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Research Article

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# Remote Sensing Based Analysis of the Latest Development and Structure of Abidjan District, Cote d'Ivoire

**Jean Homian Danumah[3]*, Mahaman Bachir Saley[3], Samuel Nii Odai[1], Michael Thiel[2], Lucette You Akpa[3] and Fernand Koffi Kouame[3]**

## Abstract

The purpose of this study is to analyze the land use/land cover dynamics change in relation to urban sprawl during 1990, 2002 and 2014 of Abidjan, the capital of Ivory Coast in West Africa and develop urban structure type (UST) classification using oriented based image analysis (OBIA) method of Abidjan, the capital of Cote d'Ivoire in West Africa. This was done by using the maximum likelihood classification algorithm and post-classification change detection procedure. The spatial-temporal land use/ land cover dynamics change in relation to urbanization sprawl was assessed based on a series of Landsat images for 1990, 2002 and 2014. Afterwards, Spot 5 image from 2013 was used for UST classification through process trees method. The results revealed urban area expansion as major land use change for the periods 1990-2014 and the overall accuracy and kappa of the classification averaged 97.5 % and 0.96 respectively for the three years. However, there was an important increase in urban area between 2002 and 2014 compared to 1990-2002. Also, The result of UST classification revealed a disproportion in all classes' areas coverage with 2.97% of industrial area, 3.21% of public services, bare soil are of 2.03%, informal, medium and high level residences areas covered 0.28%, 7.83% and 3.2% respectively, and they were surrounded by 70.35% of vegetation area and 10.13% of water body with an overall accuracy estimated to be 62%.

**Keywords**

Urban land use; Land cover; Change detection; Urban structure types; Remote sensing; GIS; Abidjan

## Introduction

Land use dynamic is an important factor to better understand physical vulnerability patterns induced by human activities and its implications in climate change [1]. Also, the understanding of the interactions between land cover and land-use in their spatial and temporal appearances is fundamental to comprehension of land-use and land cover change [2].

***Corresponding author:** Jean Homian Danumah, Ph.D., Centre Universitaire de Recherche et d'Application en Télédétection (CURAT), Laboratoire Associé Francophone (LAF n° 401), UFR des Sciences de la Terre et des Ressources Minières, Université Felix Houphouet Boigny, 22 B.P. 801, Abidjan 22, Côte d'Ivoire, Tel: +22507529238; E-mail: danumahjean@yahoo.fr

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Urbanization dynamic is a global issue and need to be examined at global, regional and local scale and it's more crucial in the developing country. To analyze the dynamics of urbanization and their processes, it is important to get a deeper understanding of urban morphological processes and the physical patterns of a city [3]. Population growth has become a world issue on this century and has a consequence on urban sprawl due to human demand and development [4]. However, dynamics of urban area are a challenge to a sustainable development [5].

In West Africa, there is a rapid increase in the urban area in order to satisfy people's needs but there is a dilemma in the urban planning about how to obtain urban sustainable development. Land use/ cover (LULC) disappearance and dynamic in urban area are characterized by a process of rapid urbanization with changes in land use and urban morphology. These changes are caused by an expansion of planned areas, and informal housing settlements which reduce the number of open spaces, degradation of vegetation and environment.

Therefore, it is essential to assess the dynamics of LULC within urban area by having a particular interest in assessing the relationship between land use dynamics and built-up expansion. Then, bring out the urban structure types because these are a key factor to comprehend change in urban zone. Traditional, visual mapping and updating of urban structure information of cities is a very laborious and cost-intensive task, especially for large urban areas [6]. Several strategies and methods to do supervised classification and highlight land use change were offered by previous research using remote sensing tools.

Nowadays, remote sensing has become an efficient tool for providing land use information for acquisition and mapping of the urban spatial dynamic and structure. Recently, remote sensing data has increasingly been used in order to generate LULC [7]. Object-based image analysis (OBIA) is gaining rapid popularity in remote sensing science because of the capability to link very high resolution (VHR) imagery and GIS [8]. Many ideas concerning image segmentation approaches and tools [6] and object-oriented classification in urban areas have been presented [4]. OBIA is based on two main steps: segmentation and classification. Multi-scale image segmentation is a major step in OBIA, however most important step in OBIA until now is the estimation of the optimal scale parameter of each class which is yet the highest challenge related to several previous study [4,8-11]. Many researchers have worked on satellite images for detecting different land use/land cover changes (LULCC) and various change detection techniques have been summarized in several reviews [8,10-13].

More recently Abidjan district in Cote d'Ivoire, has experienced increasingly important change in land use due to various causes including population exodus during the crisis that the country experienced and rapid controlled and uncontrolled urbanization. A lot of researches have been done non- existence. There is a clear lack of knowledge in these areas, which means a need for assessing LULC dynamic change and determines the structure types within Abidjan district. Therefore the motivation of in assessing LULC in several parts of the country and few in Abidjan district except Yao et al., who assessed LULC dynamic change of Abidjan between 2002 and 2014. The significant research gap identified by this study is that, recent scientific work undertaken in the district of Abidjan concentrated on

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others field not related to land use. Moreover, assess land use change over 3 periods (1990, 2002, and 2014) and do classification of urban morphology through OBIA are practically this study is to fill these gaps by assessing the dynamic of LULC and develop urban structure type (UST) map of Abidjan using remote sensing tools. This will facilitate decision making for better land use planning in Abidjan.

## Methodology

### Study area

The District of Abidjan is located in the south of Cote d'Ivoire between latitudes 5°10 and 5°38 North and longitudes 3°4 and 5°21 West (Figure 1). It consists of thirteen (13) municipalities since 2001, ten (10) municipalities in Abidjan and three (3) other communes namely Bingerville, Songon and Anyama and covers an area of approximately 2,119 km$^2$ (Figure 1). According to the statistic institution of the country, Abidjan district has an estimated population of 4,739,752 inhabitants in the metropolis, and 4,460,355 inhabitants in the city of about 5 million people (INS, 2013), or 20.3% of the national population as of 2013.

Vegetation: Abidjan district vegetation has part of wet dense forest vegetation type with evergreen and large rainforest attieen domain (Figure 2). It was observed many protected areas consisting of classified forests (M'brago, Djibi, Bedasso, Tagbadié, Languededou, Audoin, Mafe, Ile boulay) and the Banco National Park. The vegetation was characterized by the presence of large trees which may exceed 50 m. However, land cover in Abidjan was seriously degraded and changed compared to 30 years ago. This degradation was due in large part to human activity including urbanization, industrialization, and industrial cropland extension. These industrials cropland were palm oil, bananas, coconut and cashew plantations.

Population growth: Abidjan is the economic capital of Côte d'Ivoire and knows a perpetual population growth since 1998 characterized by high industrialization, business, jobs and welfare. Abidjan district has an estimated according to the statistic institution of the country (INS) in 2013 of 4.739.752 populations in the metropolitan area, and 4.460.355 residents for the city of around 5 million people (INS, 2013), or 20.3% of the national population (Figure 3a).

### Data acquisition and processing

**Data acquisition:** In order to analyze the trends in LULC change in Abidjan district, time series remote sensing data has been used. These images were selected based on time coverage, and amount of clouds. The study area covered by two different Landsat scenes 196-56 and 195-56. Landsat TM and ETM+ images for the years 1990, 2002 and 2014 have been acquired from http://www.usgs.gov/ specifically from Climate Data Record (CDR) which was defined by the National Research Council (NRC) as a time series of measurements with sufficient length, consistency, and continuity to identify climate variability and change except image from Landsat 8 which were yet not available within CDR. We assumed that 12 years between the images is large enough to allow identifying dynamism and changes

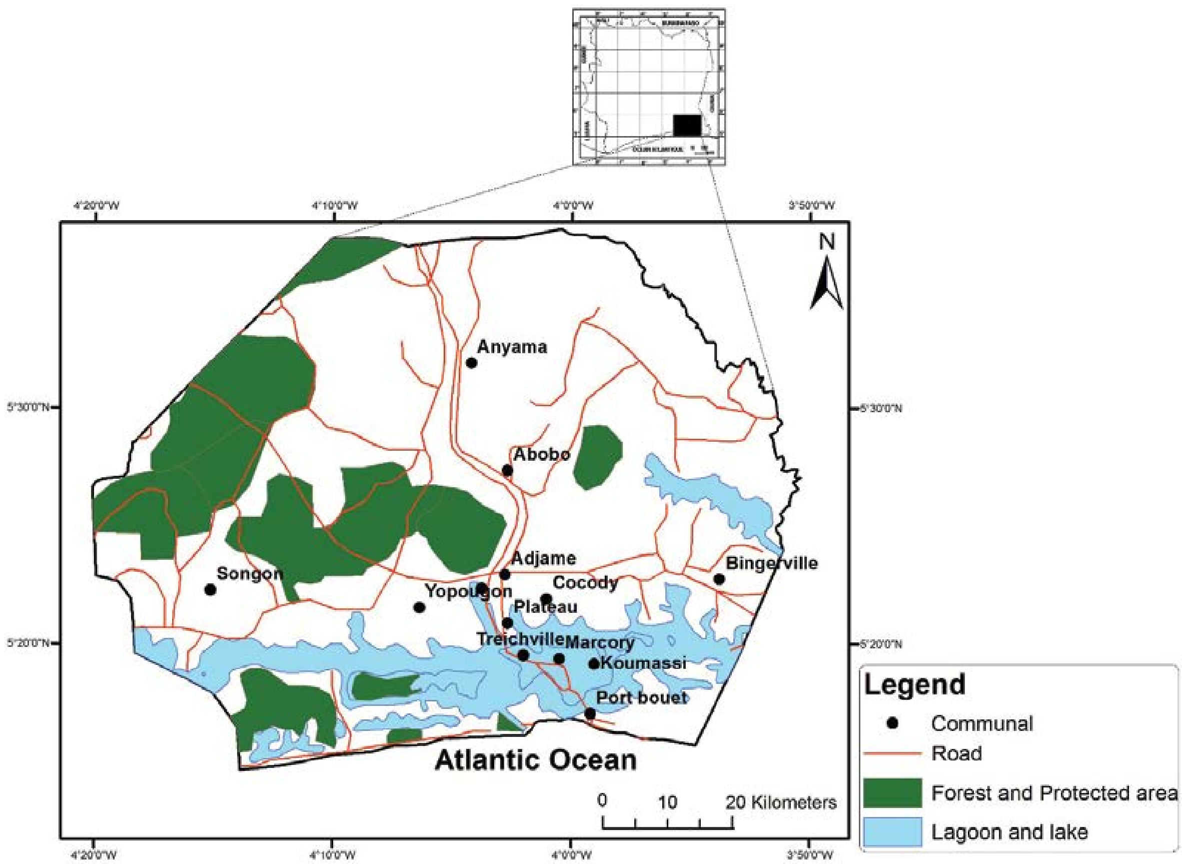


**Figure 1:** Location of the study area.

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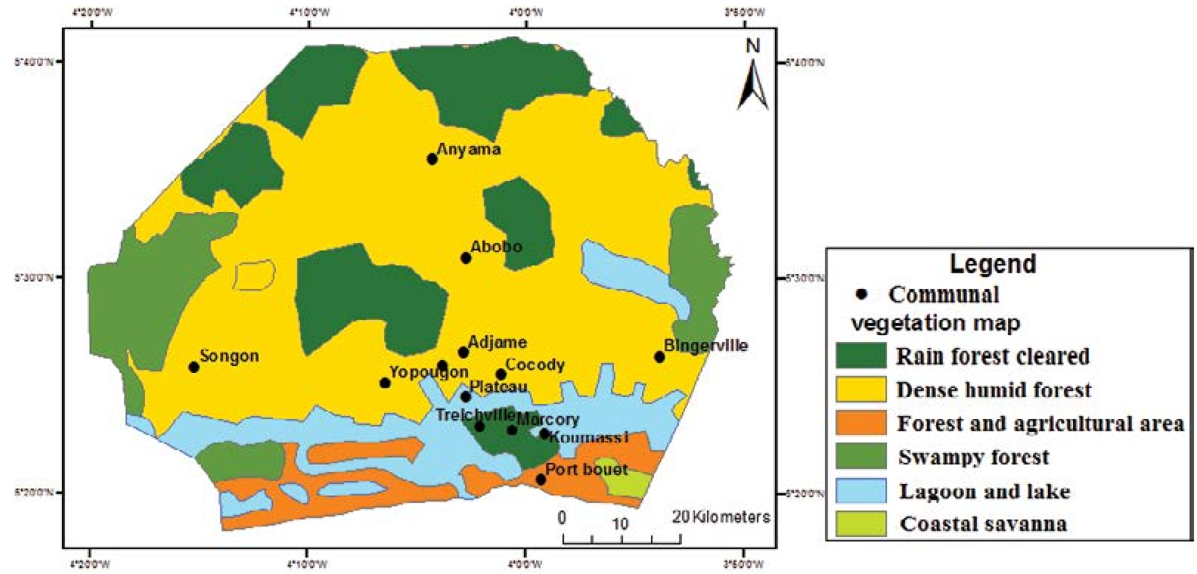


**Figure 2:** Vegetation map of Abidjan (CCT, 2008).

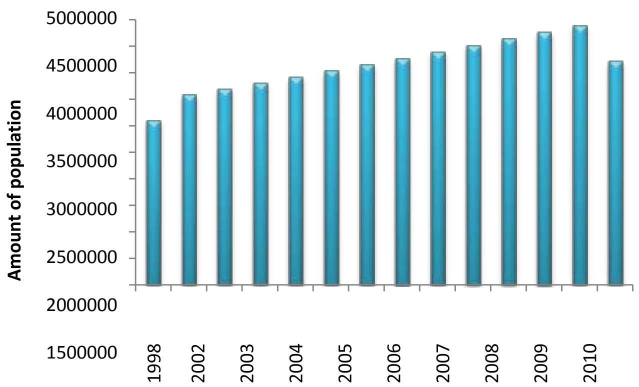


**Figure 3a:** Population growth of Abidjan from 1998-2014 (INS, 2014).

in land use and land cover. Secondly, in order to analyze the trends in urban structure types (UST) in Abidjan, image spot 5 with 10 m of resolution from 2013 was used.

### Processing

**Land use/land cover classification:** The threat Landsat data were classified to reveal changes in land use/land cover between 1990, 2002 and 2014. Supervised classification was carried out for each satellite images (1990, 2002, 2014) separately using the maximum likelihood algorithm based on the collected training data site in Figure 4.

For each land use/cover class, the maximum training and validation samples were implemented. The number of region of interest built in each classification was more than 500 respectively.

Hence, more than 100 ground truth points were randomly selected for all identified land use/land cover classes collected from the field for validation and accuracy assessment for 2014 years. The same classification algorithm was used to classify images of the years 2002 and 1990. However, for these periods, validation of classification was relied essentially on sites where there was no change (identified

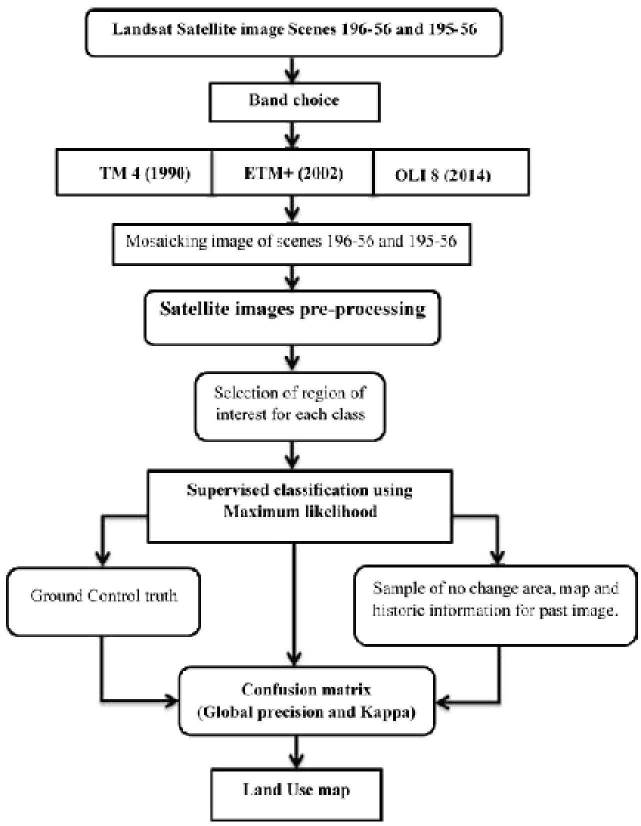


**Figure 3b:** Flow chart for mapping the dynamic of land use in Abidjan.

from the current image and the oldest ones), using existing land use maps in that period or near. Also, historical LULC information was recorded to derive knowledge of the LULC changes that have occurred on the surveyed sites between 1990 and 2002 from the national center of mapping and remote sensing. Sample from spot image from 1990 with 10 m resolution too was recorded. Accuracy assessment was performed independently for each image period using Envi post classification assessment.

Post-classification: Image classification accuracies were determined by applying statistical analysis for validation based on confusion matrix and Kappa. Overall accuracy, producer's accuracy and user's accuracy were also determined. The confusion matrix provides information on the correct and incorrect prediction made by a classification algorithm by comparing a classified map with ground information.

Land use change detection: From aforementioned, in this study technique for image classification and post-classification were applied in Envi (Figure 3b) while land use change detection was applied in Geographic Information System (GIS) interface. The three (3) classified images were saved to TIFF format and opened in ArcGIS. The new land use TIFF images were then converted to polygon for change detection analysis, and later extracted by mask using the study area polygon in spatial analyst tools. Then in the same spatial analyst tools, I compared the three (3) classified two by two as initial and final images using combine method. The resulting combine image obtained table attribute allowed land use change detection analysis by observing where there was change and no change.

Urban structure types (UST) process: Here, the classification of SPOT data set was based on OBIA approach using process tree method which consists of several steps. Estimate scale parameters, multiresolution segmentation and classification. The process tree method serves for clarity and illustrates the steps carried out when and how.

## Image segmentation

Segmentation is the process of dividing remotely sensed images into discrete regions or objects that are homogeneous with regard to spatial or spectral characteristics. The first step in the object based image analysis (OBIA) was segmentation of the spot image into several objects as minimum mapping units with multiresolution segmentation tool in eCognition Developer 9 software (Trimble). Multiresolution segmentation allows for flexibility in output object

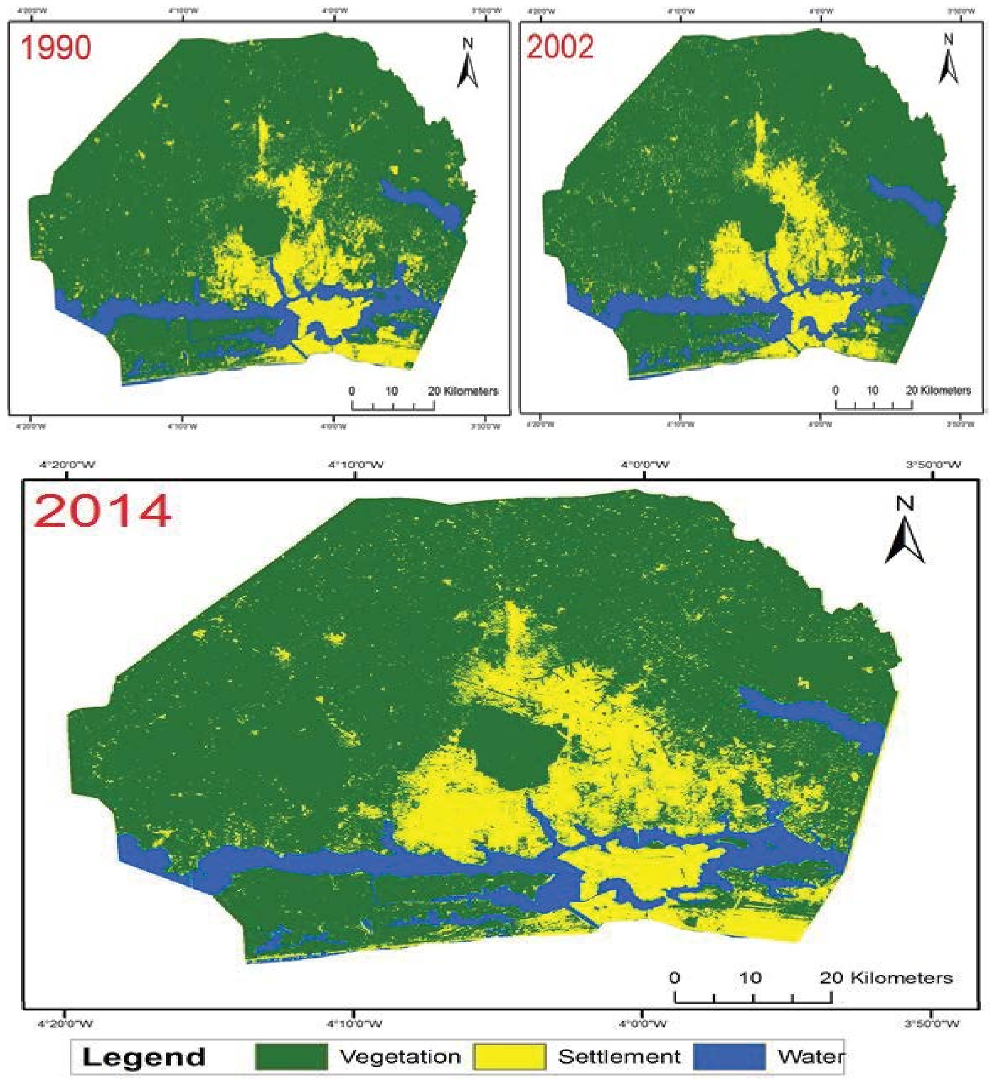


**Figure 4:** Land use/Land cover dynamic of Abidjan district.

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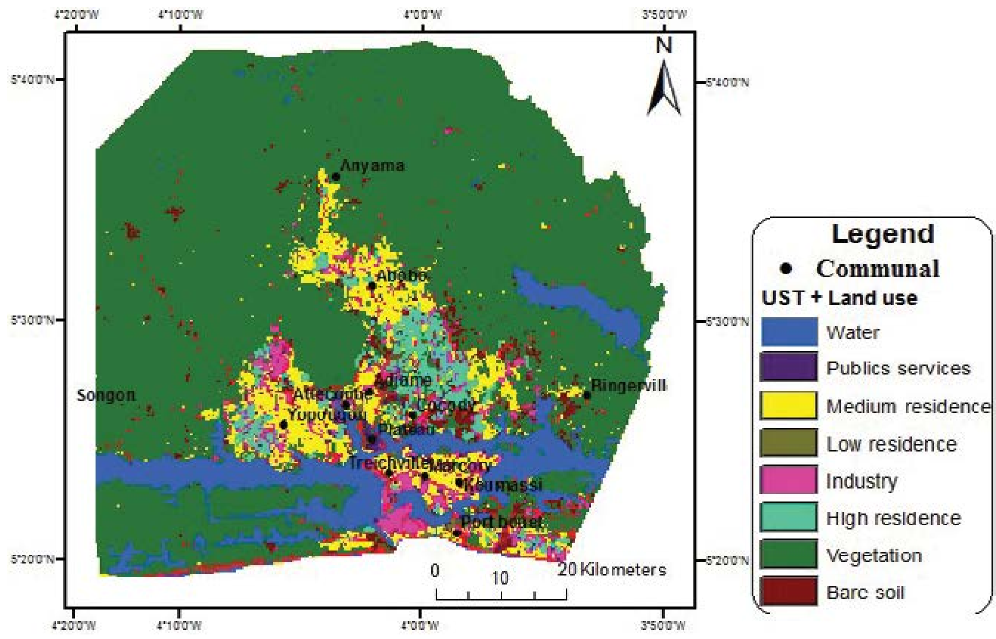


**Figure 5:** Urban structure types of Abidjan from spot image.

sizes. In this study after several training, three scale parameters which are 20, 30 and 50 were used in the multiresolution image segmentation and three segmentations: S20, S30 and S50 based on the multiresolution segmentation algorithm were made. In addition to multiresolution segmentation, spectral difference segmentation was used to differentiate and merge object with same spectral difference using the spectral difference 5 and 7 as scale parameter to couple them with S20 and S30irst segmentations.

After segmentation using both method, areas of homogeneous morphology within the study area are grouped together based on their physical appearance and image object information existing in object feature such as customized where some index calculation were made including NDVI and Ratio (NIR/Red); layer value including mean of Brightness, Green, Red, NIR and maximum difference and standard deviation of Green, Red, and NIR; then geometry extent (Number of pixel) and geometry shape (compactness, density, rectangular fit values). All these image object information will be used to the final step which is object classification.

### Oriented object classification

Afterwards, it was then conducted urban structure type's classification using process trees method to do hierarchical image classification. The image objects are assigned to a class based on its individual membership value that means image object information to the corresponding class. The classification process is a hierarchical process where objects in the optimized segmentation level are classified first until the final classification is reached on the basic segmentation level by merging homogeneous urban morphology selected object in one class industry, high and medium residences as formal residence and informal residence, road, publics' services, bare soil, vegetation and water respectively. This method requires specifying a set of class discriminating attributes a priori from a potentially large number of various object variables. The classified image was validated by using the ground truth data collected during the field campaign and Google Earth.

## Results

### LULC dynamics change

The results obtained from the process of the satellite images of the years 1990, 2002 and 2014 are shown in the Figure 2. The overall accuracy of the classification derived from confusion matrix was estimated to be 93.9%, 99.58% and 98.96% for 1990, 2002 and 2014 images, respectively. The study area has known important land use/cover conversion from one type to another. Analysis of the land use dynamic shows a disappearance of the vegetation(forest, national park, crop and green space) which was taken over by the settlement (build up and bare soil) in general.

From 1990-2002, nearly 6.17% and 1.6% of vegetation and water respectively decreased and was mainly degraded and converted to settlement area.

During the period 2002-2014, around 7% and 4% of vegetation and water areas respectively decreased as a result of settlement purpose while 9.59 % of settlement area was reconverted to vegetation area.

From 1990 to 2014, an average of 9.6% and 5.3% of vegetation and water areas respectively were converted to settlement area.

In the LULC dynamic of Abidjan, vegetation undergoes a speedy decrease and converted to settlement during the period 1990-2014.

Analysis of the general land use/land cover dynamics and change showed vegetation area was taken over by settlements (build up and bare soil). The dynamics of settlement area between 1990-2002 and 2002-2014 were different. Settlement area in 2014 was higher than that in 2002 which implies a fast increase in urbanization sprawl. The explanation of the rapid urbanization sprawl from 2002-2014 is due to the civil war that was experience in the country from 2002-2011 which resulted in the migration of people from affected areas during the civil war. Also, there was an increase in infrastructure projects during this period hence an increase in settlement area.

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Finally, Abidjan being the economic capital of Cote d'Ivoire with developmental projects including construction of roads, houses and industries, as well as population growth is still increasing and therefore vegetation area is still expected to be transformed further into urban area.

### Urban structure type classification

The results obtained from the process urban structure types of Abidjan using spot images from 2013 of and process tree method is shown in the Figure 5. The overall accuracy of the post classification derived from confusion matrix was estimated to be 62%. The study area has known various urban structure types diversity. Analysis of UST shows a disappearance of the built-up area including industrial, public services, residence (informal, medium and high level) and bare soil which was surround with mixed vegetation (forest, vegetation, cropland and grassland).

## Discussion

In this study, a spatial temporal dynamics of land uses/land cover in Abidjan was assessed based on image classification and change detection method. The method applied was to highlight urban area process within Abidjan district and get a deeper comprehension. The results shows change in the three classes: vegetation, water and settlement from one place to another. The increase in settlement area was identified as major land use change compared to vegetation and water areas. The reliability of this study is based on the accuracy assessment results. An increase in settlement area over 14.95% from 1990 to 2014 was highlighted by the dynamic results. Regarding urban land use change, the increase in settlement areas has been documented extensively [14,15]. This urbanization sprawl explained the consequence of population growth and demand for goods and is supported by Yao et al., who indicated that, urban sprawl in Abidjan district from 2002 to 2014 is mainly due to population growth during the crisis (2002-2011) and its demand for development. Indeed due to the country's crisis which started in 2001, there was a lot of population migration (rapid uncontrolled urbanization) from the north to the southern part of the country mainly to Abidjan.

Moreover, due to Landsat image resolution and reflectance it was difficult to differentiate between bare soil and build- up during the processing and analysis which can be factors of some bias.

In addition, the urban structure type (UST) classification helps to identify and discriminate more details of the morphology within Abidjan. These two methods applied and OBIA-UST approach developed in this study are based on find out the city structure. The rule set based OBIA approach utilizing the eCognition software allow to discriminate more details on the settlement type within the city of Abidjan which is helpful in case of vulnerability assessment because UST results gives also information about social level. The accuracy assessment of the UST classification by doing confusion matrix has shown some confusion between medium and high residence area. This confusion is explained by the fact that there is a lot mixed residence (medium and high) areas in the study area.

Moreover, the results from this study are acceptable and give us precise idea on LULC change and the UST in Abidjan. These methodological approaches were inspired by various previous works [4,6-8,10,11-13,15-17]. However, the result can be improved by the application of the land use/ land cover and UST analysis and assessment with high-resolution images such as Ikonos, RapidEye, and QuickBird to have more details in classes, reduce or avoid confusion between some classes (bare soil and settlement) and reliability in the accuracy.

## Conclusion

In this research, Maximum likelihood method has been used to do supervised classification during the period 1990, 2002 and 2014 to observe land use/land cover dynamism and analyze the change detection over this period at Abidjan. The results of this work show the investigation of the spatio-temporal dynamics of land use/cover change between 1990, 2002 and 2014 using the Maximum likelihood within Abidjan district revealed a considerable change in the landscape. Sprawl of urban area and forest degradation were the major land use change observed from 1990-2014. Vegetation change was the most important with a rate of 9.64% of the total change that occurred during the 24-year period. Also, water change showed a rate of 5.31%. Both changes involved total conversion of 14.95% abstraction of landscape to urban zone.

In view of the results obtained, the Abidjan district land use change is mainly due to urbanization and the urban area composite are industry, informal and formal residential areas. Therefore, strict measures need to be taken concerning the rapid and uncontrolled urbanization; deforestation, and land degradation must be implemented by planners under climate change context. The results obtained in this study can be improved with the use of high spatial resolutions satellite image and constitute a research perspective. This study also put in evidence the irrefutable role play by remote sensing nowadays in land use/land cover dynamic and change analysis.

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### Competing interests section

I declare and certify that this research article is for pure academic purpose. In fact, it is one specific objective of my PhD research. Therefore, there is a non-financial competing interest.

### Authors' contributions

JHD collected data from various sources, performed the research and drafted the manuscript. BMS, SNO, LYA, FKK provided skills development, comments and suggestions during data analysis, and results interpretation. MT provided software and methods guidance to develop urban structure type (UST) classification. All authors read and approved the final manuscript.

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## Author Affiliation

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[1]*WASCAL PhD Program in Climate Change and Land Use, Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*

[2]*Department of Remote Sensing at the Institute of Geography and Geology, University of Wurzburg, Oswald-kulpe-Weg 86, 97074 Wurzburg, Germany*

[3]*Centre Universitaire de Recherche et d'Application en Télédétection (CURAT), Laboratoire Associé Francophone, Université Felix Houphouet Boigny, 22 B.P. 801, Abidjan 22, Côte d'Ivoire*