Asian Journal of Agriculture and Rural Development, 3(6) 2013: 387-399

Asian Journal of Agriculture and Rural Development

journal homepage: http://aessweb.com/journal-detail.php?id=5005

Characterization and Dynamics of Agrarian Structures in Bouna, Northeast of Côte d'Ivoire

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Abstract

In order to better reproduction of the information that is as close as possible to reality, we have established a procedure for analyzing images based on visual interpretation and digital processing. In digital processing, supervised classification by maximum likelihood, based on a fieldwork allowed to discriminate elements of land. Recovery of geometric shapes by scanning fallow and bare soil from panchromatic *Spot* image yielded the map of agrarian structures. Different queries and statistical operations performed were used to assess the areas of agrarian structures. The analysis of the dynamics of agrarian structures showed that the period 1986 - 2000 was marked by environmental degradation, while the period 2000 - 2004 has seen a regeneration of the natural environment. Treatments applied to images and ensuing results indicate the feasibility of monitoring by remote sensing of agricultural structures in northeastern area of Côte d'Ivoire. This research shows that the Geographic Information System is an effective tool for the evaluation of agrarian structures. However, manual scanning of elements in the environment requires careful attention to avoid skewing the results.

Keywords: Characterization, Dynamic, Agrarian structures, Geographic Information System, Bouna, Northeastern Côte d'Ivoire

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Introduction

In the northeastern Côte d'Ivoire, human occupation changes remarkably. This area has focused in recent years, to commercial agriculture centered on food production. In 2001, the agricultural population of this area was 490,463 inhabitants with a cultivated area of 149,038 hectares (Ministère de l'Agriculture, 2001).

The report of the National Agency for Rural Development Support (ANADER), during the period from 1998 to 1999, reported 7,233 hectares of cultivated land in the South of Bouna. Changes in land use that result from complex interactions between social and environmental systems evolving over time; create an increasing pressure on space and an evolution of natural landscapes.

If climatic and biophysical phenomena have long been the main drivers of terrestrial transformations, man is now at the origin of most of the transformations affecting terrestrial ecosystems (Steffen *et al*., 2004). Changes in land use will then appear as a key factor in sustainable development.

To research, understand and characterize the functioning of agro-ecosystems to control and direct interactions between humans and the environment have become a priority, taking into account the state in which there are some natural resources. In this context, knowledge of the spatio-temporal variations of the land is of undeniable interest in a process of restoring the quality of life. The organization of space is under the double influence of the physical environment and human activity.

In the absence of pioneering work on the dynamics of agrarian structures, this study is a quantitative and qualitative assessment of the pressure of agrarian structures on the environment. It is to analyze the relationship between agrarian structures and space. Several studies on changes in land use and their relationship with the biosphere (Allain, 2000; Gueye and Ozer, 2000), show that they are a significant indicator, even major in the study of environmental change on a global scale (Mather and Stanyuk, 1991). In such a context, space management requires that it been analysed in order to understand its mechanisms.

Materials and Methods

Presentation of the Study Site

Located in the sub-prefecture of Bouna, the study area lies between latitudes 8°40' and 9°30' North and longitudes 2°45' and 3°30' West. It is bordered to the North by Burkina Faso and sub-prefectures of Doropo, Tehini, to the South by the sub-prefectures of Nassian and Bondoukou, to the East by Ghana, to the West by the National Park of Comoé (Figure 1). It extends over an area of 311,365 hectares (ha).

The northeast of Côte d'Ivoire is characterized by the monsoon and harmattan is a source of heat.

The vegetation of this area consists mainly of wooded savanna and/or shrub savanna and gallery forest. Wooded savanna is scattered trees and shrubs. They are dense if recovery timber is between 30% and 60%, and clear if it is below 30% (Poilecot *et al*., 1987).

The relief of the northeast of Côte d'Ivoire is modest (Atlas, 1988). The main elevations are between 190 and 440 m. This is an area of low undulating plateaus, which are installed on granite bedrock. The altitudes between 190 and 250 m are located along the Black Volta. South remains the area most rugged, with elevations of 400-440 m. The slopes are low (1-3%). The rest is composed of ridges and outcrops glaze and armor.

The study area is located between the basins of the Comoé and the Black Volta, but only West tributaries of Black Volta water the study area. Regime of rivers is irregular and follows rainfall.

Different soil sketches (ORSTOM, 1960; Atlas de Côte d'Ivoire, 1979 and Atlas du Nord Est de la Côte d'Ivoire, 1988) show the soil types in the area of study.

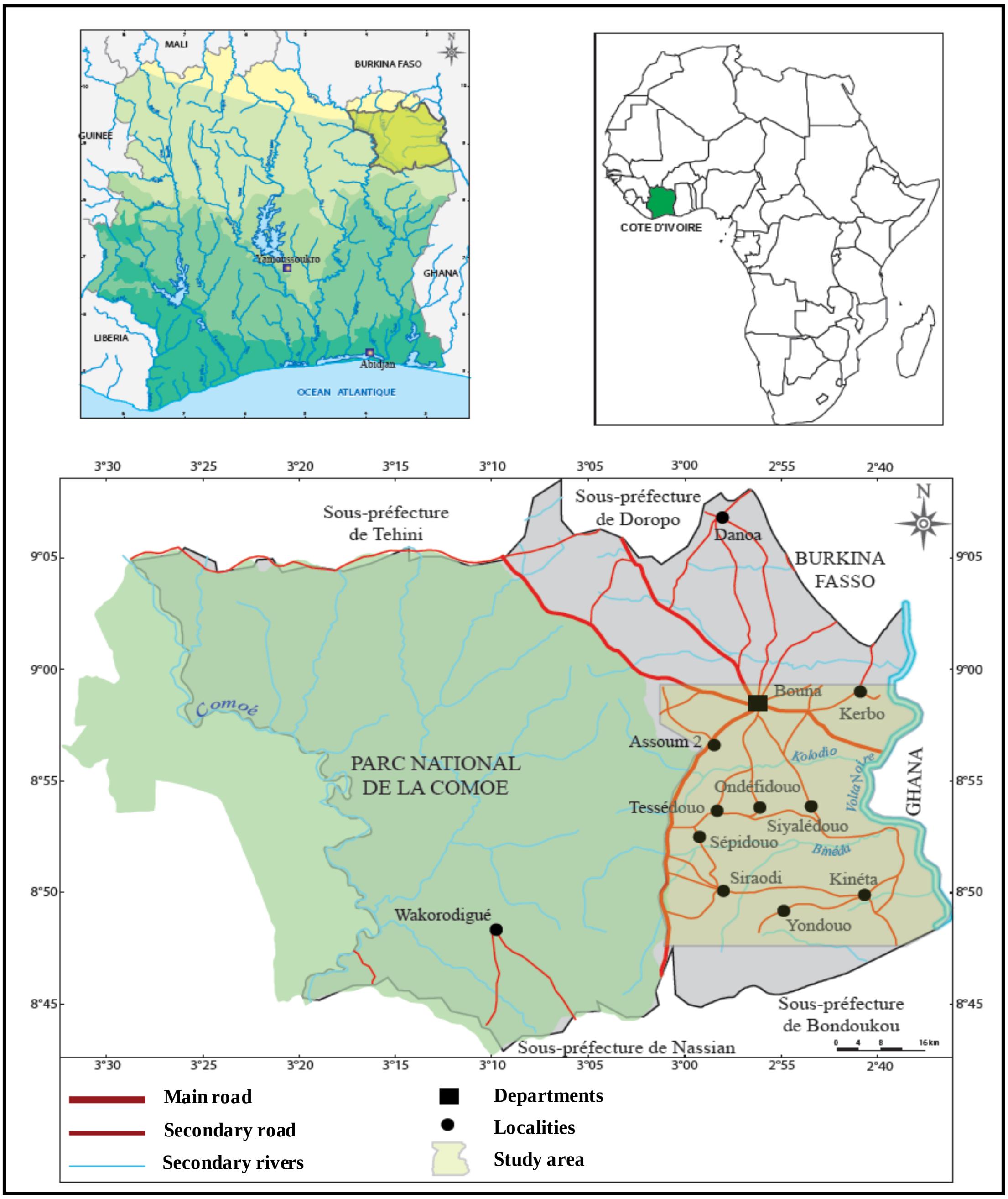

Figure 1: **Location of the Study Area**

Materials

Data analysis required the use of different types of equipment.

The hardware consists of

1. Excel for statistical processing of data;
2. Paint for image editing;
3. Envi (Environment for Visualizing Image) 3.6, for processing satellite images;
4. Arc View GIS 3.2 for GIS: It is a tool dedicated to the use of mapping and analysis of spatial data;
5. Map info 9.0, for geo-referencing and digitizing different cards;
6. Data mapping, photographic and satellite.

Field equipment consists of a digital camera to take pictures (habitat, vegetation and crop areas) and GPS (Global Positioning System) to record ground coordinates.

Methods

Analysis of the Evolution of Agrarian Structures

The analysis of the evolution of agrarian structures on physical media (soil and topography) can develop a Geographic Information System (GIS), attached to two concepts:

1. The system: according to Joel (1975), is a set of elements in dynamic interaction, organized according to purpose;
2. Geographic information is information attached to a location on the earth. It is about information on space objects, natural phenomena, cultural resources, human or economic.

Design of the Digital Database Geocoded

The database is a data structure for receiving, storing and providing, on request, data to multiple independent users. The reality is complex; so GIS will rely on a decomposition of the database into simple elements, simple themes, and simple geometric elements. To achieve our goal, we focus on the use of satellite data, the mapping of topographic classes, the design of the soil map, mapping volumes and population densities.

Use of Satellite Data

The processing of satellite images provides maps of agrarian structures in 1986 and 2000 (Table 1).

Table 1: **Description of Satellite Information**

Topics	Entities	Semantic descriptors
Vegetation	Surface	Fallow, culture
Habitat	Point	localities
Watercourse	Ligne	Main rivers
		secondary rivers
Road network	Ligne	Main road
		Side road

Development of the Topographical Map Classes

Data exist in analog form that is to say on traditional paper media and polyester. We used the northeast topographic map at scale 1/50000 (topographic base from the generalization of topographic maps at 1/200000) published in 1994 by Centre de Cartographie et de Télédétection (C.C.T.) and the northeast pedology map (Institut de Géographie Tropicale, 1988).

The use of these data in a GIS requires their transformation into digital data. The transition from analog to digital form is done by scanning. It is to recover the geometry of objects. This vectorization is achieved by automatic scanning (scanning electron). It involves the conversion of the topographic map in a coded digital file. The procedure was the setting for the card by the geo-referencing, which is to set the document digitized in a geographic coordinate system (WGS84).

Scanning is done on *Arc View 3.2*. Monitoring is carried, point to point, of characteristic lines of the relief, assigning an attribute to the contour lines. The attribute contains all the information for each point on the map. This is the latitude, longitude and altitude (X, Y, Z).

Digitizing provides a digital file containing scanned resolution 0.01mm curves. *Arc View 3.2* software allows to call the "poly line" program, whose role is to convert the digitized curves into a set of spot elevation. The model representation is raster. It is the representation by the nodes of a network. Each node thus represents either a physical point or a certain area around the node. From scanning the contour lines, we establish by computer, the elevation (Z) of each spot elevation. Thus, we have the map of topographical regions.

Design of the Soil Map
By scanning the soil map on *Map Info 9.0*, we get the geometry of the forms of analog card that we converse in an exchange format (AutoCAD) to retrieve the shapefile converted to vector file format, in the GIS universe of *Arc View 3.2*.

Mapping Population Densities
Territorial raster of each site enables to understanding cultural practices and spatial policies. It may explain the idea of competition or defense in the conquest of the land. Population density is the measurement of time relative to the area population. It is expressed in people per square kilometer (inh/km²). So we have a relationship between the population and the spatial unit it occupies. The difficulty of delimitation of village lands has brought Duchemin (1971) to develop a novel mapping technique that has been used in many works: Filleron (1990) for the mapping of settlements in West and Kangah (2006) in the square degree in Katiola. We also use this technique to calculate the population densities of our study area.
It revolves around two key elements: a manual phase and a digital phase.

The manual phase includes the construction of the grid and the calculation of densities:

1. The construction of the grid (map squaring) and the circular target: various locations in the area are printed in scale 1/200, 000. Each locality is assigned the value of the population in 1988 and 1998. A grid of 4 cm wide (8 km on the ground) is built on the printed along the lines of the UTM (Universal Transverse Mercator) coordinates. To calculate the density, we construct a circular target of 4 cm radius (8 km on the ground), covering an area of 200 km². The radius of the target is the communal territory, that is to say, the minimum space which carries the weight of the population of the village.

2. The calculation of densities: the center of the circular target is placed at each intersection of the map squaring. The sum of populations of all communities observed in the target is related to the surface of the target (200 km²). The density obtained is at the intersection of the grid. A grid with values is obtained at each intersection of the map squaring.

Digital Design: the grid is scanned and geo-referenced from the control points. The geo-referencing can be overlaid with other maps. Each point of a set of grid coordinates (X, Y, Z). (X, Y) are the map coordinates and Z represents the density value calculated on the grid.

The density values of each grid intersection are entered. By interpolation, it generates the map densities. We have vector data that is integrated directly into the database. In the database, we standardized the different data (satellite, cartographic and alphanumeric) in the same map repository (WGS 84 Zone 30 North) and converted to shapefile format of the *Arc View 3.2* software.

Data Modeling

It includes the identification, prioritization criteria and processing spatial data.

Identification and Prioritization Criteria
It is to characterize the study area for the effective management of the natural environment. This involves the search for factors that influence the agrarian structures. Thus, to better identify areas favorable to agrarian structures, we selected criteria. To be valid, these criteria must have data in close collaboration with the agrarian structure and the information available on our study area for the years 1986, 2000 and 2004. These data should be of high quality, that is to say they must be abundant and well distributed in our study area to avoid erroneous results during spatialisation or interpolation (Jourda, 2005).

From these conditions, the criteria are the topographical regions (altitudes) and soil types.

1. Topographic criterion permits to determine altitudes classes or topographical regions. For our area, the topographic map generated on *Arc View 3.2* allows for the following classes: 190-250 m, 250-300 m, 300-350 m and 350-440 m;

2. Soil test identifies the types of soils used.

Treatment of Spatial Data
The objective is to obtain a map of areas suitable for agricultural structures by defining multiple spatialized environmental parameters

(topography and soils) that would correlate well with areas of agricultural structures. Thus, we need to combine different themes of the database to extract useful information. The crossing of themes on *Arc View 3.2* allows synthesizing spatial data. Transactions are:

1. crossing agrarian structures map and topographic classes;
2. crossing agrarian structures map and the soil types.

Statistical calculations are performed to determine the overall evolution rate and the average annual change in the agricultural area depending on soil type and topography, during the periods 1986-2000 and 2000-2004.

Characterization of Agrarian Structures
The evolution of agrarian structures in time and space enables to locate and assess the surface of its components (land occupied by habitats, cultivated land and fallow).

Identification of Land Occupied by Habitat
The grouping of habitats in a given area forms a village or town. The habitat in the environment gives a particular landscape. His analysis is done from the habitat structure and spatial distribution of localities.

Structure of the habitat
It reflects the vision of the people who live there. The enumeration of habitat type occurs depending on the actual households (Figure 2).

Results

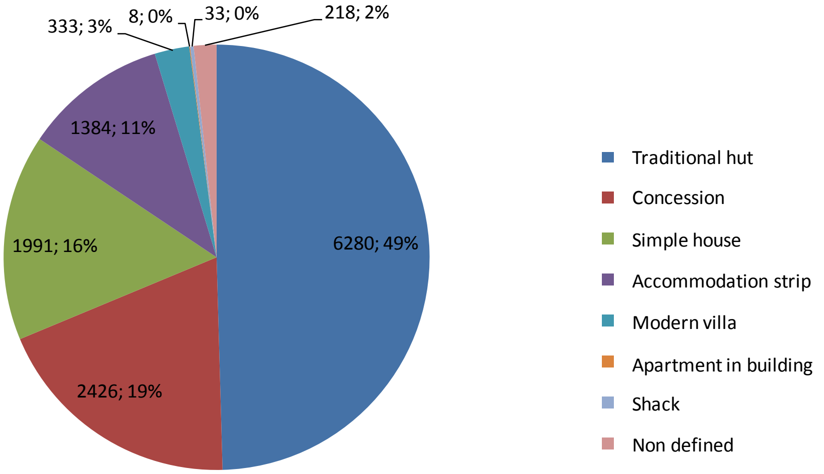

Figure 2: **Distribution of Habitat types by Households in the Sub-prefecture of Bouna**

Spatial Distribution of Localities
The analysis of this distribution is done by contiguity. It is the expression ratios of distance between neighboring villages. To better appreciate the distance between two locations, the establishment of buffer (3000 m, 6000 m and 9000 m) is shown in Figure 3.

These groups can distinguish a big bow around Bouna and along major communication routes, secondary nodes, consisting of two to six villages and isolated villages.

Overall, the North is characterized by a contiguity of villages within a radius of 3000 m and 6000 meters (m). The nearby villages of 9000 m are concentrated in the South. We note, however, that isolated villages are at the Centre and South.

The establishment of the buffer can be noted between two neighboring communities, we have 30% of distances less than 3000 m, 43% between 3000 and 6000 m, and 16% between 6000 and 9000 m. Distances greater than 9000 m are 11% of the distances between neighboring localities. The average distance of 6000 m indicates a near village to each other.

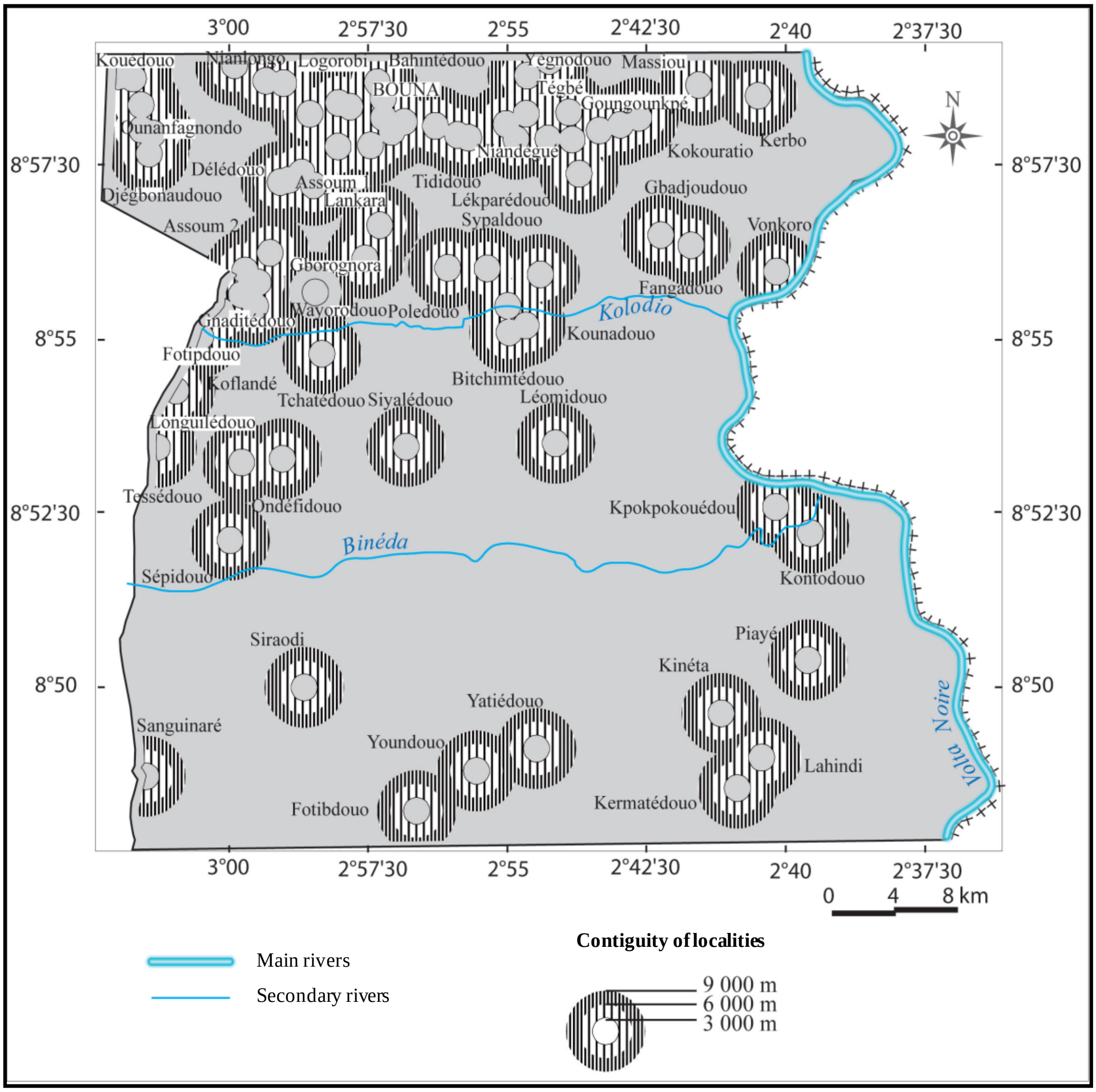

Figure 3: **Adjacency Communities in the Study Area**

Identification of Cultivated Soils

In the study area, the area of crop covers an area of 1180 hectares (ha). In Zone Kolodio Bineda, particular emphasis is given to food crops. Thus, a survey conducted in 1986 in the area Kolodio Bineda provides information (Table 2).

Overall, the association maize and sorghum occupying 39.67% of the cultivated area, is the most widely practiced in the region. As the association yam yam early and late, it ranks second crops grown. The combination of cultures is much practiced in the land in the north-eastern Côte d'Ivoire.

Table 2: **Areas and Yields of some Crops to Kolodio Bineda**

Main cropping	Areas (ha)	Yields (Kg/ha)			
		Main culture 1st harvest	Main culture 2nd harvest	Secondary Culture	Total
Early yam	2.61	1489	9147	-	**10636**
Early+late yam	79.50	5027	3806	817	**9650**
Late yam	2.63	11303	-	-	**11303**
Late+early yam	0.25	5133	-	3747	**8808**
Maize + sorghum	93.70	793	-	580	**1373**
Maize + mil	21.82	638	-	444	**1082**
Sorghum	21.80	467	-		**467**
Mil	13.86	479	-		**475**

The report of activities of Agence Nationale d'Appui au Développement Rural (ANADER) on the Bouna crops' area in 1999 provides information on the cultivated soils of this region (Table 3). In this region, there are a variety of industrial crops (cashew, mango) and food crops (yam, cassava, maize, rice, millet, sorghum, peanuts and beans.). The yam crop area (2705 ha) is the most important. They constitute 37.40% of the total area of crops. Maize is one of the important crops and represents 20.54% of the total area.

Table 3: **Agricultural Area in the Sub-prefecture of Bouna**

	cultures pérennes		cultures vivrières								
	Cashew nut	Mango	Yam	Cassava	maize	Pluvial rice	riz bas fond	mil	sorghum	Groundnut	bean
Crops	284	1	2176	232	1215	32	132	637	620	581	377
Areas (ha)	178	30	2705	156	1486	17	10	799	890	564	398

Distribution of Fallow

The study area presents recent and old fallows. On old fallows, there are species selected by farmers when clearing fields: shea (*Vitellaria paradoxa*), locust (*Parkia biglobosa*) etc.

Fallows occupy an area of 67,432 ha, or 22% of the North-East. They can be observed along the axis Bondoukou-Bouna, around Bouna and west of Bouna. The fallow is decreasing due to a major transformation of the latter in natural vegetation. Crossing themes bare soil and fallow allowed mapping the evolution of agrarian structures in Figure 4.

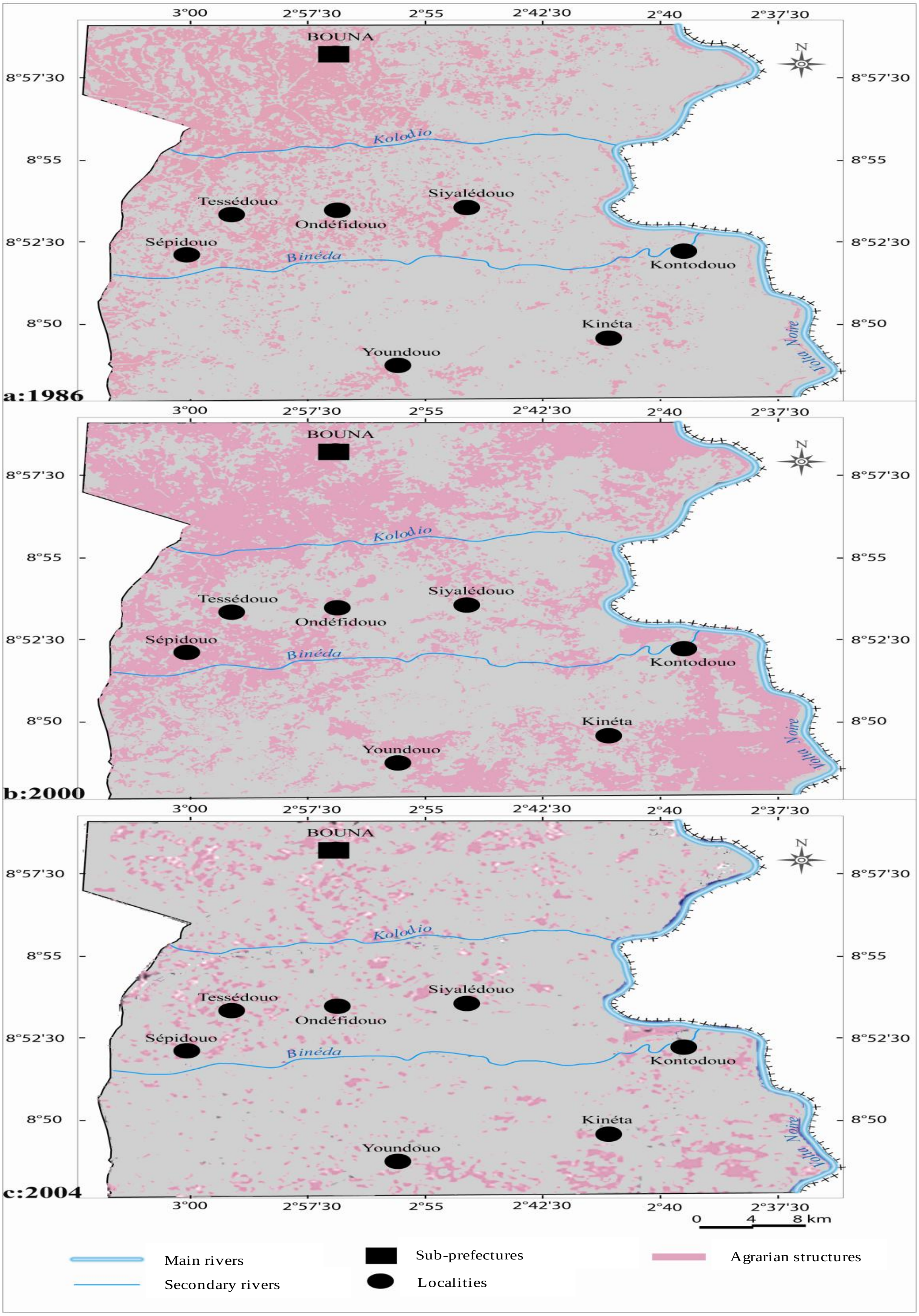

Figure 4: **Map of Agrarian Structures**

Dynamics of Agrarian Structures

This dynamic is achieved by statistical analysis of data and the transition matrix.

Statistical Analysis of Data

More detailed observations are made on bare soil and fallow to identify and understand changes over time (Table IV).

In our study area, agricultural structures have shown two phases in their evolution:

1. 1986-2000: this period has shown an average annual spatial increase of 4.54%. The components of agrarian structures evolve differently in space. The average annual expansion of bare soil (15.72%) remained significantly higher than fallow (4.05%). The dynamics of bare soil is the result of the practice of slash and burn agriculture.

2. 2000-2004: this period was marked by the decline of agrarian structures. The average annual rate of expansion space is -12.22%. The average decay rate of fallow (17.24%) is almost the same proportion as the average annual rate of growth of spatial expansion of bare soil (17.67%). However, relatively large areas of fallow land (129,665 ha) influence the strong decrease of the average annual rate of growth of agricultural structures (12.22%).

If we consider the period 1986-2004, the average annual rate of spatial evolution is very low (0.01%). Contrary to the bare soils that have shown a growth rate (16.15%), declining fallow is slow (-0.67%).

Table 4: **Average Annual Rate of Change of the Spatial Land**

Soil occupation	**Average annual rate of spatial evolution (%)**		
	1986 – 2000	2000 – 2004	1986 - 2004
Fallows	4,05	-17,24	-0,67
Bare soil	15,72	17,67	16,15
Agrarian structures	4,54	-12,22	0,01

Discussion

The basic premise of the use of remote sensing for change detection boils down to what changes in land cover result in a change in the spectral values (Hountondji et al., 2008). Generally, agricultural structures include surfaces where ground reflectance is high. Characterization of Bouna's agrarian structures takes place from Landsat TM, ETM+ and *Spot*. The spatial resolution of 30 m for Landsat and 5 m for panchromatic Spot appears to be satisfactory. Indeed, in the savannas Burkinaké, mid Sudanian Defourny (1992) noted that the shape of the plots is identifiable up to 50 m spatial resolution. Thus, the spatial heterogeneity of the natural vegetation in the Sudanian region requires resolution Landsat TM, ETM+ and *Spot* for a valid mapping (Achard, 1989). Plant communities will be identified by remote sensing if they have, to date, a particular spectral behavior, to separate them from other groups (Girard, 1982). Jensen (2000) states that the images taken during the dry season, has a very good contrast details in the middle. The observation of the seasonal cycle in rural Sudan established by Koli Bi (1990) shows that the satellite images were taken during the dry season (November 1986, February 2000 and January 2004). Although he finds good light conditions, with a decrease rate of aerosols and cloud cover lower than 15%, the presence of the harmattan creates a strong presence of dust, mist and haze. This has an impact on the canals. This explains the atmospheric correction performed on the image. Based on the cycle of vegetation and crop calendar, spectral confusions are observed for agricultural areas are confused with bare soils. Indeed, the harvest is completed and crop plots are mostly naked images in February 2000 and January 2004. However, in November 1986, we still have corn to second cycle, sorghum, groundnuts and rice flooded long cycle. Under these conditions it is easy to associate the recent fallow bare soil. Thus is explained the confusion observed during evaluation. This season promotes firing of herbaceous vegetation plots and ancient cultures. This practice, associated to water deficit plant influences the signal received by the sensor.

Critical analysis of the results shows some shortcomings. Relatively coarse spatial resolution Landsat (30 m) generates a margin of error inherent limits of the sensor. Satellite images show a landscape without apparent order with areas of agrarian structures marked by splashes of color white to gray. According to Monnier *et al.* (1973) the provision of plots is no pre-established order and their contours are not geometric. Fields are rectangular in shape, open in the extension of one another. A network of trails connects the villages with areas of crops. The result on the landscape of this form of development is characteristic of traditional agriculture. Limits of agrarian structures pose problems of interpretation. In addition to the irregular contours of the plots, it is mostly unclear boundaries between fields, recent fallow and savanna with peripheral degradation that poses serious problems (Wilmet, 1996). For Defourny (1992), this entanglement of transitional facies has resulted in an increase in border pixels. This leads to spectral overlap with neighboring taxa. The relationship between human pressure and the soil is influenced by population density and mode of development. We are in a traditional environment, the population centers are villages and town of Bouna. The study of space, habitat through a weakness of human settlements (25% of localities have less than 50 people). The spatial distribution of habitat intrigues more than one observer due to scattered settlements (Hauhouot *et al.,* 1988). A distance of 200 to 300 m separates the various families. This often leads to ignorance of spatial reality of Lobi's villages by observers unwise. However, according Fieloux (1980), the "ditil" which is a tutelary fetish is a reference to geographically delimit the village lands. This fetish is given to the first occupant of the place that would later become a village. The dispersion of houses, how to group in small villages, are characteristic of the Lobi (Hoffmann, 1983). Therefore, it is often difficult to distinguish some hamlets on satellite images. However, field inspections in 2002, 2004 and 2005, helped to highlight the land on different dates. Thus, the 1986 image shows an anthropisation of the environment much more expressive around Bouna and along roads. It is the dense urban area of Bouna where the bulk of the population of the study area. However, in 2000, we observe wide white to light gray ranges on the extent of the study area. Indeed, the eradication of onchocerciasis plays an important role in the system of agrarian structures in the East. Endemic disease causing blindness, it is a limiting factor in human settlement. According to O.M.S. (2000), the opening up of areas freed from onchocerciasis has opened opportunities for agricultural and pastoral products that accelerate the spontaneous migration. In 2004, we denote the thinning of these ranges. That area has been the scene of clashes between belligerents during the military and political crisis in Côte d'Ivoire 2002, emphasizing population migration and the abandonment of agricultural activity. Characterization of agrarian structures highlights habitat, areas of crops and fallow. From 1986 to 2000, they grew, in relation to the growth of the population, which increased from 36,664 inhabitants in 1988 to 45,947 inhabitants in 1998. However, Hauhouot *et al.* (1984), show that "the migratory flow does not occur randomly in time and space; it obeys a strategy implemented by the farm manager" to increase the population of his locality. Population movements lead to an active spatial dynamics whose effects are reflected by changes in the environment and stable areas. Then the space status changes under human pressure on the environment. This is why it is necessary to assess the spatio-temporal dynamic. It is about the transformations of bare soil areas (habitats and areas of crops) and fallows constituting agrarian structures. Thus, the most important loss of employment to ground in 1986-2000 is attributed to the shrub savanna (90,491 ha). They constitute 84% of the total loss area. There is a trend of degradation of vegetation cover. During the 14 years, they have achieved a gain of 29,483 ha. This clearing is partly due to traditional farming techniques, based on shifting cultivation. Such agriculture is characterized by the use of a large rural area (Lebeau, 1991). For the period 1986-2000, shrub savanna lost 90,491 ha. The variation of the land is in favor of bare soil and fallows. It is the explication of the growth of agrarian structures in 2000. This result confirms the work of Ouadba (1989): the interpretation of diachronic study from 1958 to 1979 on vegetation of the site of Niaryarlé and Burkina Faso show a destruction (-73%) of the shrub savanna in favor of agricultural areas. Mama (2002) found the same trend in towns

Savè, Tchaourous and Ouessè of Benin. The author notes that this dynamic affects the social cohesion of populations and induced to conquer new lands. Kosaka (2005) believes that the fusion of panchromatic bands with color can significantly improve the accuracy of results. Thus, we observe on the merged image of 2000-2004, an area dominated by instability of agrarian structures. They got 50,314 ha, including 31,046 ha of fallows and 19,268 ha of bare soils. The main areas of fallows (88% or 27,266 ha) are from the shrub savanna. Gains of agrarian structures are estimated at 37,210 ha, against 90,491 ha in 1986-2000. Agrarian structures lose 89,780 ha against a gain of 37,210 ha. Koné (2004) showed a regeneration of woody cover in the Korhogo region. Similarly, Coulibaly (2002) highlights the increase of natural areas in the region of Bouna. Inglanda (2001) shows that the satellite images are important tools to identify differences zone status by observing them at different times.

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