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URBAN SPRAWL MONITORING IN BAMAKO FROM 1990 TO 2017 USING REMOTE SENSING DATA

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ABSTRACT

Our study was conducted on the city of Bamako, the capital of the Republic of Mali, to monitor the evolution of urban sprawl from 1990 to 2017. For this study, four multi-dated Landsat satellite images were used. From image processing, three classes were extracted to understand the phenomenon of urban sprawl: built-up area, non-built area, and water (river). From the analysis of the image processing results, it can be seen that the urban sprawl in Bamako during the study period has grown exponentially over the years; and has grown in the late periods. Urban sprawl was first important on the left bank of the Niger River before exporting to the right bank to be more important today than on the left bank. Urban sprawl was so important during this period that it consumed all the administrative space of the district of Bamako, and exported greatly to the surrounding rural municipalities. This shows the importance of urban sprawl in Bamako from 1990 to 2017; as shown in the results of expansion ratio compared to 1990, the area of built-up area increased 33.52% in 1998, 211.77% in 2006, and 400.40% in 2017, respectively.

Keywords: *built-up area, classification, none built-up area, remote sensing data, urban sprawl, water.*

I. INTRODUCTION

Urban sprawl has been one of the growing research issues in the present development situation, where population growth and migration for better livelihoods have paved the way for rapid urban expansion [1].

A simplistic definition of urban sprawl refers to the expansion of urban concentration beyond its initial limits. However different definitions exist of urban sprawl according to schools. Although a precise definition of urban sprawl is discussed, a general consensus is that urban sprawl is characterized by unplanned and uneven use and an increase in the built-up area along the urban and rural fringe or may be defined as a peripheral growth an unlimited and non-contiguous path to the outside of the solid core of a metropolitan area [2]. Sprawl features on spatial configuration: fragmentation and irregularity of land use patches, strong evidence for discontinuous, strip and leapfrog development, and noticeable planning inconsistency [3]. The urban sprawl of a given region results from the use of land and land cover for socio-economic purposes by the populations of that region. This would argue that the causes of urban sprawl are related to factors of socio-economic and even environmental factors. Urban sprawl can also result from a real political will for urban planning and uncontrolled sprawl as is the case in China. First, Chinese local governments have set up a large number of 'development zones' that are often so large and discontinuous from cities, especially when considering the mass transportation mode in China, that they can best be characterized as leapfrog development at macro-level. Despite their fancy titles, the boasted impact of these development zones on the local economy is doubtful and large amount of land inside these development zones remains vacant. The second type of urban expansion is the expansion of urban population, especially migrant workers and temporary urban residents such as students, and accompanying 'illegal' construction into rural villages on the urban fringe that gradually become ghetto-like, sprawling migrant enclaves [4]. A study was done on spatial and temporal dynamics of urban sprawl along two urban–rural transects in Guangzhou [5]. It focused on comparing the differences of urban expansion over time to investigate the driving forces. It addressed the general temporal and spatial trends of landscape changes along the two transects, any difference in the rates of landscape changes through time by comparing four remote sensing data sets, the driving forces that cause the differences in land use and their implications for planning, and exhibit a diffusion-coalescence process with a multi-nucleated urban pattern.

In underdeveloped countries like Mali, as it was in developed countries; one of the first causes of sprawl is the rural exodus, growth and population pressure, and this in most cases, in a situation of multidimensional incapacity of states to contain these phenomena. Demographic pressure in the face of the structural weakness of public institutions in terms of sustainable urban planning is a factor that upsets the appearance of cities through the densification and considerable spread of neighbourhoods - spontaneous - filling buffer and peripheral zones [1]. In several African cities, housing production takes place through informal channels. About 70% of the population and even 90% in some African countries find themselves in spontaneous neighbourhoods [6]. Urban sprawl, although generally having features in their manifestations, can operate in different contexts depending on the realities of the regions concerned, either voluntarily or involuntarily. Looking at the example of the United States, urban expansion has occurred in a perfect market economic system. However, urban sprawl in many Chinese cities has emerged during a transition period from China's economy from a planned economic system to an economic market system [7]. Urban growth supported by high population growth is generally accompanied by a socio-spatial dynamic such as Cairo in Egypt. For 40 years, Cairo's population growth has been accompanied by a profound readjustment of socio-demographic distributions. Measuring the spatial structuring of social disparities on the basis of social area analysis models shows how the Cairo society went from a cleavage, which was expressed at first glance in terms of socio-professional hierarchy, to which was associated spatial structuring rather sectoral, with a rather halo-shaped model relying more and more on age differences and family structures [8]. Urban sprawl results in changes in land cover and use resulting in various types or forms of land use or land cover. Driving forces, including planning policy, population size and composition, transformation of the industrial structure and economic growth of the development zone are the main reasons for urban sprawl [6]. The planning system and government policies are fundamental to encourage or prevent urban sprawl. Taking the American example, local governments are motivated to offer vacant land for commercial purposes because of the taxation generated by retailing [9]. The sale of the surrounding lands by countries, either for financial reasons or because of urban pressure on their land, contributes to urban sprawl or other motivations. County and village chiefs prefer to "sell" their land and annex their municipalities to the central city because peasants around the city center want to become "urban residents". This decentralized land use power thus contributes to urban sprawl [10]. Rather than a bad case of urban sprawl, the physical expansion of China's megacities may be viewed as a combination of 'urban spill over' and 'local urban sprawl'. The evidence suggests that entangled land use regulations for "urban" and "rural" land have imposed serious constraints on urban growth, while the contradictions of different policies and regulations in the use of rural lands for urban construction have led to intensive and unhealthy competition among stakeholders [11]. The exceptional growth of many urban agglomerations in many developing countries is the result of a three-fold process of structural change: the transition of agricultural employment, strong overall population growth and increased urbanization rates [12]. Urban competitiveness among many others would be one of the fundamental reasons for urban attraction and growth or urban sprawl. The 'urban competitiveness' discussion inquires into the ability of metropolitan areas to attract investment, addressing also the socio-economic implications of the re-orientation of planning goals in this direction [13]. Currently, debates over urban form have generally focused on the contrast between the "sprawl" often seen as typical of the United States and "compact" urban forms found in parts of Europe. Although these debates are presumed to have implications for developing worlds as well, systematic comparison of urban forms between developed and developing countries have been lacking [14]. Remote sensing data and their specific method-based computer processing offer advantages for extracting and understanding spatial information and phenomena. The automatic computer identification classification of the remote sensing image is based on differences and pixel changes in remote sensing images. It is the specific application of computer shape recognition technology in the field of remote sensing, as well as important content of remote sensing image processing. Remote sensed datasets nevertheless have great potential to inform the planning process and to monitor and characterize many urban models and processes [15]. Whether object recognition or classification, the function plays an important role in the outcome of the classification. The characteristic space is a collection of multiple spatial elements in the geographical space and the image space of the objects. The traditional remote sensing image analysis is based solely on the spectral characteristic. The phenomenon of the same objects with different spectra or different objects with the same spectrum is very common. To classify an image, the spectral characteristic alone cannot satisfy the accuracy of the classification. It is necessary to enlarge the space of the original characteristics to improve the accuracy of the classification [6].

The literature on remote sensing urban studies is quite extensive and covers a variety of topics such as growth and urban sprawl, which is the focus of this study. However, remote-sensing urban studies are very recent or in their early stages in Mali, regardless of the field of study concerned. The only main study on urban dynamics in Bamako dates back to 1999 and covers the period from 1980 to 1996. So, to say that no study has yet covered our study period, hence the need for this study for better to follow and appreciate the degree of urban sprawl in Bamako from 1990 to 2017.

This article aims to assess grossly the urban sprawl in Bamako in recent decades by relying on the capabilities of satellite images to contribute to monitoring the phenomenon of urban sprawl, in order to draw attention to the extent of the phenomenon and open a perspective for other more detailed earlier studies on urban sprawl in Bamako.

This study is presented and discussed in four sections: the first section provides an overview of current knowledge on urban sprawl as a whole. In the next section, the materials and methods are presented: it presents the study area, the remote sensing data and the software used and the methodology of data processing. The third section discusses significant results and discussions. The last section draws conclusions and suggestions.

II. MATERIALS AND METHODOLOGY

Study area

The study area of this research is Bamako, the capital of the Republic of Mali. Bamako is a district composed of six municipalities (figure 1: map of Bamako and its six municipalities) and is located in southern Mali (figure 2: map of Mali and Bamako location). The maximum area of Bamako is 267 sq km and has 1809,106 inhabitants and a density of 6775, 7 inhabitants per sq km, according to the last census (source: District Town Hall, 2009).

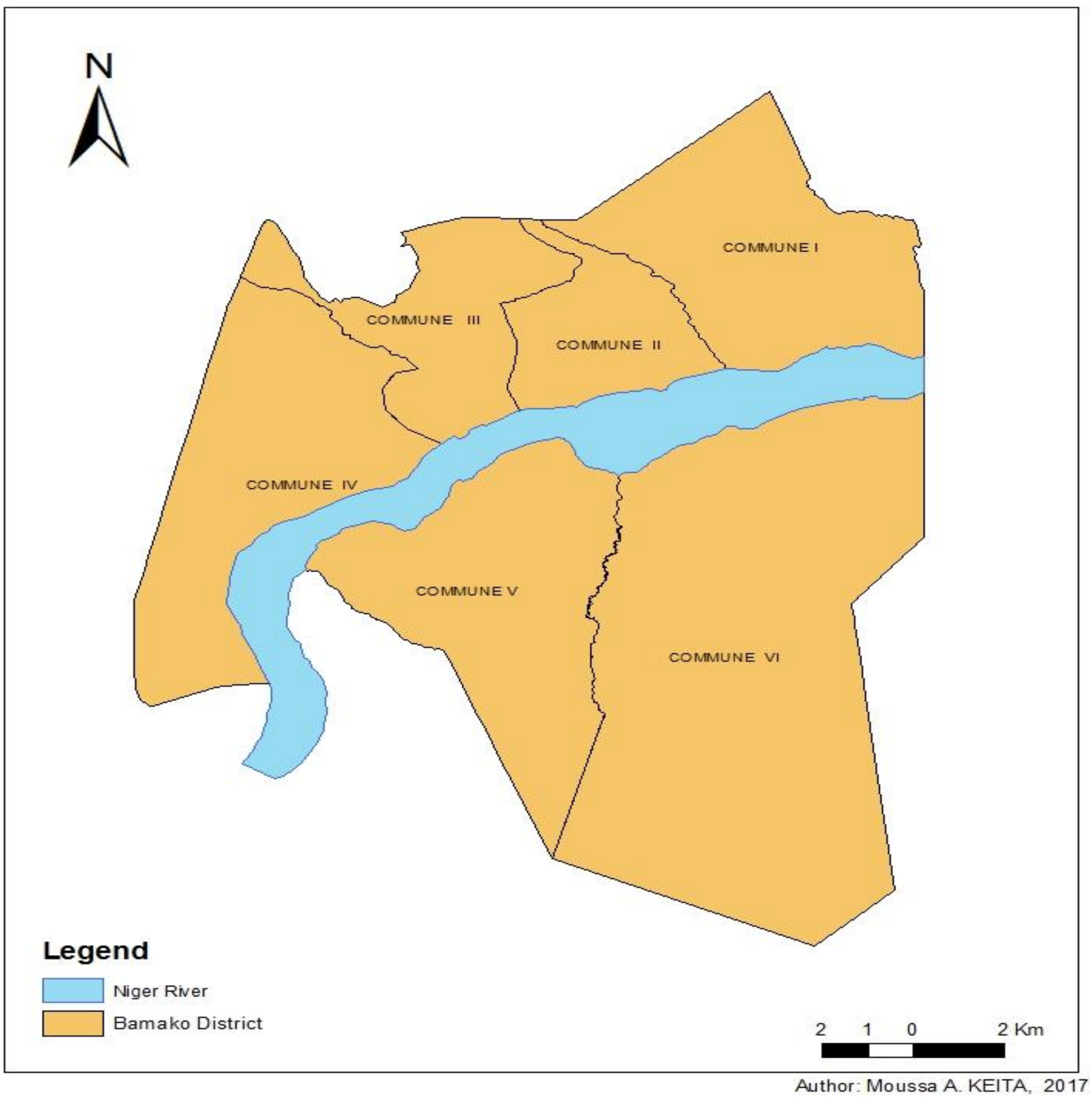

Fig. 1 Bamako and its municipality

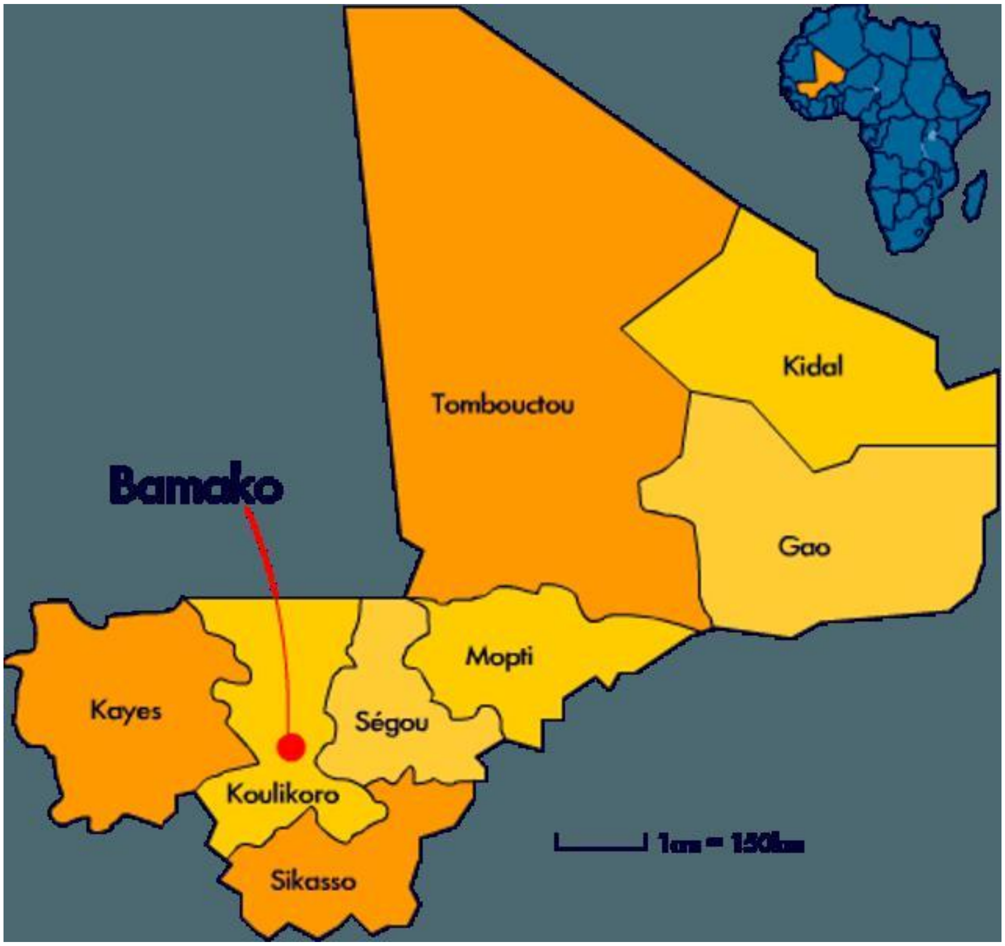

Fig. 2 Mali administrative map and Bamako location

Data used

For this study, four Landsat images for the years 1990, 1998, 2006 and 2017 were downloaded free of charge by Earth Explorer [16]. The characteristics on these images are shown in table 1 below. In the absence of high-resolution images, we found that the spatial resolutions of these images, which are 30 m, a medium resolution, could serve well for our study, hence their retention.

Table1 characteristics of images data

Landsat	Path	Row	sensor	Spatial Resolution	Bands number	Radiometric resolution	Acquisition date
Landsat 5	199	51	TM	30 m	7	8 bits	27/12/1990
Landsat 5	199	51	TM	30 m	7	8 bits	20/03/ 1998
Landsat 5	199	51	TM	30 m	7	8 bits	23/12/ 2006
Landsat 8	199	51	OLI-TIRS	30 m	11	16 bits	25/03/ 2017

OLI-TIRS: Operation Land Imager- Thermal Infrared Sensor; TM: Thematic Mapper

Methodology

The methodology for this study was done in three parts: The selection and downloading of image data, pre-processing, segmentation, classification and post-classification operations. We call here post-classification operations, the steps concerning the export of the results of the classifications to the realization of the final maps and the accuracy assessment of the classification results. Figure 3 illustrates the flowchart of the methodology applied in this study.

The four images of the different years (1990, 1998, 2006 and 2017) have undergone, with the aid of the remote sensing image processing software ecognition Developer 8.7, a selection of subsets to which color compositions have been applied to RGB to improve the quality of spectral features of geographic features on the image to facilitate their identification and then facilitate segmentation and classification.

Multi-resolution segmentation using the multi-resolution segmentation algorithm, whose idea is to gradually merge regions around their starting point according to a user-defined homogeneity criterion, has been applied to different images. See the homogeneity criteria used in Table 2 below after methodology flowchart.

The segmented images were classified under the same ecognition Developer 8.7 software using the object-oriented classification approach. This object-oriented approach is based on the assumption that the semantic information necessary for the interpretation of an image is not represented in the individual pixels, but in significant objects and their mutual relations [17]. The advantage of this approach is to take into account the spectral and spatial characteristics of the pixel and its neighbourhood in the classification process [18]. This is why the nearest neighbour classification method based on predefined class samples was used in this study. Three large classes have been grossly cleared: built-up area, none built-up area, and watercourse. See details on the classes in Table 3 below. The classified images were exported in the Arc GIS 10.2 software for final mapping and classification results accuracy assessment.

For the assessment of accuracy or validation of classification results, a confusion matrix was generated under ARC GIS 10.2 software by creating ground truth points based on the random sampling method. Statistics on the assessment of classification accuracy such as producer accuracy, user accuracy, overall accuracy, and Kappa coefficient are presented in table 4 below. Validation of image processing results has become an inherent component of mapping projects using remote sensing. Many studies have been done on the validation of classification results and their methods [19-20-21-22-23].

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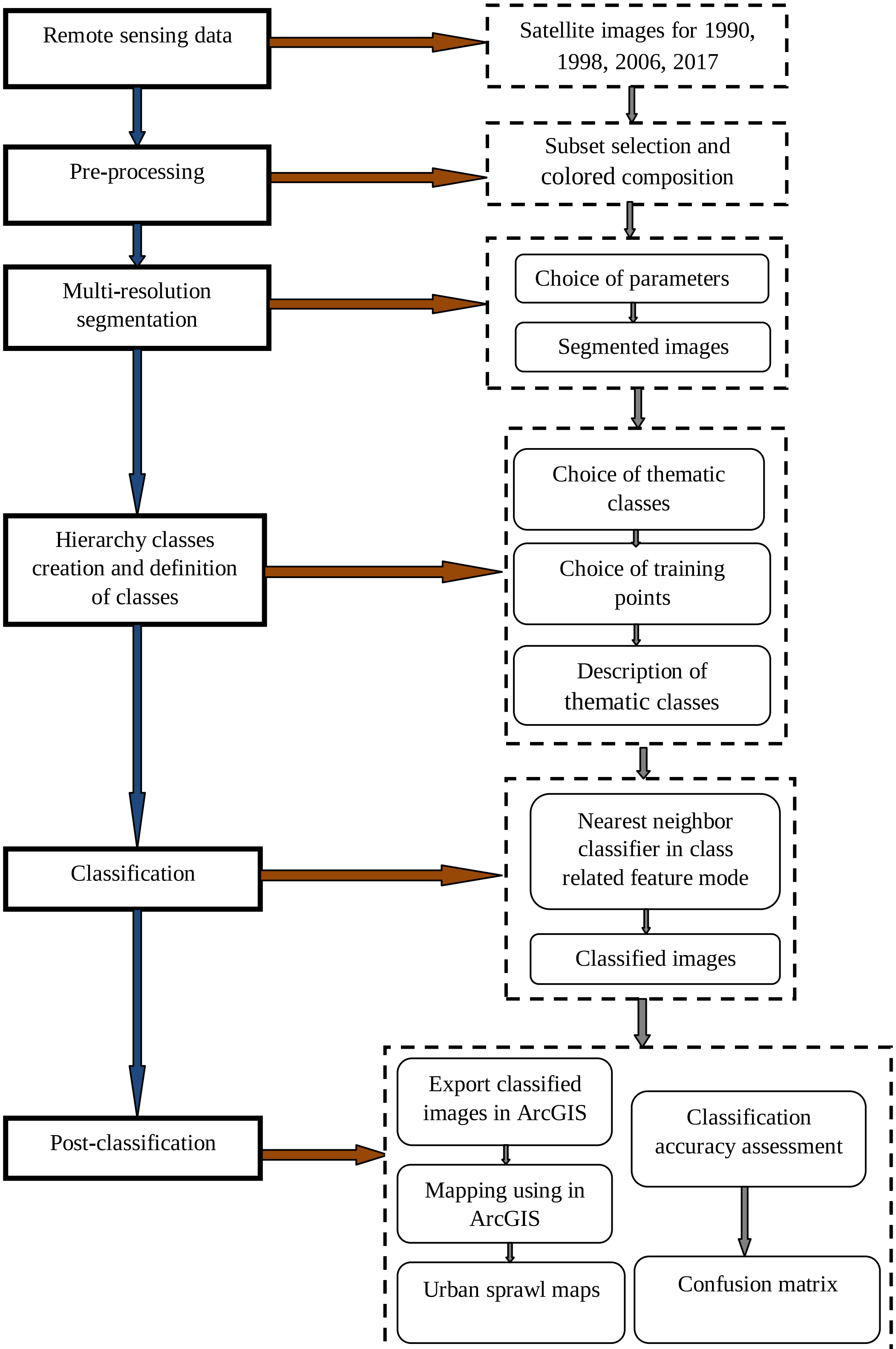

Fig. 3 Methodology flowchart

Table 2 parameter values of segmentation algorithm

Images	Scale parameters	Shape	compactness	level
Landsat 5	20	0.1	0.9	1
Landsat 5	20	0.1	0.9	1
Landsat 5	20	0.1	0.9	1
Landsat 8	20	0.3	0.9	1

Table 3 class types and components

Class type	Class components
Built-up area	- Housing - Economic zones - Industrial zones - Facilities - Transportation network
None Built-up area	- Soil - Vegetation - Montain - And so on
Water	- River

Table 4 Confusion matrix of classification

	Built-up area	None Built-up area	Water	Total	User's accuracy
Built-up area	**50**	19	1	70	71.41%
None Built-up area	9	**114**	1	124	91.93%
Water	0	0	**12**	12	100%
Total	59	133	14	176	
Producer's accuracy	84.74%	85.71%	85.71%		

Overall accuracy : 85.44%
Kappa coefficient : 0.7147

III. RESULTS AND DISCUSSIONS

Results

The use of remote sensing techniques and GIS allowed identification and monitoring the evolution of urban sprawl in Bamako over the period covering our study (1990 to 2017). The results show a significant and continuous increase in urban sprawl throughout the study period on both sides of the river. Figure 4 in the next page, derived from the image classifications of the four different years of the study period, shows the spatial-temporal evolution of the sprawl.

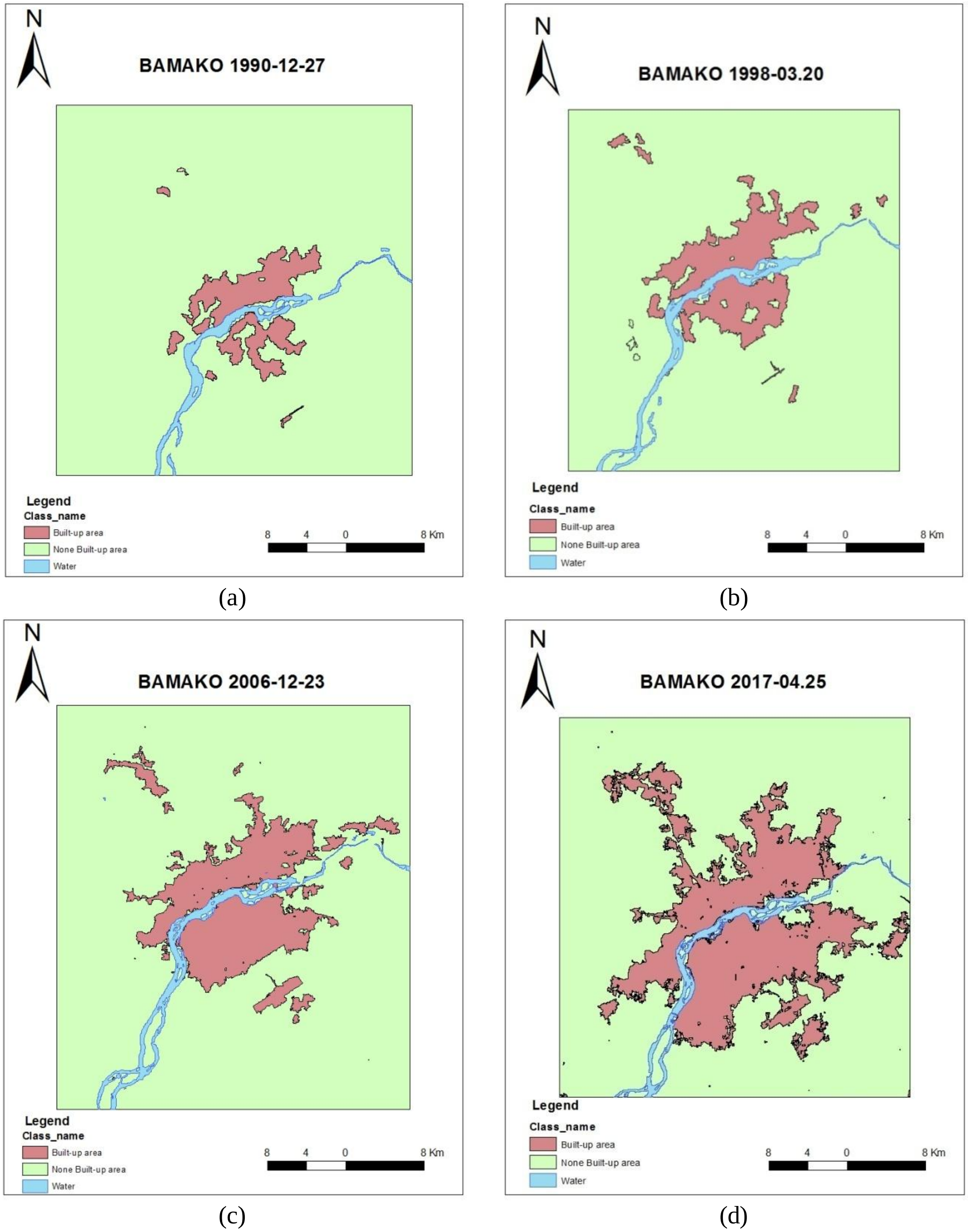

Fig. 4 Mapping of the spatial-temporal evolution of urban sprawl: (a) 1990; (b) 1998; (c) 2006; (d) 2017.

The spatial-temporal evolution of the built-up areas on the maps in Figure 3 and built-up area statistics in table 4 show to a sufficient degree and the evolution and the extent of urban sprawl from 1990 to 2017.

From 1990 to 1998, growth or sprawl was largely internal by the gradual transformation of interstices into built-up areas, but also by spreading towards the urban peripheries; and that in both directions of the river and on both banks.

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From 1998 to 2006, the phenomenon of sprawl is identical to that of 1990 to 1998, this time by a quasi occupation of the interstices between the built-up areas on both banks. In addition to the left bank of the river (northern zone), there is a development of the city in the west-north-east direction, which is explained by the presence of a mountainous formation preventing urban sprawl towards the north, hence the band development of the city along the plain between the mountain and the river. Figure 4 on the colored composition of the Landsat 8 image shows the existence of the said mountainous formation. On the right bank (southern zone), sprawl becomes important and that in all directions either towards those of the river or towards the south.

From 2006 to 2017, this is the period when urban sprawl takes an extreme extent on both shores at once. Urban sprawl, formerly blocked by the mountain on the left bank, continues between the mountains and their valleys, even on the mountains; hence the ramifications of built-up areas that extend further north but also to the southwest and northeast. On the left bank, urban sprawl becomes more important than on the left bank. This would be due to the existence of a relief and free space favourable to urban sprawl such as a wide plain spreading in all directions (see Figure 5 in the next page after table 5).

In sum, with regard to the results obtained from treatments, and considering the increasing or even accelerated pace during the last study period, we can say without reservation that urban sprawl is today a phenomenon and a major and uncontrolled problem in Bamako. Like other major cities in underdeveloped or developing countries. Urban sprawl, which has become an issue for many rapidly developing sectors, refers to the uncontrolled growth of an urban area resulting from poorly or totally unplanned urbanization. The inability to visualize such growth during planning, policies and decision-making has led to sprawl that is both unsustainable and ineffective [24].

Table 5 built-up area statistics

Years	**Built-up area per sq m**	**Growth ratio % compared to 1990**
1990	62 653 500	
1998	83 656 800	33,55
2006	195 335 100	211,77
2017	313 516 575	400,40

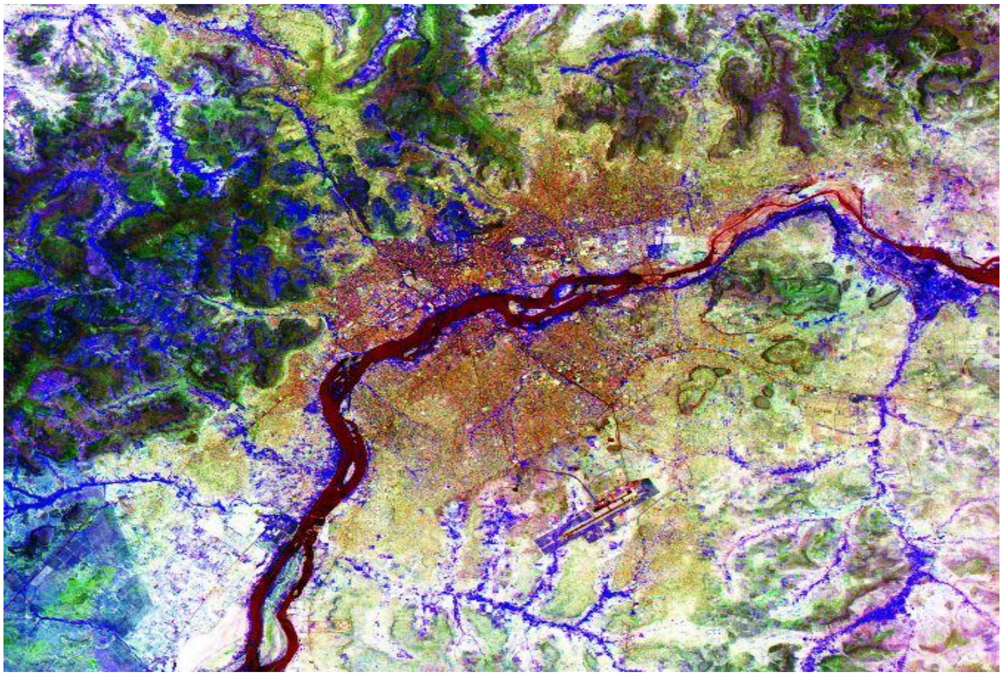

Fig. 5 colored composition of Landsat 8 image

Discussions

The results of this study can be considered satisfactory in so far as they provide a global vision of urban sprawl through the different changes in built-up areas; as we know that it is the extension of built-up areas that is the first factor in assessing urban sprawl.

However, these certainly important results would have been more significant if the study had been extended to other parameters such as to give more detail on the feature classes and to define the boundaries of the Bamako district in relation to its surrounding rural municipalities of which the specific interest would be to appreciate the influence of the spread of Bamako on these municipalities. The ambition of this study was to study urban sprawl in Bamako in its greatest details such as the identification of housing areas, economic zones, industrial zones, transport infrastructures, administrative zones, and so on. This noble ambition of a large study on urban sprawl was limited by the non-availability of high-resolution satellite imagery allowing the extraction of these classes of entities in their greatest details.

Nevertheless, this study should be seen as a forerunner to other more important previous studies, taking into account the shortcomings of this study, even though these shortcomings do not greatly diminish the quality of the results of this work.

IV. CONCLUSIONS

Urban sprawl is a major problem of urban planning given the scale and the uncontrolled pace of the phenomenon to date. It was so important that a comparative visual observation between a Google maps image and a mapping of Bamako administrative boundaries shows that sprawl continued beyond the boundaries of the Bamako district in neighbouring municipalities. This does not remain without environmental socio-economic consequences such as the reduction of agricultural land, pollution, land disputes become recurrent and the lack of social infrastructure because the sprawl remains uncontrolled without prior planning. Rapid urbanization to wildlife habitat, watershed lands, farmland and open spaces has many unintended consequences, including loss of key agricultural land, loss of natural resources, increased environmental pollution, congestion traffic and many other physical, social and economic effects [25-26-27]. We propose a series of five indicators that examine the per capita consumption of land taken in new development in relation to several critical land resource impacts associated to sprawl including: density of new urbanization; loss of prime farmland; loss of natural wetlands; loss of core forest habitat; and increase of impervious surface [28].

Finally, the control of urban sprawl for a viable urban environment would require the implementation of an urban planning policy and a reliable and controllable urban development scheme, in complicity with the central authorities of the Bamako district and those of the surrounding municipalities. A more in-depth study of the state of sprawl making an inventory of its causes, its driving forces, its manifestations, its consequences; would be an important support for valuable assistance to the authorities and all actors involved in urban management. This study would then contribute to the establishment of an appropriate urban planning policy and the development of an urban plan and an appropriate development plan to help control urban sprawl.

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