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Impact of Land use Dynamics on Runoff in the Agnéby Watershed, South-Eastern Ivory Coast

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Abstract-This research work appears to be useful for understanding phenomena such as the impact of land use dynamics on surface runoff from one period to another. Located in the south-east of Côte d'Ivoire, the Agnéby catchment area, with a surface area of 8640 km2, has undergone changes in its vegetation cover between the periods 1988-2020. These changes have resulted in the regression of dense forest with a loss of 53% to the benefit of crops and fallow land with a gain of 41%. Bare soil and water habitats have increased by 5% and 2% of the total area of the basin. During the same period, the annual retention capacity indexes fell from 162.08 in 1998 to 102.56 in 2020 with an annual regression rate of 0.38. On the other hand, the average annual runoff coefficients have increased from 12.80% to 23.77%. In the near and distant future, the Agnéby area will experience a form of degradation in view of its rapid economic growth, where there is no policy of sustainable management of natural resources. In this context, crops and fallow land and bare soil habitats will be dominant and will occupy proportions of 64.56% and 12.40% respectively in 2050 and 67.20% and 14.33% in 2080. For these same horizons, the retention capacity indices will be 94.48 and 90.51 in 2050 and 2080 respectively. The annual runoff coefficients will be 25.66 in 2050 and 26.70 in 2080. These different values of the retention capacity indices and runoff coefficients show that the basin has experienced and will experience a strong degradation under the scenario of rapid economic growth. Decision-makers and stakeholders in charge of territorial management must therefore take these results into account in their decision-making. The values of the runoff indices and coefficients show the total anthropisation of the Agnéby catchment area and the impact of the dynamics on the surface runoff in the near and distant future.

Keywords:- *Impact ;land use dynamics; runoff ;Agnéby watershed ;Ivory Coast*

I. INTRODUCTION

Combating land degradation is one of the major challenges facing humanity in the 21st century. It is mainly caused by human activities that tend to reduce the vegetation cover such as agriculture, logging, forest fires, livestock and mining [18].

Côte d'Ivoire is a country of 322,462 km2 located in West Africa. Since 1960, its development policy has been based on agriculture, with coffee and cocoa as the main cash crops. While this agricultural expansion has made Côte d'Ivoire the world's leading cocoa producer, it is also one of the countries in the world that is destroying the most forest resources, particularly the dense rainforest. This situation exposes the country to various threats, including biodiversity loss, land degradation and desertification, which are factors of poverty. In addition, population growth requires more agricultural land. This increases the pressure on the land, accelerating its degradation.

To avoid a catastrophic situation for the country, successive governments have carried out several planning processes that potentially contribute to sustainable development. These are mainly the development strategy based on the Millennium Development Goals (MDGs), the Poverty Reduction and Development Strategy (PRDS) and more recently the National Sustainable Development Strategy (NSSD) and the National Development Plan (NDP) (2012 - 2015).

In this context of land use, the Agnéby watershed suffered a degradation rate of about 2.01% between 1990 and 2002 [15]. Based on rainfall, the runoff recorded a hydrometric deficit of nearly 46% [14]. According to [4], there was a significant recovery in average flows from 1996, with a rainfall surplus of +7%, which resulted in a hydrological response of 149%. In the face of this problem, few scientific studies have highlighted the impact of terrestrial changes on surface runoff in this area.

The scientific understanding and changes at the origin of floods generally make it possible to assess their impact on the environment and to propose forms of development and protection that are better adapted to the natural environment.

To do this, Landsat TM, ETM+ and OLI satellite images were processed for the years 1988, 2002 and 2020. Then, we made predictions of land state changes with the Land change Modeler. Throughout this work, we will analyse the dynamics of land use and simulate future

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horizons in order to assess its potential impact on surface runoff.

II. SITE DESCRIPTION

The Agneby watershed is located in the south-east of Côte d'Ivoire, between the Bandama watershed to the west and the Comoé and Mé watersheds to the east (Fig. 1). The basin studied is part of the coastal basins of Côte d'Ivoire. It is located between latitudes -4°30' and -3°36' North on the one hand and between longitudes 5°24' W and 6°54' West on the other hand and covers an area of 8,640 km2. The economic activities of the Agnéby basin are quite 8/4 diversified, but agriculture remains the main income generating activity. It occupies the majority of the population. The agricultural dynamic is essentially based on perennial cash crops since the 1970s (coffee, cocoa, rubber, oil palm), food crops and market gardening. The agricultural system is evolving towards a much more intensive agriculture due to the scarcity of arable land. Food crops are grown for family consumption, the surplus is sold and they play a major role in agricultural activities. Rainfall in this area and therefore on the water bodies is about 1500 mm/year [1].

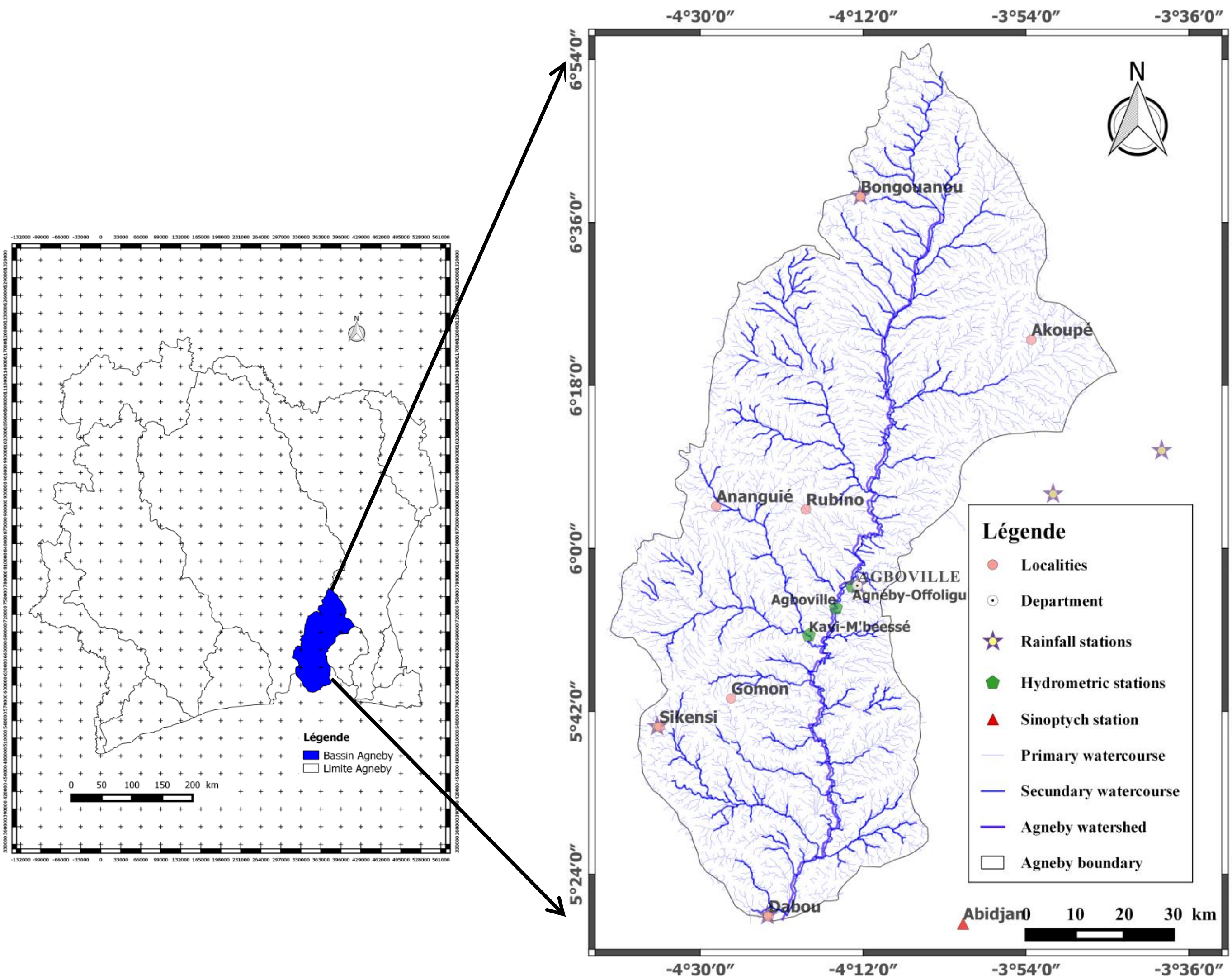

Fig. 1: Location of the Agnéby catchment area

III. DATA AND METHODS

A. DATA

The data used for this study are landsat images from 1988, 2002 and 2020 covering the Agnéby catchment area, which can be downloaded from http://earthplorer.ugs.gov/.

B. METHODS OF ANALYSING LAND COVER DYNAMICS ON PAST SURFACE FLOWS

Landscape dynamics can be studied through the analysis of land cover change [13]. From its acquisition to the production of a land cover map, a remote sensing image goes through a whole series of processes: from pre-processing to image analysis, through classification and post-classification [21].

a) Kappa index

The Kappa index (K) is an indicator of classification concordance [20]. It allows for a quantitative evaluation of the overall accuracy of a classification in relation to the ground truth. It can be calculated using the values provided by the confusion matrix [19] by applying equation 1 by [8]:

$$K=\frac{T\sum_{i=1}^{r}X_{ii}-\sum_{i=1}^{r}(M_i*N_i)}{T^2-\sum_{i=1}^{r}(M_i*N_i)} \qquad \text{Eq.1}$$

With
r: Number of classes in the confusion matrix
T: Total number of observations
Ni: Marginal total of row i
Mi: Marginal total of column i

b) STATISTICAL EVALUATION OF LAND USE DYNAMICS

This simple statistical analysis consists in calculating the rate of change observed on all classes of the whole landscape. The formula used is that of [11]. Authors such as [27] have used this formula in their studies of land cover change. The rate of change of a class between two dates [11] is expressed by the equation 2:

$$Tc = \left[\left(\frac{S_2}{S_1}\right)^{\frac{1}{(t_2-t_1)}} - 1\right] \qquad \text{Eq.2}$$

c) CALCULATION OF THE RATE OF CHANGE

The dynamics of each land cover category will be assessed by calculating the rate of change E (i, k) of land cover areas as follows

Let Si be the area of a land cover category in year i and Sk, that of a land cover category in year k, with k > i. E (i, k) will be equationto :

$$E_{(i,k)}= \frac{S_k-S_i}{S_i} \quad X \quad 100$$

Eq.3

If (i,) = 0, it is concluded that there is stability of this land use category;
If E (i, k) < 0, it is concluded that there is regression in this category;
If E (i, k) > 0, there is an extension or evolution of this category

C. METHODOLOGY ADOPTED FOR THE LAND COVER PREDICTIVE MODELLING PROCESS

The predictive model used here is the Land Change Modeler (LCM) implemented in the Terrset software (formerly Idrisi). This model was developed to study soil loss, project its dynamics into the future and assess its impact on biodiversity [10].

The first step is the creation of maps with the envi software, then for the application of the model it is necessary to convert these maps into output "rst" files in order to be able to integrate them into the LCM model. For this study the input data are the land use maps of 1988, 2002 and 2020.

To model land use for the year 2020, the model must first be validated on known land use data. The image of 2020 = t2 being the most recent will be used for a first test simulation, calibrated by two previous dates (t0 =1988 and t1 = 2002) Markov chain of order 2. The 1998 and 2002 images are used as a basis for extrapolating the quantities of the future date of land use. This is a linear extrapolation because the simulation is based on two points in time tocalibrate the model. The comparison between the simulated map and the observed map in 2020 will allow, on the one hand, to quantify the errors between the models, and on the other hand, to quantify the quantity of changes by the Markov matrix and the spatial distribution of changes by MLP.

Two scenarios have been developed to predict current trends in land use and change in order to facilitate decision-making. These are:

a) SCENARIO 1: RAPID ECONOMIC GROWTH (REC) "2050 AND 2080" DEFORESTATION

In this scenario, population and economic growth will be very high, resulting in increased environmental degradation. This is a pessimistic scenario, but very likely in this study area where there is currently no sustainable natural resource management policy. It is a scenario in which only the areas of crop mosaics and fallows and settlements will be increased significantly.

b) SCENARIO 2: COORDINATED ENVIRONMENTAL SUSTAINABILITY (CES) "2050 AND 2080" REFORESTATION

In this scenario, the government encourages forestry. It is a scenario in which government legislation and subsidies encourage the emergence of forestry (increased plantations and agroforestry) and the protection of wood resources by subsidising the price of gas to make it affordable for all households or by creating fuelwood plantations for people to exploit. In this scenario, the probabilities for crop and fallow land and degraded forest transformed into dense forest in 2050 and 2080 have been modified upwards in the transition matrix so as to protect (favour the persistence of) the tree and shrub cover still present.

The flowchart below summarises the three main steps in the application of the Land Change Modeler for prediction purposes (Fig.2).

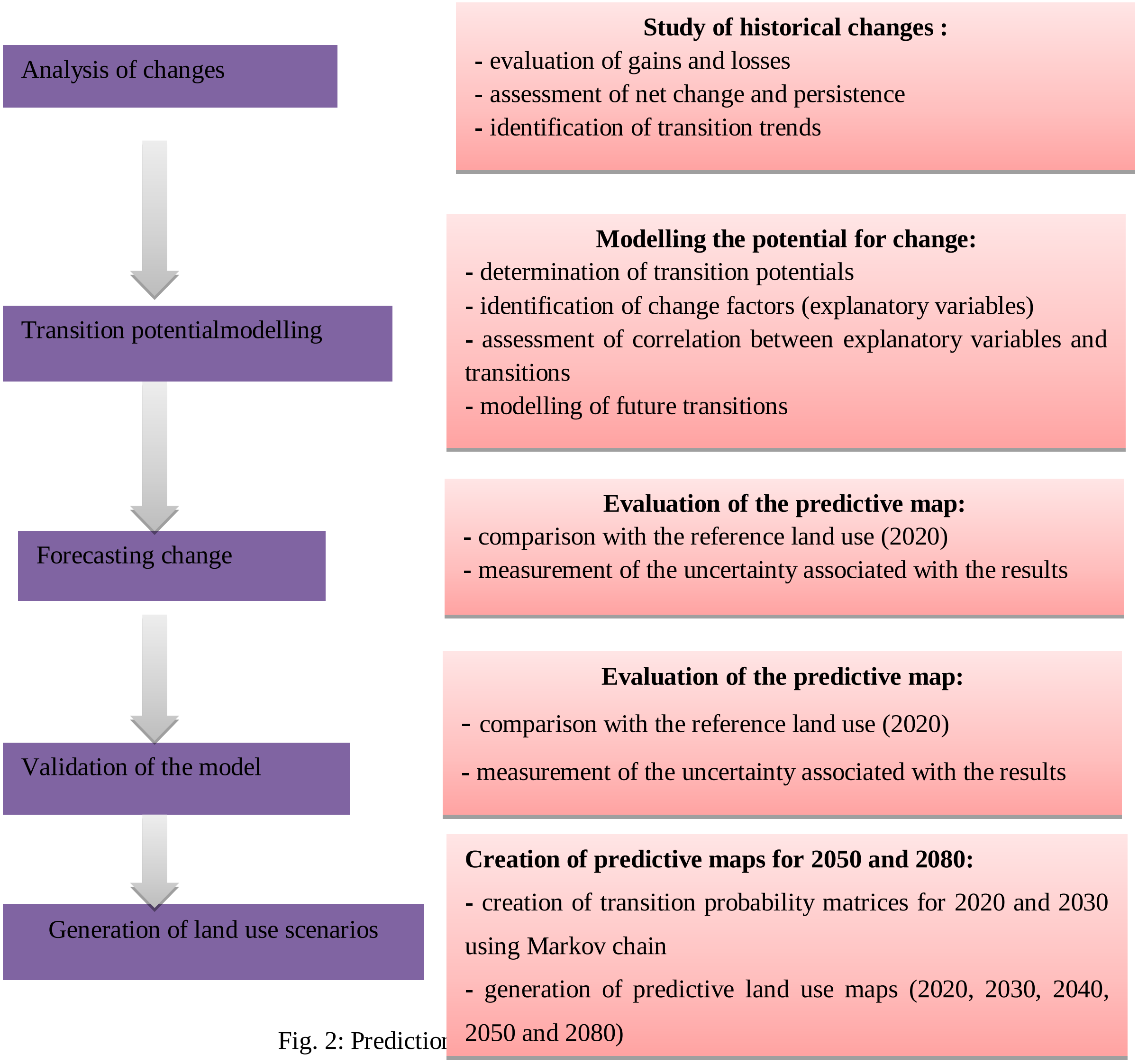

Fig. 2: Predictior

c) RELATION OF LAND USE DYNAMICS AND SURFACE RUNOFF

The formula applied by [7] and [24] has been applied for the impact assessment TABLE I equation 4:

$$RCI = \sum_i P_i \times A_i \qquad \text{Eq.4}$$

Pi: percentage of the study area occupied by land use class i;
Ai: weighting coefficient indicating the effective water retention capacity of land use class i;
RCI: annual retention capacity index.

Land use class	Ai
houses and bare ground	0
Degraded forest	1
Food crops and fallow land	1
Industrial crops: rubber and palm	1
Dense forest	2

Table 1: Retention capacity coefficient of the studied occupancy classes

d) EVALUATION OF THE RUNOFF COEFFICIENT
In the framework of this study, the formula of runoff coefficients established by some authors on experimental basins in Ivory Coast were taken into account (TABLEII).

Surface condition	*Study area*	*Arc (%)*	*References*
Savannah	Toumodi (Ivory Coast) Borotou (Ivory Coast) Sud du Burkina Faso	15 12-16 13	[9] [6] [12]
Natural forest	Adiopodoumé (Ivory Coast)	7,8	[22]
Cultivated area	Adiopodoumé South of Burkina Faso	24 20	[22] [12]
Fallow land	Adiopodoumé Borotou	28 22-42	[22] [6]
watershed	South and North of Burkina Faso	100	[12] [28]
High standard housing (large and medium) Popular housing	Yopougon (Ivory Coast) Yopougon (Ivory Coast)	25-30 70-80	[3]

Table 2: Average annual runoff coefficient by surface condition (Arc)

The average annual runoff coefficient of the catchment is then determined by the following formula equation 5:

$$\text{Arc}= \frac{\sum c_{ru} \times A_i}{\sum A_i} \qquad \text{Eq.5.}$$

With:
Cru: runoff coefficient of surface condition I;
Ai: area occupied by land use class i in the catchment;
Arc: average annual runoff coefficient of the catchment.

IV. RESULTS

A. DIACHRONIC ANALYSIS OF LAND USE ON THE AGNÉBY

The analysis of human activities in the Agnéby basin is presented in this section in order to show the dynamics of land use between the dates 1988 to 2002 and 2002 to 2020.

The different land use units resulting from the classification between 1988 and 2002, 2002 and 2020 show that the hierarchy of land use types has remained the same. However, we could observe changes in area between the different units.

Examination of the (Fig.3) shows that between 1988 and 2002, the dense forest portion of the unit experienced a remarkable regression. This regression was to the benefit of degraded forest, crop and fallow, water and bare soil and habitats units. From 2002 to 2020, the portions of the dense forest and degraded forest units also experienced very significant regressions, while the portions of crops and fallow land, water and bare soil and habitats experienced very remarkable progress in their portions of the basin. This strong degradation of the natural cover of the basin is explained by the fact that there has been a considerable extension of crops and fallow land in the area. It is important to note that human activities in 2020 occupy more than half of the total area of the basin with an almost total disappearance of natural resources.

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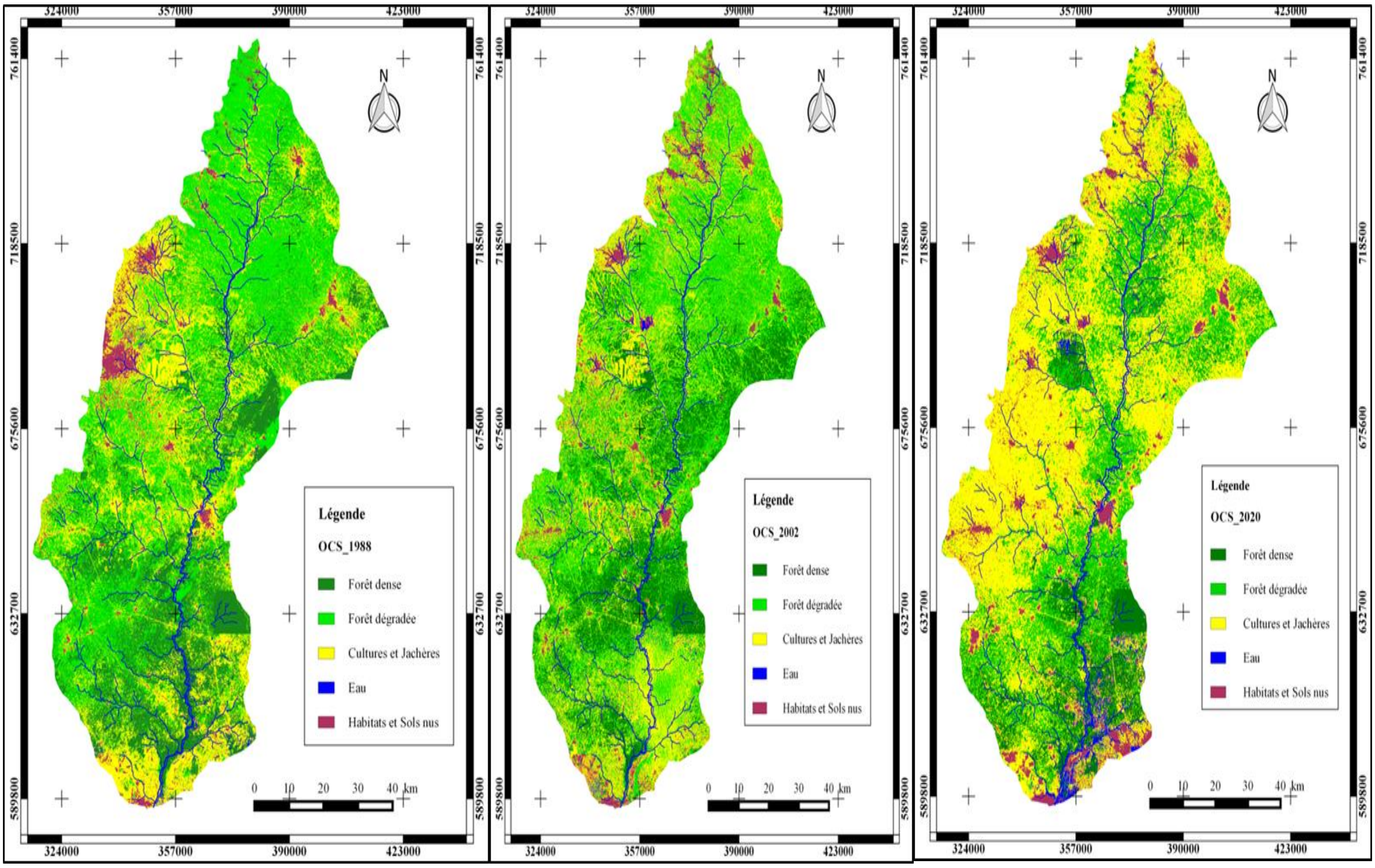

Fig. 3: Land use dynamics of the Agnéby catchment area between 1988 and 2020

The classification of land use units in 1988 shows that the Agnéby catchment area was dominated by dense forest with a surface area of 5559.84 km2, or a proportion of 64.35% of the total area. Degraded forest, crops and fallow land, water, and habitats and bare soil covered the respective areas of 1651.96 km2, 1232.09 km2, 28.51 Km2 and 167.6 Km2(TABLE III).

The variations in land use units between 1988 and 2002 showed increases and decreases in both units in 2002. Dense forest went from 5559.84 km2 in 1988 to 1780.79 km2 in 2002, i.e. a loss of 90.32% compared to its area in 1998. This regression resulted in a proportion of 20.61% and is explained by the accentuation of anthropic activities in the basin. Degraded forest, crops and fallow land, water and habitats and bare soil have increased in area from 1651.96 km2 to 3526.28 km2, 1232.09 km2 to 2792.26 km2, 28.51 km2 to 96.59 km2 and 167.6 km2 to 444.15 km2 respectively. The different progressions show an intensification of anthropic activities in the basin with gains of 113.46%, 126.62%, 238.79% and 165%

Finally, in 2020, the catchment area is dominated by crops and fallow land, water and habitats and bare soil, which have increased from 2792.26 km2 to 4765.47 km2, 96.59 km2 to 213.97 km2 and 443.83 km2 to 567.08 km2 respectively. These increases were 70.66%, 221.52% and 127.77%. As for the dense forest and degraded forest units, they experienced regressions of 778.21 km2 and 1435.63 km2 respectively.

	1988	***2002***	***2020***
Land useunits	Area (Km²)	Area(km²)	Area (Km²)
Dense forest	5559.84	1780.79	1002.58
Degradedforest	1651.96	3526.53	2090.9
Crops and fallow land	1232.09	2792.26	4765.47
Water	28.51	96.59	213.97
housing and barefloors	167.6	443.83	567.08

Table 3: Evolution of the surface areas in Km2 of soil changes in Agneby

B. ASSESSMENT OF THE DYNAMICS OF LAND USE IN THE AGNÉBY CATCHMENT AREA

Spatial and temporal dynamics are expressed in terms of regression, stability and progression of land use units (Fig.4).

- Stability: this refers to areas that have apparently not changed significantly, or at least have remained the same over the course of the different aerial photographs taken in 1988, 2002 and 2020. The analysis of the table showed that none of the units remained stable between 1988 and 2020 (Table 5).

- Regression refers to those portions that have been degraded or reduced in area. Only two orders of regression were observed in this study.

The first-order regression (R1) concerns units that have undergone very pronounced degradation (the dense forest of 1988 was transformed either into degraded forest or into crop and fallow land in 2002).

- The second-order regression (R2) concerns dense forest, degraded forest in 2002, which were transformed into crops and fallow land, habitats and bare soil or water in 2020. These two orders of regression show the impact of the different activities carried out by the populations on the environmental components.
- The progression concerns the portions that have evolved to become denser or more provided (in 2002 and 2020 compared to their state in 1988. Two orders of progression have been identified in this case, namely:
- The first-order progression (P1) concerns the large areas of dense forest in 1988 that were transformed into degraded forest with crops and fallow in 2002.
- The second order progression (P2) takes into account dense forest and degraded forest in 2002 transformed into either crops and fallow land, habitats and bare soil and water in 2020.

These different evolutions of the units allow us to understand the impact of human activities on the natural resources in this area (Fig.4).

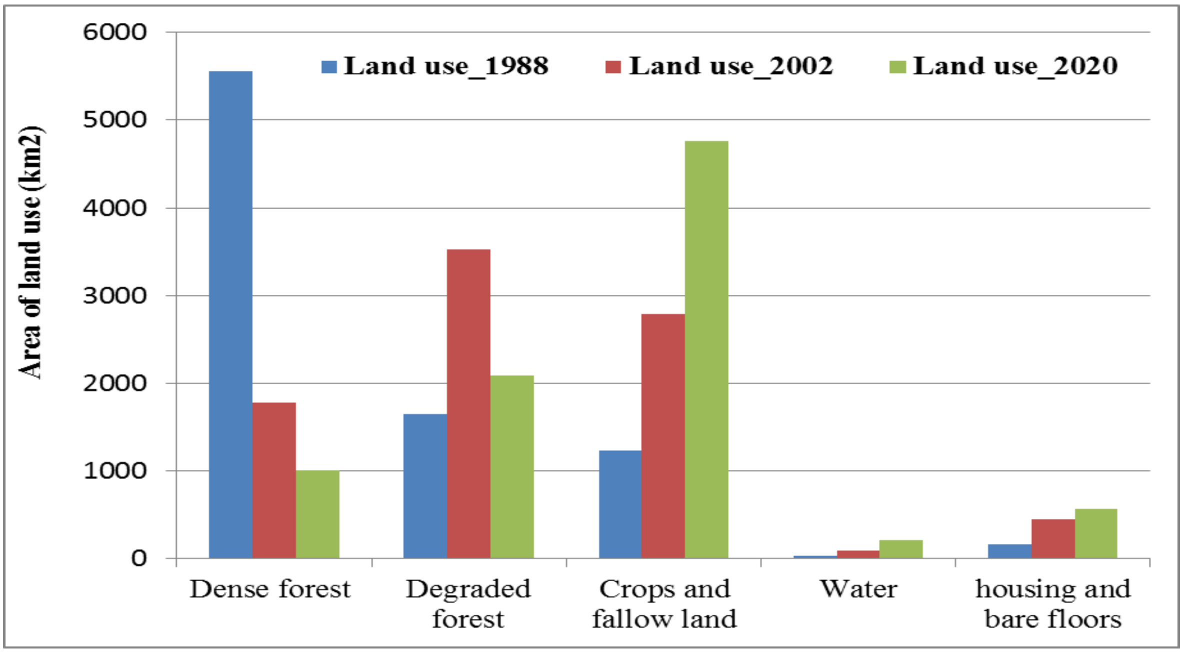

Fig. 4: Variation in the evolution of the land covers of Agnéby

In general, Fig. 5 shows that the cultivated areas of the basin are predominant and occupy almost 2/3 of the total area of the basin. Crops and fallow land, water and habitats and bare soil units increased in proportion from 14.26%, 0.33% and 1.94% in 1988 to 55.16%, 2.55% and 6.49% respectively.

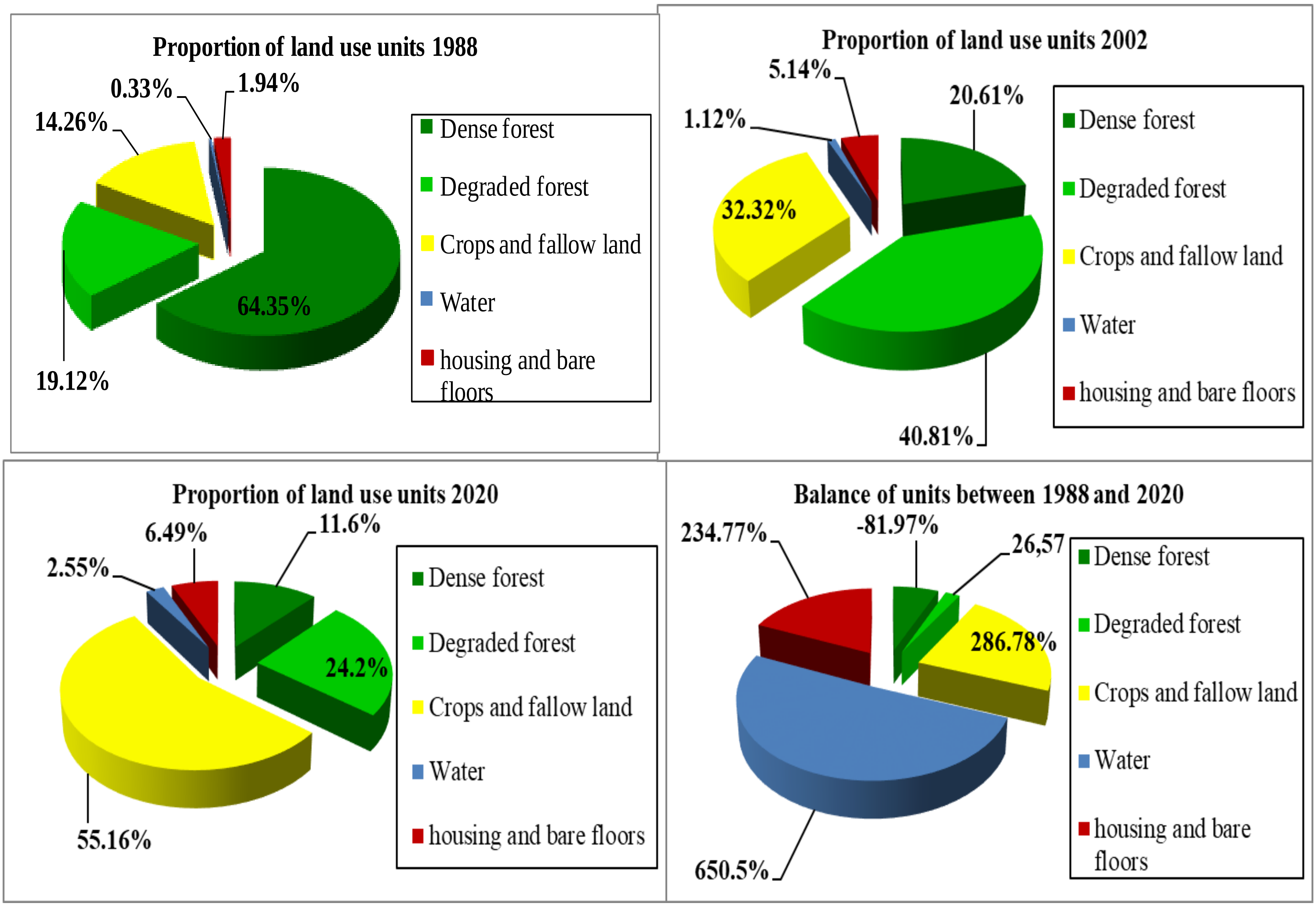

Fig. 5: Balance of land use units between 1988 and 2020

C. PREDICTION OF SIMULATED LAND USE IN 2020

The analysis in Fig.6 shows the results of the model calibration based on the two land use maps of 1988 and 2002 and the prediction of the 2020 land use map (Fig. 6ab).

The simulation of land use in 2020 shows regressions on the one hand and progressions on the other hand of the different units. The dense forest has experienced a regression of its area from 1002.58 km2 to 690.13 km2 in the observed and simulated images respectively. The degraded forest increased remarkably from 2090.9 km2 to 2431.32 km2. On the other hand, crop and fallow land units, water, and bare soil and habitats were stable in their simulations compared to the actual land cover map. The variations in area between the observed and simulated maps show the good calibration of the model by comparing the areas of the units in their progressions, stabilities and regressions (TABLE IV).

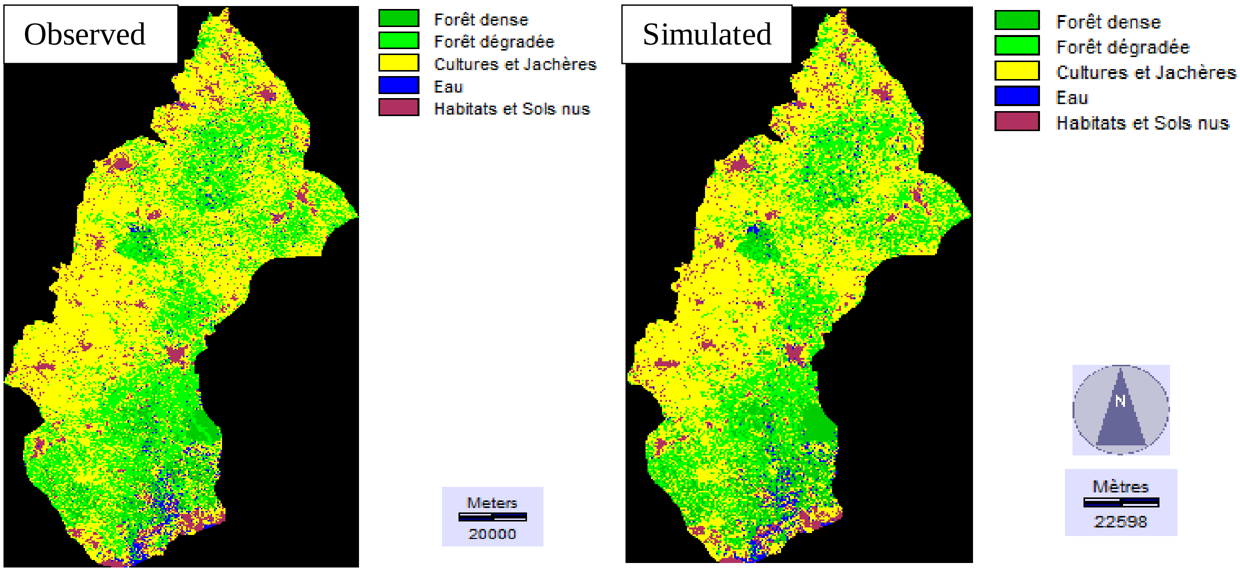

Fig. 6: a) Observed land use 2020 and b) Simulated land use

Land use units	*observed*	*simulated*
Dense forest	1002.58	662.16
Degraded forest	2090.9	2431.32
Crops and fallow land	4765.47	4765.47
Water	213.97	213.97
housing and bare floors	567.08	567.08
Total	8640	8640

Table 4: Area of land use units realised and simulated from 2020

D. PREDICTION OF LAND USE MAPS FOR 2050 AND 2080

a) SCENARIO 1: RAPID ECONOMIC GROWTH (REC) "2050 AND 2080" DEFORESTATION SHORT AND LONG TERM LAND COVER MODELLING PROJECTION

Over the periods of the land-use modelling considered, examination of Fig.7 shows gains and losses between the different projected land-use units. The land use types will remain the same during our different simulations. Under the scenario of rapid economic growth (deforestation), a general remark can be made regarding the dominance of certain units (crop/fallow and habitat and bare soil) in the 2050 and 2080 horizons. Dense forest mosaics will shift to degraded forest, degraded forest to crop/fallow and crop/fallow to habitat/bare ground. As far as the water unit is concerned, it will remain the same and none of the land-use types will be transferred to it. This is a pessimistic scenario, but very likely in the study area where there is no sustainable natural resource management policy. The dominance of crops/ fallow land and habitats/bare soil will show that no land use regulations will be put in place for the protection and sustainable development policy that the Agnéby area will be very much antrhoped for by human activities dominated by these changes in the surface areas of the units show an amplification of human activities in the area with an extension of anthropogenic activities in the area. The maps in 2050 and 2080 show that crops/fallow will occupy more than half of the total area of the basin with an almost total disappearance of the dense and degraded forest.

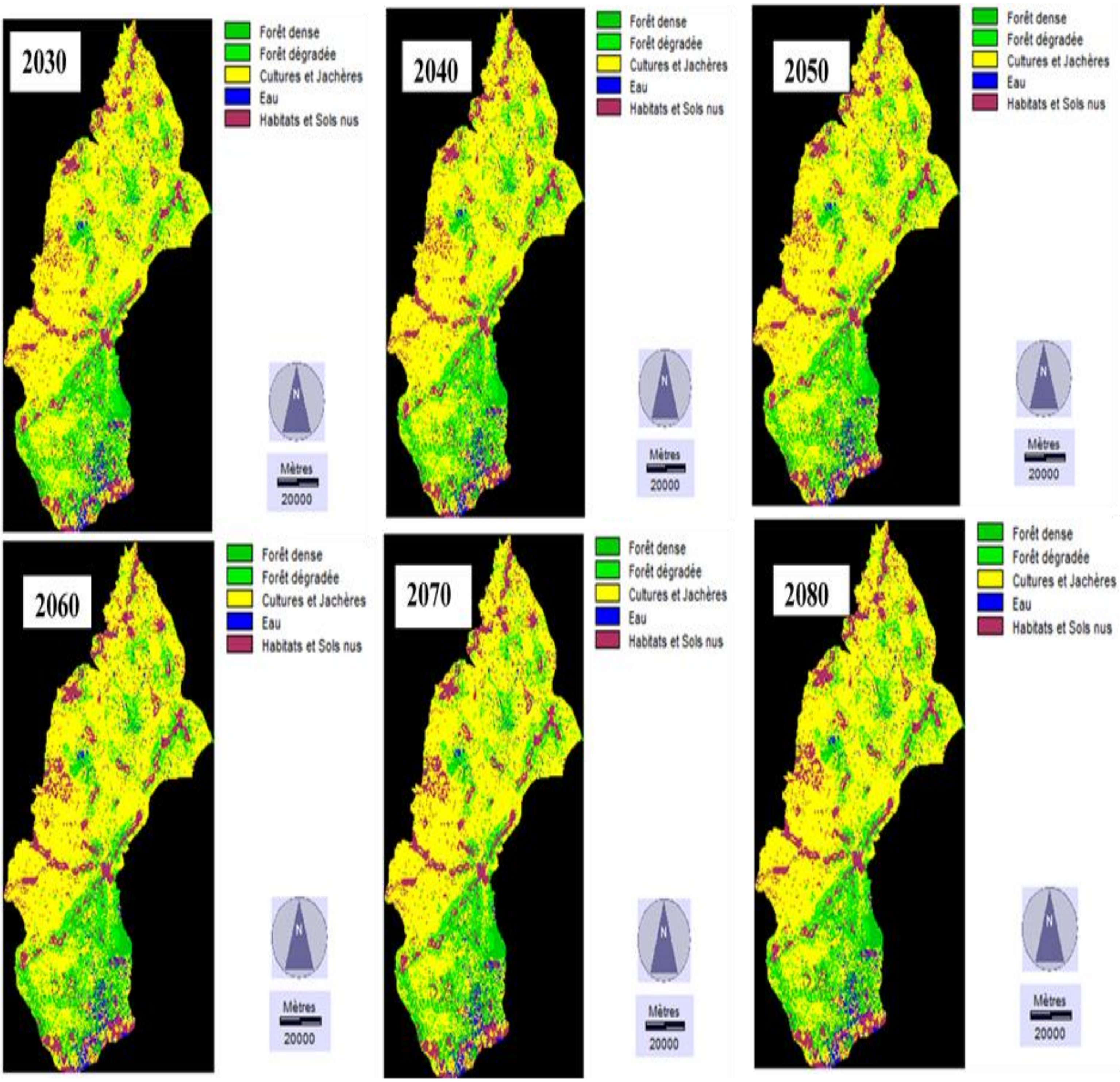

Fig. 7: Prediction of land use changes

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b) ANALYSIS OF THE LAND USE DYNAMICS MODELLED ON THE AGNÉBY SCENARIO 1

Fig.8 shows that the simulation of land use shows that there will be a continuous increase in crop/fallow and habitat/bare land, while dense forest and degraded forest will disappear in our study area.

In the year 2030, the areas of dense forest and degraded forest will be 906.13 km2 and 1196.66 km2 respectively. The areas of crops/ fallow land and habitats/bare land will be 5480.18 km2 and 960.42 km2 respectively. The water resource area will be 96.61 km2 and will remain stable in the short and long term under the deforestation scenario.

Between 2030 and 2040, dense forest will lose 14.85% of its area to forest, crop/ fallow land and habitats/bare land. These three units will experience gains of 0.08% (degraded forest), 0.09% (crop/fallow) and 0.07% (habitat/bare ground) compared to their areas in 2030.

In 2050, the two units of crops/fallow and habitats/bare ground will have respective gains of 1.79% and 11.54% compared to their areas in 2030. Dense forest and degraded forest will lose 2.38% and 0.05% respectively.

Between 2050 and 2060, losses will be more pronounced with 4.12% for dense forest and 8.36% for degraded forest. Crops/ fallow land and habitats/bare land will experience gains of 1.37% and 4.87% in their areas. During the period 2070-2080, the areas of dense forest and degraded forest will record losses of 1.78% and 6.40%. During the same periods, crop/ fallow land and soil habitats will gain 1.67% and 7.22% respectively.

In the Rapid Economic Growth (REC) scenario, crop/fallow mosaics and bare soil habitats will change considerably (exaggerated) during the 2050 and 2080 time horizons. According to our scenario, crop/fallow and bare soil/habitat will occupy 64.56% and 12.40% respectively in 2050. In the same scenario of rapid growth 2080 the percentages will increase to 67.20% for crops/ fallow land and 14.33% for habitats/bare land. These different values of rapid growth of crops/fallow and habitats/bare soils will once again testify to the anthropisation of the Agneby catchment in the short and long term horizons. The consequence is a more accentuated regression of natural vegetation formations.

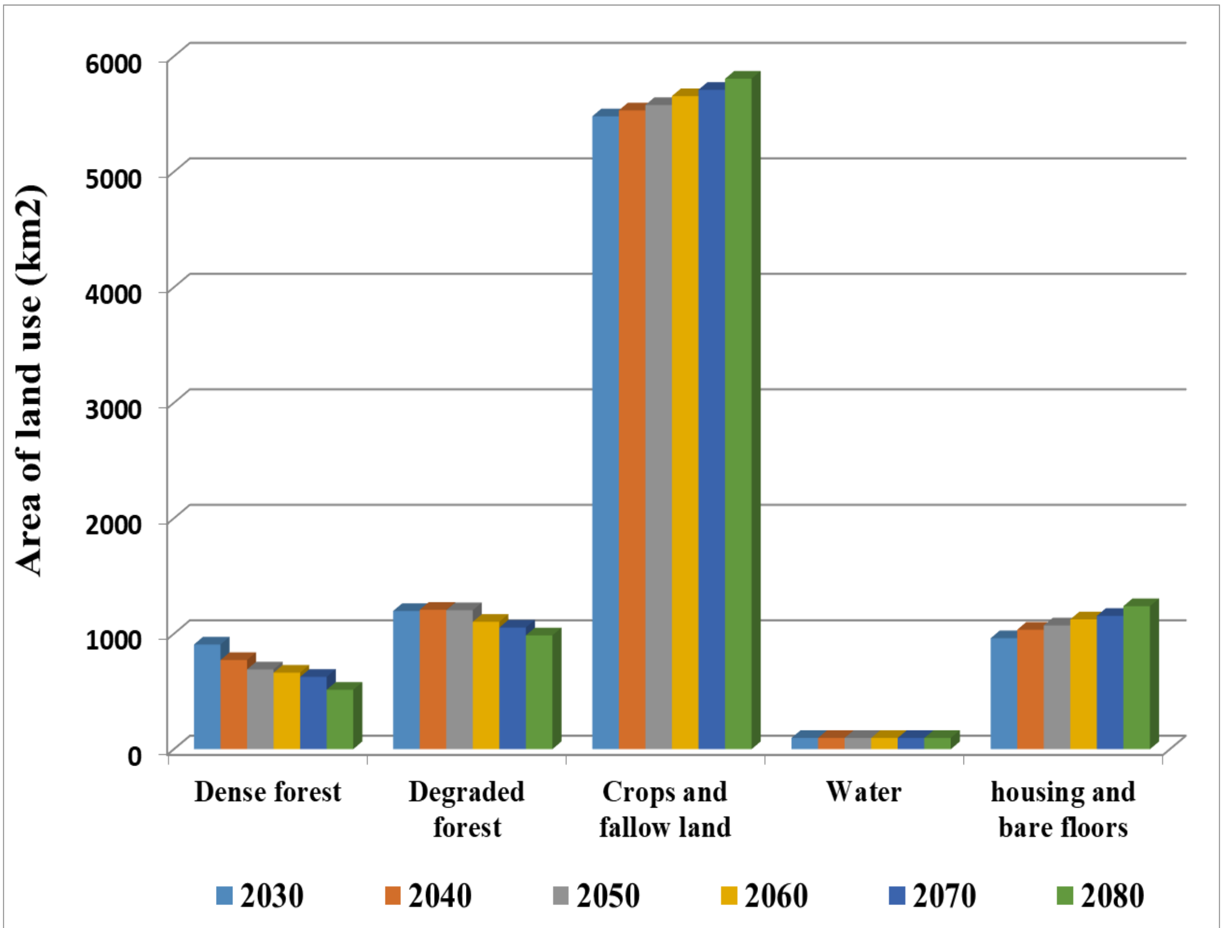

Fig. 8: Deforestation scenario in the Agnéby basin at 2050 and 2080

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E. SCENARIO 2: COORDINATED ENVIRONMENTAL SUSTAINABILITY (CES) '2050 AND 2080' REFORESTATION

In the Coordinated Environmental Sustainability (CES) scenario, we have assumed that land use is regulated by an environmental protection policy in the Agneby catchment during the periods 2030-2040, 2040-2050, 2050-2060, 2060-2070 and 2070-2080.

Examination of Fig.9 under this scenario over the different modelled periods will show a significant increase in dense forest while crop/fallow and degraded forest rates will decline in the study area. Crop/fallow mosaics will shift to degraded forest and degraded forest will shift to dense forest in this environmental protection scenario.

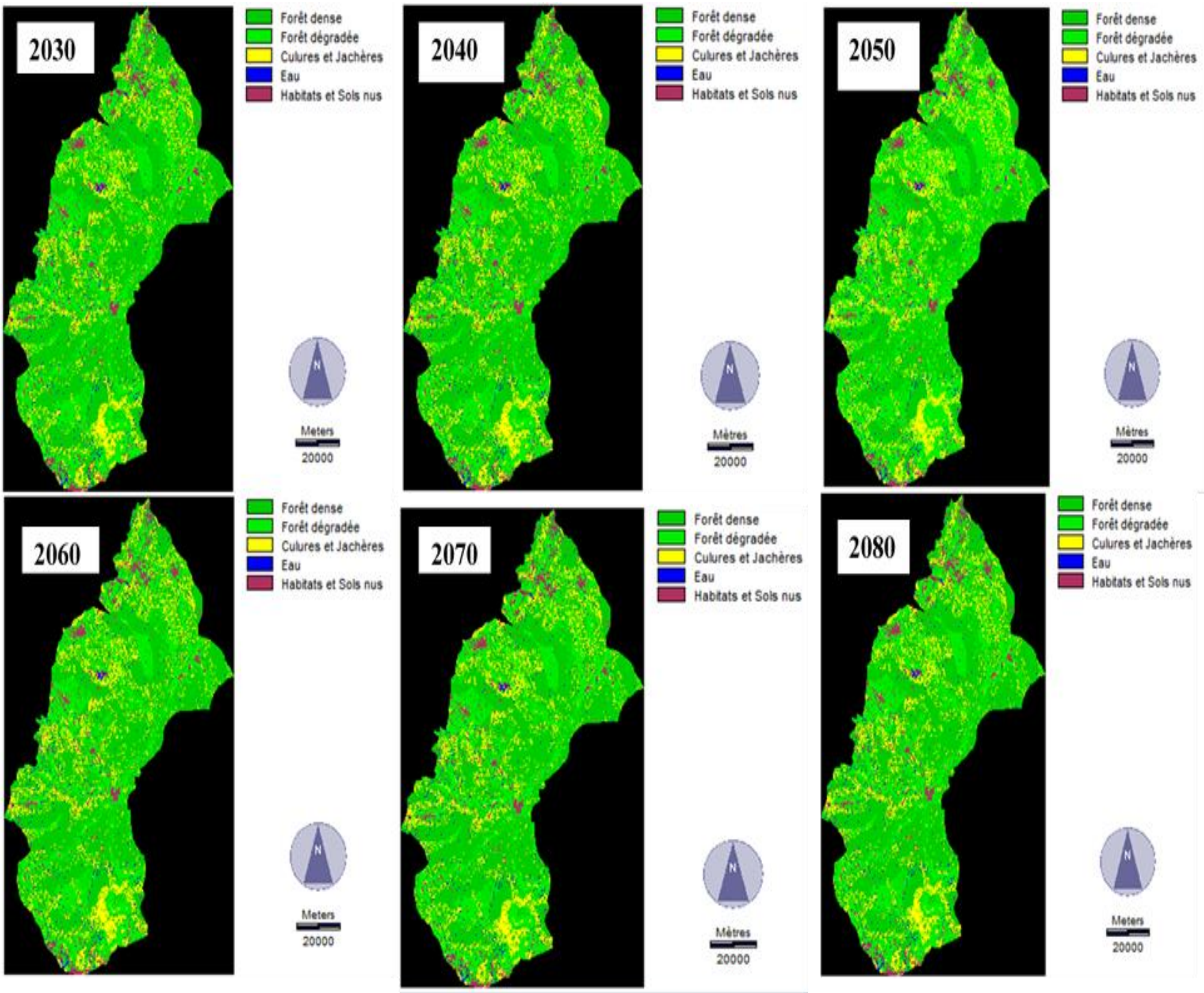

Fig. 9: Prediction of land use changes

F. ANALYSIS OF MODELLED LAND USE DYNAMICS ON THE AGNEBY (DEC) SCENARIO 2

The analysis in Fig.10 shows a progression of the dense forest over all simulated periods. In 2030, dense forest will occupy an area of 4843.1 km2 and degraded forest, crop/ fallow, water and baitat/bare soil units will occupy areas of 1878.11 km2, 1260.5 km2, 213.97 km2 and 444.32 km2 respectively.

Between the period 2030-2040 the growth rates for dense forest will be 2.84% and 1.21% for degraded forest. During the same period, crops and fallow land will lose 1.27% of their area compared to 2030. From 2040 to 2050, the dense forest will gain 3.46%, while crops/fallow and dense forest will lose 9.27% and 3.72% of their area respectively.

Over the period 2050-2060, the dynamic still shows an increase of 6.89% in its area and the crop/fallow and degraded forest will show regressions of 16.17% and 10.60% respectively.

Considering the long term simulation, the period 2070-2080 will show an extension of the dense forest in the basin with a gain of 1.97% and the crops/fields and the degraded

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forest will be disappearing with respective decreases of 2.96% and 7.15% of their area.

Finally, in the Coordinated Environmental Sustainability (CES) scenario "Reforestation", by 2050, dense forest and degraded forest will occupy 59.64% and 21.18% of the land area respectively, while crops and fallow land will occupy 11.55%. In the same reforestation simulation in the long term (2080), the rate of coverage of the watershed by dense forest is 67.66% and crops and fallow and degraded forest will occupy respective rates of 6.08% and 18.64%. This shows that the environmental protection policy will play a positive role in the conservation of natural resources. The habitat/bare soil and water mosaics will be stable in their evolution as none of the three units will shift to these two land use types

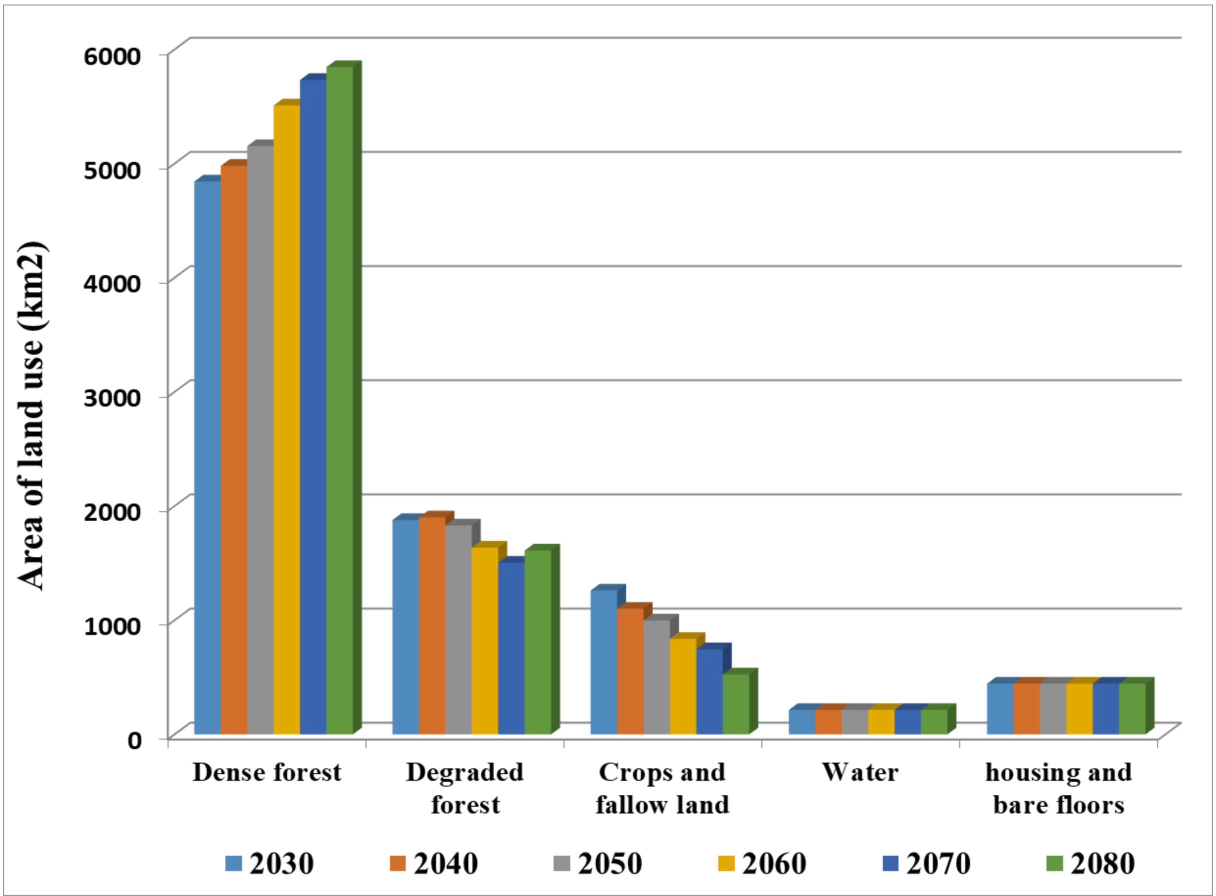

Fig. 10: Reforestation scenario in the Agnéby basin for 2050 and 2080

a) VISUAL COMPARISON OF CHANGE SIMULATIONS DEFORESTATION AND REFORESTATION

Comparing the scenarios of rapid population growth (Deforestation) and coordinated economic sustainability (Reforestation), it can be seen that in both scenarios, the deforestation scenario (CER) will be the higher in the 2050 horizons with a land cover of 64.56% against 59.64% for the coordinated economic sustainability scenario (DEC). For the 2080 time horizons, the reforestation scenario will dominate the basin area with a land cover of 67.65% versus 67.19%. It is important to note that this dominance will not be very significant between these two scenarios. The fundamental remark here between these two scenarios is that in the 2050 and 2080 horizons, the reforestation scenario of the water unit remains superior to the deforestation scenario with rates of 2.47% against 1.18% (Fig 11).

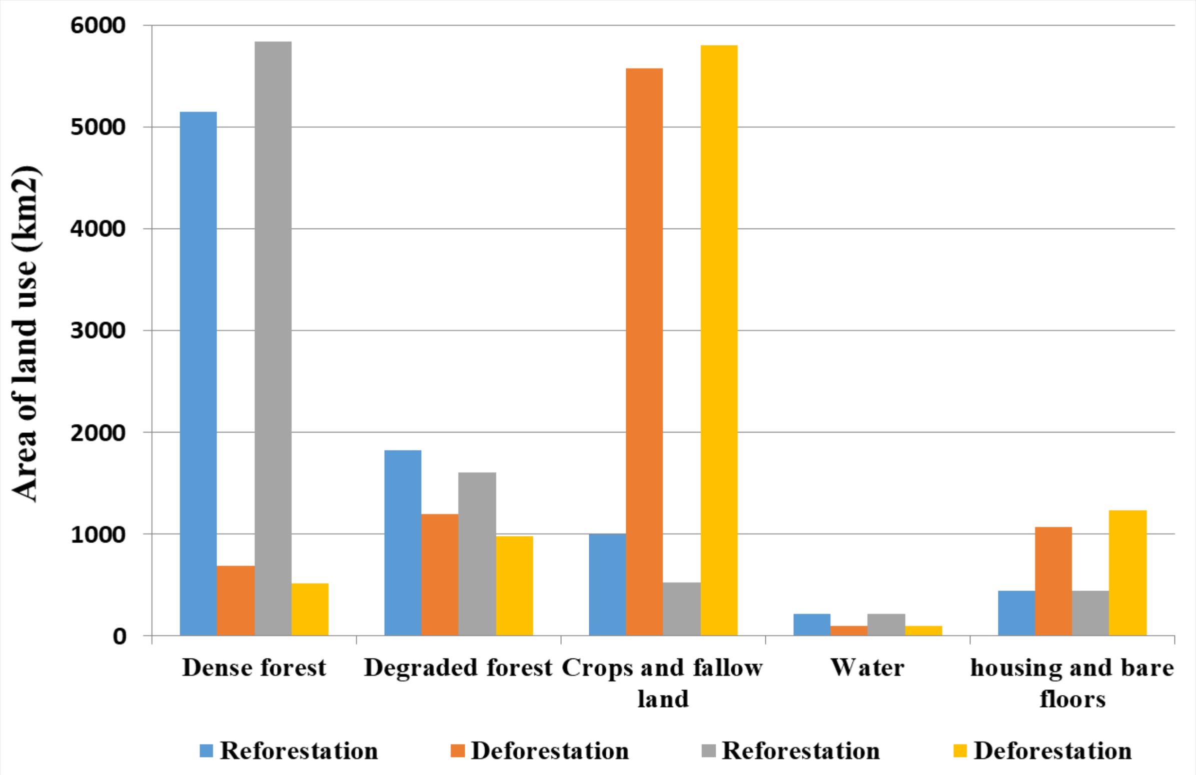

Fig. 11: Simulation of deforestation and reforestation scenarios in 2050 and 2080

G. *IMPACT OF LAND USE ON RUNOFF IN RELATION TO RETENTION CAPACITY INDICES AND PAST AND FUTURE RUNOFF COEFFICIENT*

a) Scenario 1: Rapid Economic Growth (REC) "2050 and 2080" deforestation

The analysis of Fg.12 highlights the impact of land use dynamics on the surface runoff of the Agnéby catchment area. In general, a regression of the retention capacity indices and an amplification of the runoff coefficients can be observed between 1988 and 2020 and during the 2050 and 2080 horizons.

From 1988 to 2020 the runoff coefficients have registered an annual progression rate of 2.59% and the annual retention capacity indices have regressed by 1.11. For the simulations carried out in the 2050 and 2080 horizons, the runoff coefficients will show progressive annual rates of 0.14% between the 2030-2050 period and 0.13% for the 2060-2080 period. As for the annual retention capacity indices, the simulation period 2030-2050 will show losses in the order of 3.8 and the loss in the period 2060-2080 will be in the order of 3.24. These different results of the percentages of the runoff coefficient and the values of the retention capacity indices in the past and the horizons 2050 and 2050 show the impacts of the modifications of the surface state on the surface runoff in the Agnéby area.

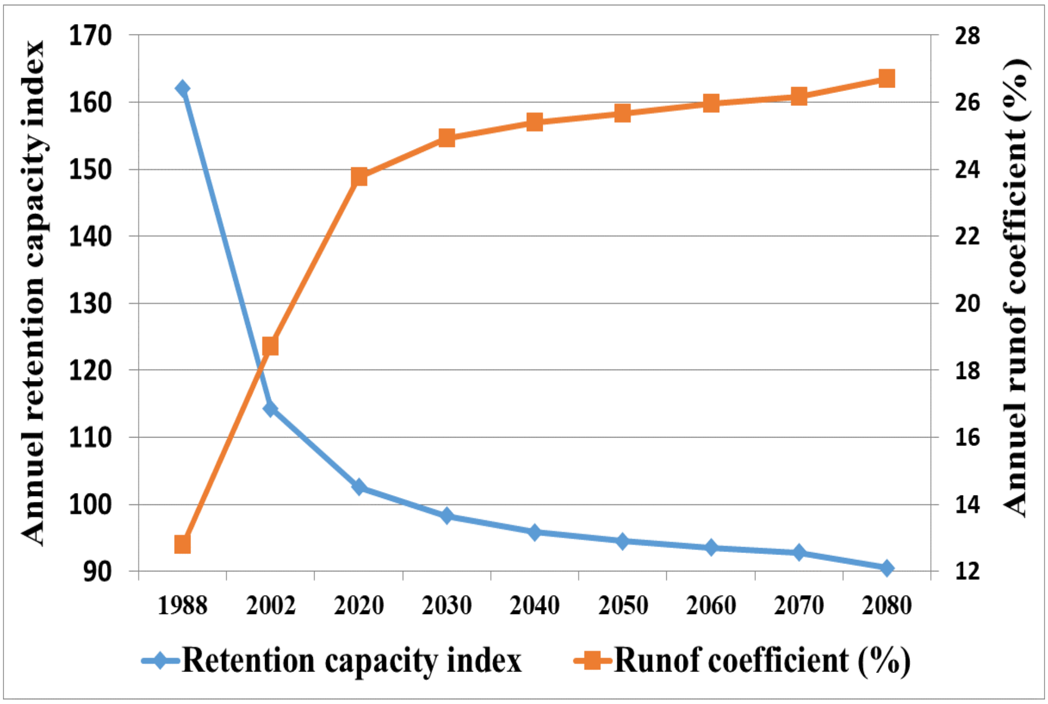

Fig. 12: Impact of land use dynamics on surface runoff.

H. IMPORTANCE OF LAND USE ON SURFACE RUNOFF IN RELATION TO RETENTION CAPACITY INDICES AND RUNOFF COEFFICIENTS

b) SCENARIO 2: COORDINATED ENVIRONMENTAL SUSTAINABILITY (CES) "2050 AND 2080" REFORESTATION
Under the coordinated environmental sustainability scenario, the simulated horizons show increases in the retention capacity indices and decreases in the runoff coefficients (Fig.13).

From 1988 to 2020, we observe an annual regression of the retention capacity from 162.08 to 102.56, i.e. a regression rate of about 0.10. According to our scenario 2, there will be an increase in annual retention capacity in the 2050 and 2080 horizons. Over the period 2030-2050 the annual retention capacities will be 148.43 and 152.02, i.e. an evolution rate of 0.024. In this same context of evolution, the 2060 and 2080 horizons will record retention indices of 156.14 and 160.03, i.e. an evolution rate of 0.025. As for the runoff coefficients, the years 1988 and 2020 recorded respective percentages of 12.80% and 23.77%, i.e. an evolution rate of 85.71%. During the simulated periods in the context of land use regulation, the runoff coefficients will experience an accentuated decrease between the period 2020-2030 which will be estimated at a rate of 31.01%. For the period 2030 to 2050 this rate of decline will be estimated at 1.60%. Considering the long-term projections, the simulations for the 2060 and 2080 horizons will give respective percentages of 15.38% and 14.77%, i.e. a regression rate of 3.95%. Finally, according to the reforestation scenario, the Agnéby watershed will have a high retention capacity for surface runoff and a low runoff coefficient in the 2050 and 2080 horizons. These values show the importance of vegetation cover on the sustainability of surface water in the study area.

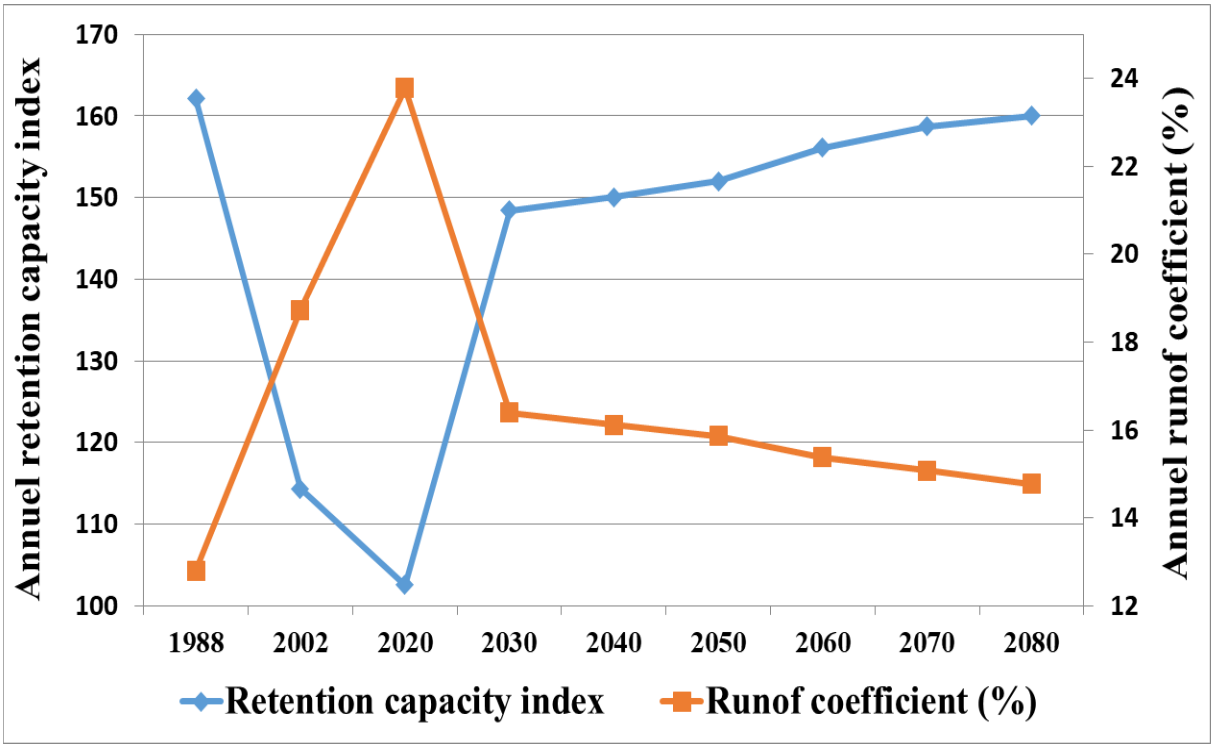

Fig. 13: Importance of coordinated environmental sustainability on surface flows

V. DISCUSSION

The results of the Landsat satellite image classifications obtained showed overall accuracies of 89.71%, 83.16% and 91.03% with kappa indices of 84.84%, 81.94% and 87.92%. These percentages show the reliability and acceptability of our different map treatments according to land use types. These results of the global accuracy of our analysis are in line with those obtained by some authors, notably [15] and [19], who obtained respective global cartographic accuracies of 97.83% and 87% by classifying satellite images covering the Agnéby and Boubo watersheds as well as the Bouaflé classified forest in the south-east and centre-east of Côte d'Ivoire.

From 1988 to 2002, the variations in land use units showed increases and decreases on both sides. The area of dense forest went from 5559.84 km2 in 1988 to 1780.79 km2 in 2002, i.e. a loss of 67.97% compared to the area in 1998. This regression, estimated at 20.61%, can be explained by the increase in human activities in the basin. Degraded forest, crops and fallow land, water and habitats and bare soil have increased in area from 1,651.96 km2 to 3,526.28 km2, 1,232.09 km2 to 2,792.26 km2, 28.51 km2 to 96.59 km2 and 167.6 km2 to 444.15 km2 respectively. The progressions of these units show an intensification of anthropic activities in the basin with gains of 113.46% (degraded forest), 126.62% (crops and fallow land), 238.79% (water) and 165% (habitats and bare soil). As for the type of water land use, the percentage indicates a rate of about 2.47% of the total area of the basin in 2020. These results show a 53% disappearance rate of dense forest between the period 1988 and 2020 and a 41% gain in the area of crops and fallow land. This study confirms that the rate of change in the surface condition of the Agnéby basin towards crops and fallow land and bare soil/habitats between the period 1988-2020 is increasing. These results are in agreement with those observed by [16], [5] and [2]. These authors explain this change by an increased development of land over large areas with a shift from subsistence peasant agriculture to a production economy for the world market. Food crops such as cassava and plantain are also affected by this extensive agriculture. Also, a very important development of market gardening in the study area, especially in the vicinity of water reservoirs, is observed. The annual retention capacity index fell from 162.08 in 1988 to 114.35 in 2002. Over the period 2002 to 2020 this annual index has decreased from 114.35 to 102.56. In the same context, the runoff coefficients increased from 12.80% in 1988 to 18.73% in 2002. From 2002 to 2020 it shows an annual increase from 18.73% to 23.77%. This amplification of annual coefficients shows the disappearance of dense forest and degraded forest in the area to the benefit of crops and fallow land as well as habitats and bare soil. Indeed, the Agnéby region is experiencing strong land pressure due to the massive presence of immigrants from the Ivorian savannah and neighbouring countries attracted by employment or agricultural exploitation of coffee-cocoa and more recently, rubber and oil palm. These results show an amplification of anthropic activities and highlight the impact of socio-economic activities on surface runoff in the Agnéby watershed. These results are consistent with the work carried out by [23] and [4] in central and south-eastern Côte d'Ivoire, which showed runoff coefficients of between 31.81% and 40.65% in the Yamoussoukro area, and an average interannualhydroclimatic coefficient of 60% in the Agnéby watershed.

The results of the simulations for the 2050 and 2080 time horizons show the almost total disappearance of dense crop/fallow forest and bare soil habitats. Crops and fallow land and bare soil habitats will be dominant in the basin. In

2030, the change in surface condition shows that crop/fallow and soil habitats will occupy areas of 5480.18 km2 and 960.42 km2 respectively. The areas of dense forest and degraded forest types will be 906.13 km2 and 1196.66 km2 respectively. By 2050, crops/fallow and habitats/bare land will occupy 64.56% and 12.40% of the total area of the basin respectively. During the same period, dense forest will lose 23.78% of its area in 2030 and degraded forest will gain 0.54%. It is further shown that the anthropogenic causes of the change in surface condition, namely overexploitation of natural resources, are determined by population growth, demographic changes, economic development and governance structures and institutions, as well as the various interactions between these factors.

For the 2080 horizon, crops/ fallow land and habitats/bare land will increase in area with respective percentages of 67.20% and 14.33% of the total basin area. The percentages of dense forest and degraded forest areas will be 5.95% and 11.40% respectively. According to [17], the change in land use can be seen as a cause of environmental degradation, or be interpreted as a consequence of stresses such as negative rainfall trends, inadequate agricultural policy and the need to increase production to cope with rapid economic growth. It is important to note here that the different prospective scenarios take into account the different anthropic and socio-economic activities developed in the study area in the past. Overall, the evolutionary trend of the vegetation formations in the Agnéby area will be regressive and that of the anthropogenic formations will evolve progressively in the horizons 2050 and 2080. The increase in land use can be explained by the increase in crop/ fallow land and habitats/soil with a view to the disappearance of dense and degraded forest. These results are consistent with those of [26] who found with the Clue's model in the central region of Benin a significant loss of dense forest area to crops and fallow by 2025. The present forecast results are also in the same order of disappearance of the natural resource (dense forest) as those observed by [25] who showed the scenario of rapid economic growth (REC) as a catastrophic scenario which will make natural vegetation formations disappear in favour of anthropogenic ones by 2034.

The annual retention indices will decrease under the deforestation scenario. In 2030 the retention capacity of the basin will be 98.25, while in 2040 it will be 95.84, a regression rate of 2.45. Between the period 2040-2050 the retention capacity will be 94.48 which again shows a regression of 1.42. From the period 2030-2050 the annual retention capacity of the basin will be regressed by 3.84. For the horizons 2060, 2070 and 2080 the retention indices will be 93.54, 92.76 and 90.51 respectively. The regression rate between the period 2060-2070 will be evaluated annually at 0.83 and between the period 2060-2080 this annual rate will be evaluated at about 3.24. Taking into account our different simulations, these annual regressions of the retention indices at the 2050 and 2080 horizons show a threat to the water resources of the Agneby catchment area and the impact of anthropogenic activities on the vegetation cover. For the simulation in 2030 the runoff coefficient will be 24.93% while in 2040 it will increase to 25.40, i.e. an annual evolution rate of 1.86%. In 2050 the annual percentage will be 25.66% while the evolution rate over the period 2030-2050 will increase to an annual rate of 2.93%. During the horizons 2060 and 2070 the runoff coefficients will be respectively 25.97% and 26.18, i.e. an annual progression rate of about 0.79%. For the period 2080 the runoff coefficient will evolve to 26.70%. For the period 2060-2080 the annual progression coefficient will be 2.80%. Finally we can conclude that during the horizons 2050 and 2080 according to the scenario of fast demographic growth the water resource of the basin will be impacted by the modification of the surface state. The different values of the coefficients show the impacts of human activities on the surface runoff of the Agnéby basin in the short and long term. These results confirm the impact of future dynamics on surface flows in the south-eastern part of Côte d'Ivoire.

VI. CONCLUSION

The objective of this study is to analyse the impact of the dynamics of land use on the hydrological functioning of the Agnéby catchment. The methodological approaches used in this study have made it possible to understand the past and to show the future of this territory in the 2050 and 2080 horizons. Overall, this environment has seen its natural vegetation formation, notably dense forests, disappear to the benefit of anthropic activities such as crops and fallow land, and habitats and soils. During the period 1988-2020. The results of the dynamics revealed that in 1988, the dense forest regressed by 53% of its area, while crops and fallow land expanded with a gain of 41%. The retention capacity indexes had a regressive annual rate of 0.36, while the runoff coefficients had increased by 85.71%. This strong degradation of the dense forest is an important factor of soil fragility and favours surface runoff. Then for the simulation we have retained that according to our scenario of fast demographic growth "deforestation", the surface of crops and fallow lands and the bare soil habitats will be in increase during the horizon with respective percentages of 64,56% and 12,40%. The rention capacity indices will decrease by 3.84% compared to the period 2030. As for the runoff coefficient, the rate of progression will be evaluated at around 2.93% with an annual progressive rate of 0.14% over the period 2030-2050. For the 2080 horizon, crops and fallow land and soil habitats will be 67.19% and 14.32% respectively. Retention capacity indices will once again decrease by 3.24% between 2060 and 2080, while runoff coefficients will increase by 2.80%. This landscape on which the survival of the population depends will evolve in the direction of degradation. Decision-makers and actors in charge of territorial management must therefore take these results into account in their decision-making. The values of the indices and coefficients of runoff show the total anthropisation of the Agnéby catchment area and the impact of the dynamics on the surface runoff in the near and distant future.

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REFERENCES

[1.] Ahoussi K., (2008).Quantitative and qualitative evaluation of water resources in the south of the Ivory Coast.Application of hydrochemistry and environmental isotopes to the study of continuous and discontinuous aquifers in the Abidjan-Agboville region.Doctoral thesis of the University of Cocody-Abidjan, 256 p.
[2.] Ambroise, B., (1999). La dynamique du cycle de l'eau dans un bassin versant. Processus, facteurs, modèles. Editions HGA, Bucarest, 1999. 195 p..
[3.] Bouvier C., Berthelot M., Janeau J. L., (1987). Rainfall simulation campaign in an urban environment, Yopougon.ORSTOM-CIEH, 16p.
[4.] Brahima K., Dao A., Fadika V., Noufé D., et Kamagaté B. (2019). Effect of Rainfall Variability on Surface Runoff in the Agnéby Watershed of South-Eastern Côte d'Ivoire. European Scientific Journal September 2019 edition Vol.15, No.27 ISSN: 1857 - 7881 (Print) e - ISSN 1857- 7431.
[5.] Brou Y. T., (2005). Climat, mutations socio-économiques et paysages en Côte d'Ivoire. Mémoire de l'Habilitation à Diriger des Recherches, Université des Sciences et Technologies de Lille, France, 226 p
[6.] Brou K., (1985). Gauging on large rivers in Borotou, Simulation of rainfall, internship report, hydrology laboratory, ORSTOM, AdiopodoumeCenter (Ivory Coast), 44p.
[7.] Cecchi P., Gourdin F., Kone S., Corbin D., Etienne J., &Casenave A., (2009a). Small dams in northern Côte d'Ivoire: Inventory and hydrological potential. Sécheresse, 20, (1), 112-122.
[8.] Congalton, R. G. (1991). A revieuw of assessing the accuracy of classifications of remotely sensed data', Remote Sensing of Environment, 37(1), pp. 34–46.
[9.] Dubreuil P. (1960). Hydrological study of small watersheds in Ivory Coast, general report, savannah zone, 169p.
[10.] Eastman J.R., (2006). IDRISI Andes. Guide to GIS and Image Processing, Worcester.
[11.] FAO (1996). Forest resources assessment 1990.Survey of tropical forest cover and study ofchange processes. Forestry Paper, 130, Roma, 152 p In Noyola-Medrano, C., Mering, C., &Rojas Beltrán, M. A. Assessment of land cover change using Landsat and SPOT images: Sierra Chichinautzin Volcanic Field (Mexico).
[12.] Fournier J., Serpantie G., Delhoume J. -P. et Gathelier R., (2000). The role of fallows on surface runoff and erosion in the Sudanian zone of Burkina Faso.Application slope development, in Floret etPontanier (ed., 2000-a): vol. 1, pp 179-188.
[13.] Gillson, L. (2009). Landscapes in Time and Space', Landscape Ecology, 24(2), pp. 149–155.
[14.] Kamagaté B. Seguis L, Kouadio Z.A, Peugeot C, Savane I &Goula B T .A., (2014) Hydrological assessment of the Agneby watershed (Ivory Coast): application of the hydrological model nTopAmma Laboratoire de GéoSciences et Environnement, Université Nangui Abrogoua, 02 BP 801 Abidjan 01, Côte d'ivoire, kambamory2@yahoo.fr2. HydroSciences Montpellier, Université de Montpellier 2, 34095 Montpellier cedex 5, France.
[15.] Kouadio Z. A., (2011). Dynamique de l'occupation du sol et comportement hydrologique : cas des bassins versants côtiers de l'Agnéby et du Boubo (Côte d'ivoire). Thèse de Doctorat de l'Université Abobo-Adjamé, 188p.
[16.] Malan, D. F. (2009). Traditional religion and sustainable management of plant resources in the Ivory Coast: The case of the Ehotilé, residents of the Ehotilé Islands National Park", Vertigo - the electronic journal in environmental sciences, Volume 9 Number 2 ; http://journals.openedition.org/vertigo/8661 ; DOI : 10.4000/vertigo.8661.
[17.] Mbow, 2015. Mbow C, Brandt M, Ouedraogo I: 2015. What four decades of earth observation tell us about land degradation in the Sahel? RemoteSensing 7(4): 4048–4067. DOI: 10.3390/rs70404048.
[18.] Ministry of Agriculture and Animal Resources (MINAGRA), Direction des Statistiques, de la Documentation et de l'Informatique (DSDI), (2002). National Action Plan to Combat Desertification and Land Degradation in the Ivory Coast.
[19.] N'guessan K. E. et N'da, D. H. (2005) Caractérisation et cartographie par télédétection satellitaire de la végétation de la forêt classée de Bouaflé (Côte d'Ivoire). Rev Ivoir. Sci. Technol., 06, p. 161-172.
[20.] Rabenilalana, F. M. (2011) Fragmentation et dynamique du paysage de la forêt dense humide Randriamalala, I. H. (2015). Analysis of the spatio-temporal dynamics of Lake Alaotra and land use in the Maningory watershed.Ecole Supérieure des Sciences Agronomiques, University of Antananarivo
[21.] Ratovoson, A. A. N. (2011). Analysis of the spatio-temporal dynamics of landscapes in the Analanjirofo region.engineering thesis, Ecolesupérieure des sciences agronomiques, University of Antananarivo.
[22.] Roose E. (1977). Erosion et ruissellement en Afrique de l'ouest, vingt années de mesures en petites parcelles expérimentales, travaux et documents de l'ORSTOM, n°78, 107p, ORSTOM Paris.
[23.] Sawadogo K. Z., (2020). Simulation and optimisation of the operation of a small dam and its irrigated rice-growing perimeter: the case of nanan in Yamoussoukro.Doctoral thesis at the INSTITUT NATIONAL POLYTECHNIQUE FÉLIX HOUPHOUËT-BOIGNY.
[24.] Soro G., Ahoussi, E. K., Kouadio, E. K., Soro, T. D., Oulare, S., Saley, M. B., et Soro, N. (2014). Dynamics of land use in the lake region (Central Ivory Coast), 10(3), 146-160.
[25.] Oloukoi J. (2013). Scénario socio-économique et écologique des changements de l'occupation des terres au Bénin », Vertigo - la revue électronique en sciences de l'environnement [En ligne], Volume 13 Numéro

1/avril 2013, mis en ligne le 16 avril 2013. URL : http://vertigo.revues.org/13267 ; DOI : 10.4000/vertigo.13267, consulté le 02 février 2014.

[26.] Orékan V. O. A. (2007). Implémentation du modèle CLUE-s aux transformations spatiales dans le centre Bénin aux moyens de données socio-économiques et de télédétection. Thèse de Doctorat de l'université de Bonn. Allemagne, 230 p.

[27.] Velázquez, A., (2002) 'Patrones y tasas de cambio de usodelsuelo en México', GacetaEcológica ISSN:, (62), pp. 21-37

[28.] Yacouba, H., Da, D. E. C., yonkeu, S., Zombre, P. & Soule, M., (2002) Characterisation of runoff and water erosion in the upper Nakambe basin (Burkina Faso). in 5ème Inter-regional conference on the environment and water, Ouagadougou, 318-325.