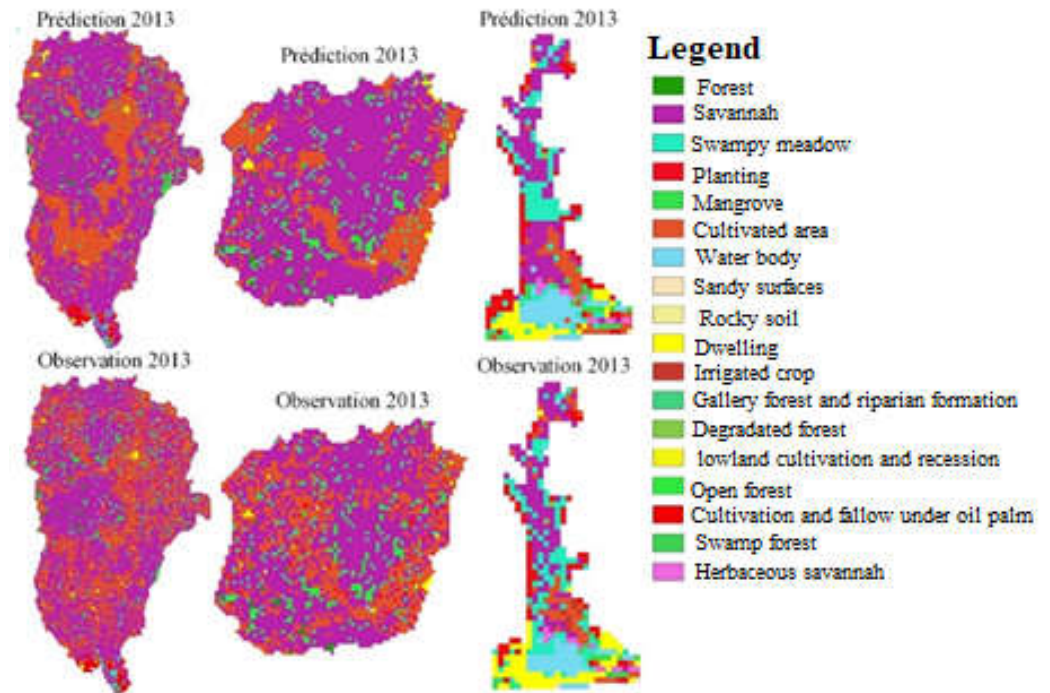
Figure 4. Spatial predictive capacity of land uses.

3.4.2. Future surface conditions in the Oueme basin

Figure 5 presents the projected evolution of the different land use units in the Oueme basin in the context of a return to the least aggravating evolution (1975-2000). Within the framework of the hypotheses of this study, it can be projected that the forest areas would almost disappear by 2085, with a considerable decrease by 2025 and 2050. The Oueme basin and its northern and southern parts will likely remain dominated by savanna. Residential areas will move into crop lands, with the latter projected to undergo significant development over the different time horizons (2025, 2050 and 2085). Furthermore, the Markov probability matrix (Table A6. In appendix) shows that the forest (class 1) would have very little chance of remaining there over the different horizons : 57.46%, 33.02% and 14.63% in the Oueme basin, 75% 56.25 and 37.34% in the upper Oueme basin at the 2025, 2050 and 2085 horizons respectively. The savanna (class 2) have a 76.48%, 66.67% and 61.24% chance of remaining in the Oueme basin compared to 82.97%, 75.56% and 71.30% in the upper Oueme. The probability is lower in the south, with 68%, 48.38% and 32.07% chances of remaining there over each of the three horizons. Cultivated areas (class 8) and water bodies (class 9) have very high chances of remaining stable over all the horizons considered. Residential areas (class 13) on the other hand will not change to other land use types. They have a 100% chance of remaining stable over all horizons and all zones of the study area.
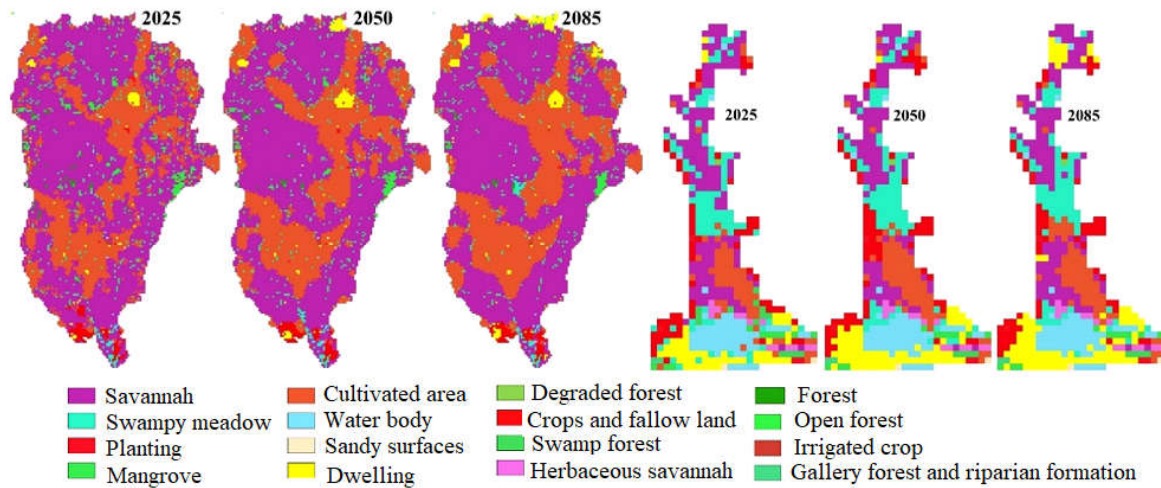
Figure 5. Predictive land use evolution in 2025, 2050 and 2085.

4. Discussion

The results show that the Oueme basin in general, including upper Oueme and Oueme delta, is dominated by savanna. This is consistent with the work of Tappan *et al.* (2016) and Cotillon (2017) who used the same land use maps to note that most of West Africa is dominated by savanna. Compared to the Oueme delta, the upper Oueme basin has a high vegetation cover. We also found that settlement areas develop slightly faster in the Oueme Delta than the upper Oueme. This agrees with the findings of Gaye (1992) which showed that southern Benin is totally undergoing human development. Indeed, the Oueme delta is a wetland whose water availability attracts a good number of farmers in a country where the rural population represents more than 50% of the total. (Mueller and Thurlow, 2019). Scattered islands are sometimes exploited for agricultural purposes, and sometimes considered as living areas for producers who seek land to develop their activities (https://eros.usgs.gov/westafrica/agriculture-expansion).

The results also showed that the savanna has regressed over the two periods (1975-2000 and 2000-2013). Similarly, forest areas have also reduced over the entire study area. On the other hand, agricultural areas are increasing. These results agree with the works of Imorou *et al* (2019), Oloukoi, et al., (2007) and Tchibozo (2020) carried out in the northern, central and southern parts of Benin respectively. These studies noted the regression of forest/savanna areas and the progression of cultivated areas over the same study periods. We note that residential areas have an average annual progression of 2.77% in the entire Oueme basin over the period 2000-2013. This rate follows the same trend as the average annual growth rate of the population of Benin, which was estimated at 3.52% between 2002-2013 (INSAE, 2015).

In the Oueme delta, a more significant change is observed. This is linked to the permanent availability of water resources in this area, a source of motivation for people seeking to leave the country. The disappearance of forest areas projected for the next few years is consistent with the studies of Vissin (2007). The aforementioned study revealed that dense forests and forest galleries in the Mekrou and Sota basins, two other basins in Benin, will completely disappear after thirteen years. The increase in water masses in the Oueme delta between 1975-2000 compared to its regression between 2000-2013 would be linked to the rainfall recovery of the late 1990s in southern Benin (Amoussou, Camberlin and Mahé (2012). According to the latter, the 1970s were a dry period, while the 1990s were recognized as a wet period. This change in rainfall is likely a consequence of the increase in water bodies in this area. Furthermore, the high demand for water resources by the ever-increasing population, coupled with their motivation to produce in the dry season to maximize their income, could justify the introduction of irrigation in this locality (irrigated crop class introduced in 2000). This is what the study of Nonvide, (2017) attempts

to demonstrate i.e., crop irrigation becomes essential in the dry season to compensate for the rainfall deficit. Our study also shows a high proportion of land occupied by oil palm in the Oueme delta, a category that is almost non-existent in the upper Oueme basin. This result indicates that the climatic and hydrodynamic conditions of the soils in southern Benin are more favorable to this crop. Furthermore, the decline of this unit could be linked to the establishment of other more economically profitable crops.

Our results on the average annual evolution of land use types show that the Oueme basin is marked by the progression of crop/agricultural land and the regression of forest and savanna. It is also shown that this evolution is accentuated over the recent period (2000-2013). These results agree with those of Akognongbe *et al.* (2014) who revealed in the Oueme to Bétérou basin that there is a stronger average annual progression in the recent period for crop and fallow areas (+82km^2 /year and +364km^2 /year); whereas savannah areas experience an average annual decrease (-32 km^2 /year and -63 km^2 /year) for the same sub-period (1979-1998 and 1998-2010). However, this is contrary to findings from a study   by Biaou *et al.* , (2019), conducted in the Ouénou-Bénou classified forest (northern Benin). This contradiction could be related to a relatively better protection of this area than the Oueme basin over the period 2000-2013. The small increase in cultivated areas in the delta between 2000-2013 compared to 1975-2000 could be due to the increase in water bodies. This result is consistent with the studies of Adjakpa (2016) which identified 2010, 2012 and 2013 as flood years, when crops were submerged in the lower Oueme valley.

For both sub-periods, the Oueme basin shows a high stability rate of savanna, gallery forest and riparian formations. This result is contrary to those obtained by Mama *et al* (2014) which showed that the Sudano-Guinean zone of Benin has 53.5% of forests and less than 16% have remained unchanged. The low rate of stability presented in this study is likely related to the lack of protection of forest areas in this zone. The lack of protection facilitates deforestation for charcoal and timber production. The work of Orekan *et al* (2019) conducted with a 6 m resolution point data shows a stability rate of 99.89% for swamp forests and savannas in southern Benin. Leroux (2012) presents approximate values for savanna (86%) in the upper Oueme basin. This shows the good performance of the maps used in our study. We note in the Oueme basin and especially in the north that more than 90% of the converted savanna area hosts crop and fallow land whether in the first sub-period (1975-2000) or in the second sub-period (2000-2013). This result shows that the main source of conversion of forest/savanna areas is the increase in agricultural areas, in agreement with the studies of Zakari *et al*, (2015), Arouna and Imorou (2016) and Imorou *et al*, (2019).

Analysis of the predictive evolution results suggests that cultivated areas may increase throughout the basin. However, forest areas are expected to decrease. These results agree with the work of Oloukoi et al. (2007) who modeled the land use dynamics in this area. Using a similar methodology as that of the present work, the authors predicted that by 2010 and 2020, fields and human settlements would increase, while forest areas would decrease. This work does not present results for 2020, but based on the 2000-2013 trends discussed above, it appears to confirm the predictive work of Oloukoi et al., (2007). In addition, their analyses showed that the rate of stability of each of the land uses types would decrease over time, indicating an overall increase in cover variability. This result does confirm the modeling studies of the spatio-temporal dynamics of land uses in the Lama territory (southern Benin) by Tchibozo (2020), which showed that the slow changes observed today will increase while the areas of stability decrease.

5. Conclusion

The present study is a contribution to the understanding of the evolution of land use categories in the Oueme basin. It provides a solid basis for hydrologists who seek to present the consequences of the current evolution on the water cycle. At the same time, the study presents what can be expected if the variations in surface conditions evolve at the same rates until the end of the century. This allows to explore the consequences of

development policies on the hydrological cycle and consequently on the water resources of this basin.

Our results show that the Oueme basin was and remains dominated by savanna. Overall, in the northern part of the basin (designated as the Upper Oueme) as well as in the south (Oueme Delta), the areas of forest, savanna, gallery forest and riparian formation, and degraded forest have decreased in the past. This decrease could also be observed at the future periods covered by this study (2025, 2050 and 2085). On the other hand, land use categories such as cultivated areas, crops, and fallow land under oil palm are expected to increase over time, as is the case for residential areas. Furthermore, the Oueme delta has undergone very strong transformations, especially in the recent period, compared to the upper Oueme basin. The current and projected maps are highly recommended to hydrologists to determine the disturbances of the future water cycle. It is important to make the results of our investigations available to decision makers to facilitate effective development policies that will preserve natural resources for future generations. The impact of current changes in surface conditions on water resources must be assessed in order to deepen the understanding of the consequences of our anthropogenic actions on the Oueme basin.

Appendix

Table A1. Evolution of land use units in the Oueme upper.

	Classes	Area in 1975		Area in 2000		Area in 2013		Evolution (km² /year)		
		(km²)	%	(km²)	%	(km²)	%	1975-2000	2000-2013	1975-2013
1	Forest	112	0,78	84	0,59	80	0,56	-1,1	-0,3	-0,8
2	Savanna	10712	74,95	9972	69,77	8452	59,47	-29,6	-116,9	-59,5
6	Plantation	8	0,06	4	0,03	208	1,46	-0,2	15,7	5,3
8	Cultivation area	1408	9,85	2656	18,58	4100	28,85	49,9	111,1	70,8
9	Water bodies	4	0,03	8	0,06	8	0,06	0,2	0	0,1
13	Dwelling	20	0,14	48	0,34	88	0,62	1,1	3,1	1,8
15	GFRF	1048	7,33	936	6,55	816	5,74	-4,5	-9,2	-6,1
21	Degraded forest	-	-	-	-	4	0,03	-	-	-
25	Open forest	980	6,86	584	4,09	536	3,77	-15,8	-3,7	-11,7
Total		14292	100	14292	100	14212	100			

Table A2. Transition matrix of the Oueme Basin between 2000-2013.

Classes	1	2	3	6	8	9	11	13	14	15	21	25	27	Total (2013)
Forest (1)	200	0	0	0	0	0	0	0	0	0	0	32	0	232
Savannah (2)	32	25148	36	8	1828	0	0	0	0	180	0	412	0	27644
Prairie (3)	0	52	180	0	4	20	0	0	0	52	0	0	0	308
Planting (6)	12	256	4	40	364	0	0	0	0	4	4	4	0	688
Growing area (8)	16	6352	0	20	8720	0	0	0	0	80	4	196	0	15388
Water bodies (9)	0	0	0	0	0	36	0	0	0	0	0	0	0	36
Rocky terrain (11)	0	0	0	0	0	0	24	0	0	0	0	0	0	24
Home (13)	0	12	0	0	148	0	0	204	0	0	0	0	12	376
Irrigated crops (14)	0	52	0	0	0	0	0	0	24	0	0	0	0	76
FGFR (15)	0	0	0	0	0	0	0	0	0	2064	0	0	0	2064

Degraded forest (21)	20	16	0	0	0	0	0	0	0	0	20	0	0	56
Clear forest (25)	28	120	0	0	8	0	0	0	0	0	0	828	0	984
CFUP (27)	0	84	0	0	0	0	0	0	0	0	0	0	452	536
Total (2000)	308	32092	220	68	11072	56	24	204	24	2380	28	1472	464	48412

Table A3. Transition matrix of the Oueme Delta between 2000-2013.

Classes	2	3	6	7	8	9	10	13	15	21	27	28	31	Total (2013)
Savannah (2)	460	48	0	0	8	0	0	0	0	0	0	8	0	524
Prairie (3)	96	292	0	0	12	32	0	0	0	0	0	48	0	480
Planting (6)	0	0	28	0	0	0	0	0	0	0	0	0	0	28
Mangrove (7)	0	0	0	36	0	0	0	0	0	0	0	0	0	36
Growing area (8)	60	0	0	0	144	0	0	0	0	0	0	20	0	224
Water bodies (9)	0	0	0	0	4	232	0	0	0	0	0	0	0	236
Sandy surfaces (10)	0	0	0	0	0	0	8	0	0	0	0	0	0	8
Home (13)	16	28	0	4	24	0	0	184	0	0	60	0	0	316
Irrigated crops (14)	0	0	0	0	0	0	0	0	0	0	0	28	0	28
GFRF (15)	0	0	0	0	0	0	0	0	8	0	0	0	0	8
Degraded forest (21)	4	0	0	0	0	0	0	0	0	4	0	0	0	8
CFUP (27)	28	0	0	0	0	0	0	0	0	0	188	0	0	216
Swamp forest (28)	0	0	0	0	0	0	0	0	0	0	0	32	0	32
Herbaceous savannah (31)	0	0	0	0	0	0	0	0	0	0	0	0	56	56
Total (2000)	664	368	28	40	192	264	8	184	8	4	248	136	56	2200

Table A4. Transition matrix of the Oueme upper between 1975-2000

Classes	1	2	6	8	9	13	15	25	Total (2000)
Forest (1)	84	0	0	0	0	0	0	0	**84**
Savanna (2)	24	8888	0	560	0	0	96	404	**9972**
Plantation (6)	0	4	0	0	0	0	0	0	**4**
Cultivation area (8)	4	1780	8	828	0	0	16	20	**2656**
Water bodies (9)	0	4	0	0	4	0	0	0	**8**
Dwelling (13)	0	8	0	20	0	20	0	0	**48**
GFRF (15)	0	0	0	0	0	0	936	0	**936**
Degraded forest (25)	0	28	0	0	0	0	0	556	**584**
Total (1975)	**112**	**10712**	**8**	**1408**	**4**	**20**	**1048**	**980**	**14292**

Table A5. Transition matrix of the Oueme upper between 2000-2013

Classes	1	2	6	8	9	13	15	25	Total (2013)
Forest (1)	64	0	0	0	0	0	0	16	**80**
Savanna (2)	4	7884	0	404	0	0	92	68	**8452**
Plantation (6)	0	72	4	132	0	0	0	0	**208**
Cultivation area (8)	0	1992	0	2080	0	0	28	0	**4100**
Water bodies (9)	0	0	0	0	8	0	0	0	**8**
Dwelling (13)	0	0	0	40	0	48	0	0	**88**
GFRF (15)	0	0	0	0	0	0	816	0	**816**
Degraded forest (21)	0	4	0	0	0	0	0	0	**4**
Degraded forest (25)	16	20	0	0	0	0	0	500	**536**
Total (2000)	**84**	**9972**	**4**	**2656**	**8**	**48**	**936**	**584**	**14292**

Table A6. Probability of stability of the different units in 2025, 2050 and 2085.

a) Oueme Basin.

2025	1	2	3	6	8	9	11	13	14	15	21	25	27
Class 1	57,46	24,63	0	0	12,69	0	0	0	0	1,49	0,75	2,99	0
Class 2	0	76,48	0,21	0,07	21,95	0,05	0	0,13	0	0	0,01	0,41	0,68
Class 3	0	16,67	83,33	0	0	0	0	0	0	0	0	0	0
Class 6	0	40	0	28	32	0	0	0	0	0	0	0	0
Class 8	0	35,24	0	0,22	62,89	0	0	1,54	0	0	0	0,11	0
Class 9	0	0	0	0	0	100	0	0	0	0	0	0	0
Class 11	0	0	0	0	0	0	100	0	0	0	0	0	0
Class 13	0	0	0	0	0	0	0	100	0	0	0	0	0
Class 14	0	0	0	0	0	0	0	0	100	0	0	0	0
Class 15	0	6,45	0,31	0	1,54	0	0	0,15	0	91,09	0	0,46	0
Class 21	0	42,42	9,09	0	33,33	0	0	0	0	0	15,15	0	0
Class 25	0	48,62	0	0,13	10,93	0	0	0	0	0	0	40,33	0
Class 27	0	25,68	0	0	0	0	0	4,05	0	0	0	0	70,27
2050	**1**	**2**	**3**	**6**	**8**	**9**	**11**	**13**	**14**	**15**	**21**	**25**	**27**
Class 1	33,02	39,32	0,12	0,05	21,27	0,01	0	0,23	0	2,22	0,54	3,04	0,17
Class 2	0	66,67	0,34	0,13	30,66	0,09	0	0,59	0	0	0,01	0,51	1
Class 3	0	26,64	69,48	0,01	3,66	0,01	0	0,02	0	0	0	0,07	0,11
Class 6	0	53,07	0,09	7,94	37,86	0,02	0	0,54	0	0	0	0,2	0,27
Class 8	0	49,26	0,07	0,23	47,36	0,02	0	2,56	0	0	0	0,26	0,24
Class 9	0	0	0	0	0	100	0	0	0	0	0	0	0
Class 11	0	0	0	0	0	0	100	0	0	0	0	0	0
Class 13	0	0	0	0	0	0	0	100	0	0	0	0	0
Class 14	0	0	0	0	0	0	0	0	100	0	0	0	0
Class 15	0	11,63	0,55	0,01	3,83	0	0	0,33	0	82,98	0	0,63	0,04
Class 21	0	52,14	9,04	0,11	35,32	0,02	0	0,57	0	0	2,3	0,21	0,29
Class 25	0	60,69	0,1	0,15	21,99	0,03	0	0,23	0	0	0,01	16,48	0,33
Class 27	0	37,68	0,05	0,02	5,64	0,01	0	6,94	0	0	0	0,11	49,55
2085	**1**	**2**	**3**	**6**	**8**	**9**	**11**	**13**	**14**	**15**	**21**	**25**	**27**
Class 1	14,63	50,17	0,29	0,11	28,52	0,04	0	0,79	0	2,58	0,26	2,14	0,47
Class 2	0	61,24	0,46	0,16	34,84	0,14	0	1,44	0	0	0,01	0,51	1,2
Class 3	0	35,55	53,8	0,04	9,92	0,03	0	0,17	0	0	0	0,17	0,32
Class 6	0	58,23	0,22	1,2	37,77	0,06	0	1,48	0	0	0,01	0,39	0,65
Class 8	0	55,99	0,2	0,2	38,89	0,06	0	3,66	0	0	0,01	0,39	0,6
Class 9	0	0	0	0	0	100	0	0	0	0	0	0	0
Class 11	0	0	0	0	0	0	100	0	0	0	0	0	0
Class 13	0	0	0	0	0	0	0	100	0	0	0	0	0
Class 14	0	0	0	0	0	0	0	0	100	0	0	0	0
Class 15	0	17,63	0,8	0,03	7,28	0,01	0	0,62	0	72,79	0	0,7	0,14
Class 21	0	55,7	7,37	0,16	34,14	0,06	0	1,44	0	0	0,1	0,38	0,65
Class 25	0	62,27	0,26	0,16	31,17	0,07	0	0,86	0	0	0,01	4,45	0,76

| Class 27 | 0 | 45,31 | 0,15 | 0,06 | 14,14 | 0,04 | 0 | 9,83 | 0 | 0 | 0 | 0,24 | 30,22 |

b) Oueme Delta.

2025	2	3	6	7	8	9	10	13	15	21	27	28	31
Class 2	70,39	15,08	1,12	0	5,59	0,56	0	0,56	0	0	6,15	0,56	0
Class 3	12	68	0	0	8	1,33	0	2,67	0	0	5,33	2,67	0
Class 6	0	0	83,33	0	0	0	0	16,67	0	0	0	0	0
Class 7	0	0	0	100	0	0	0	0	0	0	0	0	0
Class 8	6,67	0	0	0	80	0	0	13,33	0	0	0	0	0
Class 9	0	0	0	0	0	100	0	0	0	0	0	0	0
Class 10	0	0	0	0	0	0	100	0	0	0	0	0	0
Class 13	0	0	0	0	0	0	0	100	0	0	0	0	0
Class 15	0	0	0	0	0	0	0	0	100	0	0	0	0
Class 21	16,67	66,67	0	0	0	0	0	0	0	16,67	0	0	0
Class 27	14,75	0	0	0	0	0	0	8,2	0	0	77,05	0	0
Class 28	24,69	12,35	0	0	24,69	0	0	0	0	0	0	38,27	0
Class 31	0	0	0	0	0	0	0	0	0	0	0	0	100
2050	**2**	**3**	**6**	**7**	**8**	**9**	**10**	**13**	**15**	**21**	**27**	**28**	**31**
Class 2	52,78	20,94	1,72	0	9,75	1,15	0	2,79	0	0	9,87	1,01	0
Class 3	18,59	48,38	0,13	0	13,17	2,31	0	6,05	0	0	8,47	2,9	0
Class 6	0	0	69,44	0	0	0	0	30,56	0	0	0	0	0
Class 7	0	0	0	100	0	0	0	0	0	0	0	0	0
Class 8	10,03	1,01	0,07	0	64,37	0,04	0	24,04	0	0	0,41	0,04	0
Class 9	0	0	0	0	0	100	0	0	0	0	0	0	0
Class 10	0	0	0	0	0	0	100	0	0	0	0	0	0
Class 13	0	0	0	0	0	0	0	100	0	0	0	0	0
Class 15	0	0	0	0	0	0	0	0	100	0	0	0	0
Class 21	22,51	58,96	0,19	0	6,26	0,98	0	1,87	0	2,78	4,58	1,87	0
Class 27	21,75	2,23	0,16	0	0,82	0,08	0	14,59	0	0	60,27	0,08	0
Class 28	29,96	16,84	0,28	0	31,57	0,3	0	3,76	0	0	2,18	15,11	0
Class 31	0	0	0	0	0	0	0	0	0	0	0	0	100
2085	**2**	**3**	**6**	**7**	**8**	**9**	**10**	**13**	**15**	**21**	**27**	**28**	**31**
Class 2	38,56	22,45	2,11	0	13,62	1,95	0	7,44	0	0	12,58	1,3	0
Class 3	22,57	32,07	0,39	0	17,05	3,32	0	11,5	0	0	10,78	2,32	0
Class 6	0	0	53,69	0	0	0	0	46,31	0	0	0	0	0
Class 7	0	0	0	100	0	0	0	0	0	0	0	0	0
Class 8	11,93	2,65	0,21	0	47,85	0,14	0	35,89	0	0	1,21	0,12	0
Class 9	0	0	0	0	0	100	0	0	0	0	0	0	0
Class 10	0	0	0	0	0	0	100	0	0	0	0	0	0
Class 13	0	0	0	0	0	0	0	100	0	0	0	0	0
Class 15	0	0	0	0	0	0	0	0	100	0	0	0	0
Class 21	25,55	40,66	0,49	0	13,18	2,23	0	6,11	0	0,14	9,18	2,47	0
Class 27	25,19	5,76	0,46	0	2,58	0,3	0	21,8	0	0	43,63	0,26	0
Class 28	28,58	17,91	0,67	0	31,66	0,85	0	10,89	0	0	5,22	4,23	0
Class 31	0	0	0	0	0	0	0	0	0	0	0	0	100

References

1. Adjakpa, T. T. (2016) Gestion des risques hydro-pluviométriques dans la vallée du Niger au Bénin : Cas des inondations des années 2010, 2012 et 2013 dans les communes de Malanville et de Karimama, Thèse de doctorat, Université d'Abomey-Calavi.

2. Akognongbe, A. *et al.* (2014) 'Dynamique de l'occupation du sol dans le bassin versant de l'Oueme à l'exutoire de Bétérou (Bénin)', *Afrique Science*, 10(2), pp. 228-242.

3. Amoussou, E., Camberlin, P. and Mahé, G. (2012) 'Impact of climate variability and the Nangbéto dam on the hydrology of the Mono-Couffo system (West Africa) hydrologie du système Mono-Couffo (Afrique de l'Ouest)', *Hydrological Sciences Journal*, 6667, pp. 805-8017. doi: 10.1080/02626667.2011.643799.

4. Avakoudjo, J. *et al.* (2014) 'Dynamique de l'occupation du sol dans le Parc National du W et sa périphérie au nord-ouest du Bénin', *Int. J. Bio. Chem*, 8, pp. 2608-2625. doi: doi.org/10.4314/ijbcs.v8i6.22.

5. Biaou, S. *et al.* (2019) 'Dynamique spatio-temporelle de l'occupation du sol de la forêt classée de Ouénou-Bénou au Nord Bénin', in *Proceedings of the OSFACO international scientific conference*, pp. 13-32.

6. Cotillon, S. E. (2017) West Africa land use and land cover time series, US Geological Survey Fact Sheet. Reston, VA. doi: 10.3133/fs20173004.

7. FAO (2020) 'Global Forest Resources Assessment 2020, key findings', *Rome*. doi: https://doi.org/10.4060/ca8753en.

8. Gaye, K. J. G. (1992) 'Croissance urbaine, Migrations et population au Bénin', *CEPED, Paris*.

9.   Houngue, R. (2020) Impacts of climate change on the hydrodynamic functioning of the Oueme delta (Benin). PhD thesis from the University of Abomey-Calavi.

10.   Imorou, I. T. *et al.* (2019) 'Assessment of deforestation and forest degradation in protected areas and village lands in the cotton basin of Benin To cite this version : HAL Id : hal-02189556 Assessment of deforestation and forest degradation in the', *OSFACO Conference : Satellite Images for Sustainable Land Management in Africa*, pp. 1-25.

11.   INSAE (2015) "Rgph4: What to remember about the population numbers in 2013? ", *Cotonou (Benin)*, p. 10.

12.   Issiaka, N. T., Arouna, O. and Imorou, I. T. (2016) 'Cartographie De La Dynamique Spatio-Temporelle Des Parcours Naturels Des Troupeaux Transhumants Dans Les Communes De Banikoara Et De Karimama Au Benin (Afrique De L'ouest)', *European Scientific Journal*, 12(32), p. 251. doi: 10.19044/esj.2016.v12n32p251.

13.   Ladet, S. *et al.* (2005) 'Spatialized Markov chains as simulation tools: uses, advantages and limitations', *International Journal of Geomatics*, 15, pp. 159-173.

14.   Mama, A. *et al.* (2014) "Deforestation, savanization and agricultural development of savanna-forest landscapes in the Sudano-Guinean zone of Benin," *Bois et Forets des Tropiques*, 68(322), pp. 65-75. doi: 10.19182/bft2014.322.a31237.

15.   Mueller, V. and Thurlow, J. (2019) *Youth and jobs in rural Africa, United States of America by Oxford University Press*. doi: DOI: 10.1093/oso/9780198848059.003.0001.

16.   Nonvide, G. M. A. (2017) "Effect of irrigation adoption on rice yield in Malanville commune, Benin," *African Development Review*, 29, pp. 109-120. doi: 10.1111/1467-8268.12266.

17.   Oloukoi, J., Mama, V. J. and Agbo, F. B. (2007) 'Modélisation de la dynamique de l'occupation des terres dans le département des Collines au Bénin', *Contemporary publishing international*, pp. 305-323. Available at: https://www.researchgate.net/publication/279851907%0AModélisation.

18.   Orekan, V. *et al.* (2019) 'Current Evolution Of Mangrove Ecosystems In The Benin Coast', *OSFACO Conference: Satellite Images For Sustainable Land Management In Africa*. Available at: https://hal.archives-ouvertes.fr/hal-02189536.

19.   Sintondji, L. O. *et al.* (2014) 'Modelling the water balance of Oueme catchment at the Savè outlet in Benin: contribution to the sustainable water resource management', *International Journal of AgriScience*, 4(January), pp. 74-88. doi: ISSN: 2228-6322© International Academic Journals.

20.   Tappan, G. G. *et al.* (2016) 'West Africa land use land cover time series: U.S.', *Geological Survey data release*, (February). doi: https://doi.org/10.5066/ F73N21JF.

21.   Tchibozo, E. A. M. (2020) 'Modeling spatial - temporal dynamics of land use and analysis of changes in llama territory in Benin', *European Scientific Journal*, 16(6), pp. 500-524. doi: 10.19044/esj.2020.v16n6p499.

22.   Vissin, E. (2007) 'Impact of climate variability and surface state dynamics on runoff in the Benin River Niger basin'. Available at: https://tel.archives-ouvertes.fr/tel-00456097 (accessed May 10, 2020).

23.   Zakari, S. *et al.* (2015) 'Hydropluviometric variability and dynamics of land cover in the catchment of Sota at the outle in Benin (West Africa)', *International Journal of Innovation and Applied Studies*, 13(2), pp. 235-250.

24.   Brooks, S. P. (1998) 'Markov chain Monte Carlo method and its application'.

25.   Koubodana, D. H. et al. (2019) 'Impact of the Accuracy of Land Cover Data Sets on the Accuracy of Land Cover Change Scenarios in the Mono River Basin, Togo , West Africa', (June). doi: 10.23953/cloud.ijarsg.422.

26.   Tierney, L. (1994) 'Markov Chains for Exploring Posterior Distributions', The Annals of Statistics, 22(4), pp. 1701–1728. Available at: http://www.jstor.org/stable/2242477.