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Use of remote sensing and GIS to improve urban management

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ABSTRACT

Urban management is an important issue in society, as the current demography is gradually increasing. Our study is focused on the contribution of new technology (remote sensing, Geographic Information System) in urban management following a 5-year time span. The different methods used start with the processing of images to highlight the urban structure, the design of a GIS for analysis and statistics and finally the design of a web GIS for the exploitation of the work by the users. Thus, the dynamics of the built-up area were obtained as well as their states in the future. In addition, a dynamic platform was designed. The objective of this study is to exploit the potentials of remote sensing and GIS for the planning and management of the urban environment.

Keywords-urban management, remote sensing, GIS, urban space, Web GIS

I. INTRODUCTION

Mali, a West African country, is one of the developing countries currently experiencing very intense urbanization. This urbanization, which introduces quite complex phenomena, has generated a multitude of problems: transport, lack of social facilities, environmental degradation, increased risk of natural disasters, and management of urban space[1]. The implementation of urban policies for the regular monitoring and management of this urbanization phenomenon requires the acquisition, processing and analysis of reliable and updated information on all forms of evolution. The exploitation of aerial photographs, a traditional method for the acquisition of information, has always been expensive and the analysis as well as the manual processing, traditional of these photographs, require human and financial means and a very important time. Thus, digital techniques such as satellite remote sensing, digital mapping and GIS have undergone considerable development and constitute an interesting alternative for the monitoring, management and planning of urban sprawl in developing countries such as the city of Bamako[2], [3].

The general objective of the project is to exploit the potential of remote sensing and GIS for the planning and management of the urban environment, while :

- Delineating the urban forms of Bamako from satellite images using a statistically validated method,
- Quantifying changes in these urban forms,
- Predicting the level of extension
- Designing a GIS database for the improvement of the management of the commune III of Bamako.

II. MATERIALS AND STUDY AREA

The study area is called Commune III and is located in the northern part of the district of Bamako. It is located between the coordinates 12.62° and 12.68° North latitude and 7.98° and 8.05° West longitude. Part of Bamako, which has a total rainfall of 990 mm per year, its geology is composed mostly of laterite and rocky escarpments[4]. Commune III has an area of about 23 km^2 and a population of 119287.

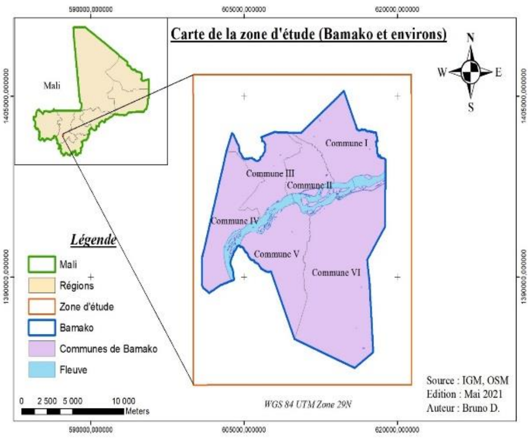

Figure 1 Study area

The data used are listed in the following Table 1:

Table 1 Used data

Types	Raster	Raster	Shape file
Data	ALOS AVNIR-2	Sentinel-2	Municipal boundaries, Building, Parcel, Road network
Source	European Space Agency (ESA)	European Space Agency (ESA)	IGM, cadastral inspection, OSM
Year	2009	2015,2020	2017-2020

The processing, implementation and realization works were carried out by the following software Table 2:

Table 2 Used Tools

Software	Work
ArcGIS 10.8	Map, Geodatabase, processing
AutoCAD2015	recalibration of analogical data with Helmert recalibration algorithm
MSAccess	Conceptual modeling of data and verification of relationships between tables.
MSExcel	Graph configuration and analysis
XAMPP	For the implementation of local web server
PostgreSQL	Implementation of our RDBMS
GeoServer	Allows to create maps thanks to the geographical data stored on a server
OpenLayers	The web interface used for the integration and visualization of layers

III. Methodology

Our methodology consisted in going through two mandatory processes, namely: Urban planning monitoring and GIS design.

III.1 Methodology for monitoring urbanization

The following flowchart outlines the key operations for the extraction of urban patches Figure 2.

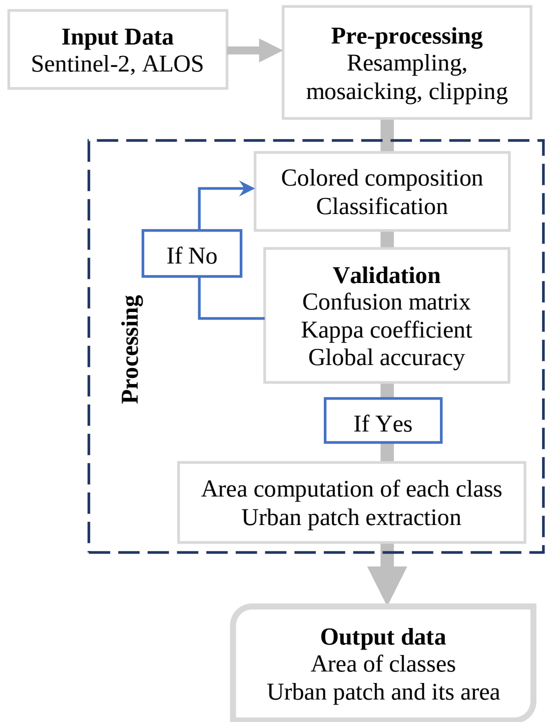

Figure 2 Flowchart for monitoring

The pre-processing constituting the basis of the work on the geospatial data, we had to resample the sentinel-2 images under the same spatial resolution which is 10 m, then stack the blue, green, red and near infrared multispectral bands of each product (ALOS AVNIR-2: 1-2-3-4, Sentinel-2: 2-3-4-8) to constitute a single one each. Then we mosaicked the 2 Sentinel-2 images and finally extracted the study area from the images.

III.1.1 Processing

During processing, the images are displayed on the screen as a coloured combination (false colour composition) of the three Near Infrared, Red, Green channels (ALOS AVNIR-2: band 4, band 3, band 2; Sentinel-2: band 8, band 4, band 3). We performed the unsupervised classification using the Iso Cluster algorithm. This algorithm only clusters pixels belonging to either the urban or non-urban class, i.e. minimising class confusion as much as possible. At the end of this treatment, the classification was composed of 3 to 5 distinct land use classes.

III.1.2 Validation

We verified the quality of the classification by randomly selecting 500 test points from each classified image using the ArcGIS "Create Accuracy Assesment Points" algorithm. The algorithm automatically classifies the 500 points according to their class

III.1.2.1 Calculation of the area of the different classes and extraction of the urban tasks

Once the classification has been validated, the area of the different classes is calculated by the (equation (1) and the urban patch is extracted.

$$\text{Area} = PN * PSG \qquad (1)$$

Sentinel-2 $\text{Area} = PN * 10 * 10$

ALOS $\text{Area} = PN * 11.64545865 * 11.64545865$

PN: pixel number, PSG: pixel size on ground

For the extraction of the urban patch, we used two different methods: the extraction from the building class from the classification and the extraction using the Normalized Difference Built-up Index (NDBI) and the Normalized Difference Vegetation Index (NDVI).

With the indices, we have built =NDBI - NDVI.

Once the built-up areas have been obtained, either through classification or the use of indices, the gaps are reduced by eliminating the spaces with a surface area of less than 500m² (it is considered that for a construction to transform the space into an urban area, it must have a surface area of more than 500m²); subsequently, a buffer zone of 50m is applied to the remaining areas (this is the "dilation"), followed by a merging of the different polygons. Finally, the 25m buffer zone is removed ("erosion") to obtain the urban patch[5]–[7].

Each commune is then dotted with envelopes that surround their built-up areas, whatever their size.

III.2 GIS DESIGN METHODOLOGY

The design of the GIS for commune III of the district of Bamako went through various stages, as shown in the following flow chartFigure 3.

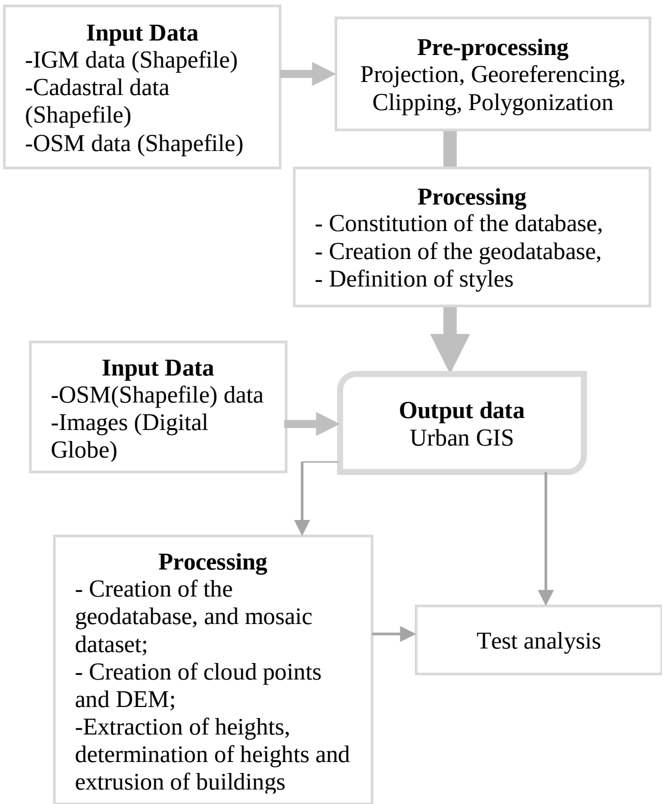

Figure 3 Flow chart of GIS design

III.2.1 Preprocessing

The collected data, coming from different sources, had to be reprojected, calibrated (spatial harmonization of the data), clipped and polygonised and cleaned (cleaning and deletion of unused fields in the database).

III.2.2 Processing

The processing of the data started with the construction of the database.

III.2.3 Design of the database

The construction of the database was carried out in order to store the collected data in the best possible way, to facilitate unified management and to facilitate analysis.The organization of the model was done according to the MERISE method. It is based on the separation of data and processing to be carried out in several conceptual and physical models.

III.2.3.1 Table structuring

In this database the entities are:

- the commune, divided into four sections;
- sections, which are divided into neighbourhoods;
- The district is composed of several blocks;
- The blocks are divided into several plots;
- the parcel, which has only one owner (or co-owners), and several buildings in this study.
-owner with its different attributes which are flexible.
- several streets serve a plot of land
- building, with its attributes also being flexible.

The attributes of the entities are flexible, i.e. they can be updated as needed and according to the field of use.

III.2.3.2 Creating relationships

To express relationships in Microsoft Access, two types of relationships can be created between tables: one-to-one relationships and one-to-many relationships.Most of our relationships are one-to-many.The Figure 5shows the relational schema of the data in Access obtained after modelling.

III.2.3.3 Geodatabase creation and data integration

The creation of entity classes with information layers. After the design and modelling stage, we realised our GIS by going through the following steps:

- Creating a file for our project.
- Creation of a new geodatabase.
- Creation of entity class sets.
- The choice of coordinate system for georeferencing (WGS 1984 UTM Zone 29N).
- Creation of entity classes.
- Integration of some information layers.

III.2.4 Web GIS design

After the design of the GIS, we proceeded to the design of the Web GIS following the methodology presented in Figure 4.

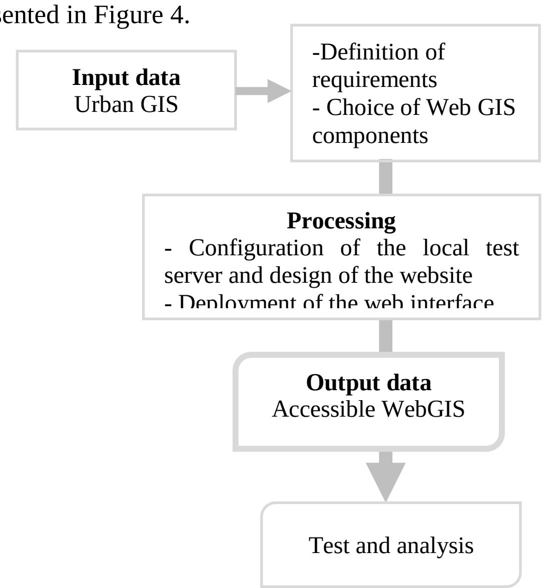

Figure 4 Web GIS design methodology

III.2.4.1 Choice of components / architecture of the Web GIS

✓ Relational database system module.

The implementation of our RDBMS was done with PostgreSQL/PostGIS.

✓ Map server module

GeoServer is a map server that we chose in our studyFigure 5. This server allowed us to share the spatial data necessary for our information system. It is important to configure this data server before using it.

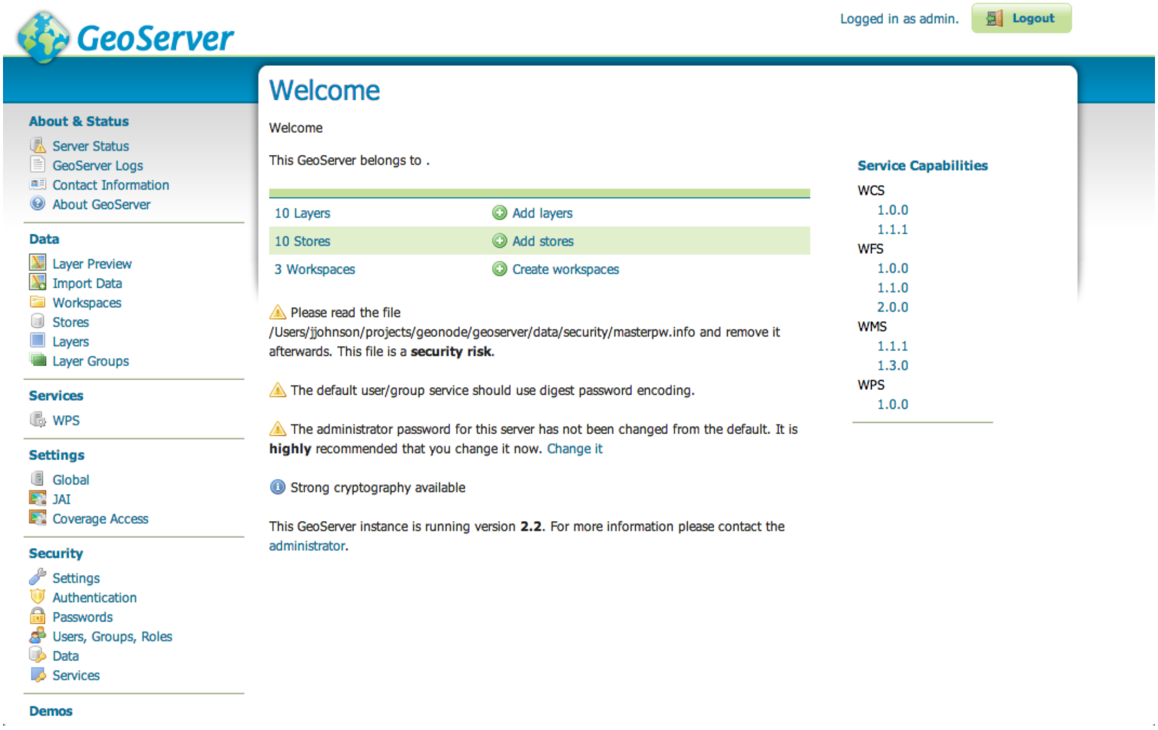

Figure 5GeoServer window

After the configuration, our database was connected to GeoServer. The tests consist of: (1) previewing and (2) displaying the data layers.Adjustments have been made to the styles of the different layers with the SLD (Styled Layer Descriptor) standard.

✓ Web interface module

The web interface used for the integration and visualisation of map layers is OpenLayers from the OpenGeo suite. OpenLayers is based on a JavaScript language and is freely licensed (Mapgears, 2015).The module was created to display the data layers. The designed web interface also has some functionalities that meet the defined needs.

III.2.4.2 Design of the website that hosts the Web GIS

The website was designed using the programming languages mentioned above, including (JavaScript, PHP). Several files with different extensions and folders were created.

III.2.4.3 Deployment of the web interface

In this section, the web interface is installed on the local test server and is not yet available to the general public (Figure 6). The full deployment of the interface will consist of testing with some users to see if our interface meets the requested needs. It has undergone some testing with fairly good feedback but which also revealed its shortcomings. Some of these shortcomings have been corrected, and others, concerning the ergonomics of the system, have not yet been corrected. Also, users should feel to do tests in real conditions (Sanchez, 2015). After the adjustments and validation tests, the web interface will be operational.

UrbanClass	Built	Built	Urban

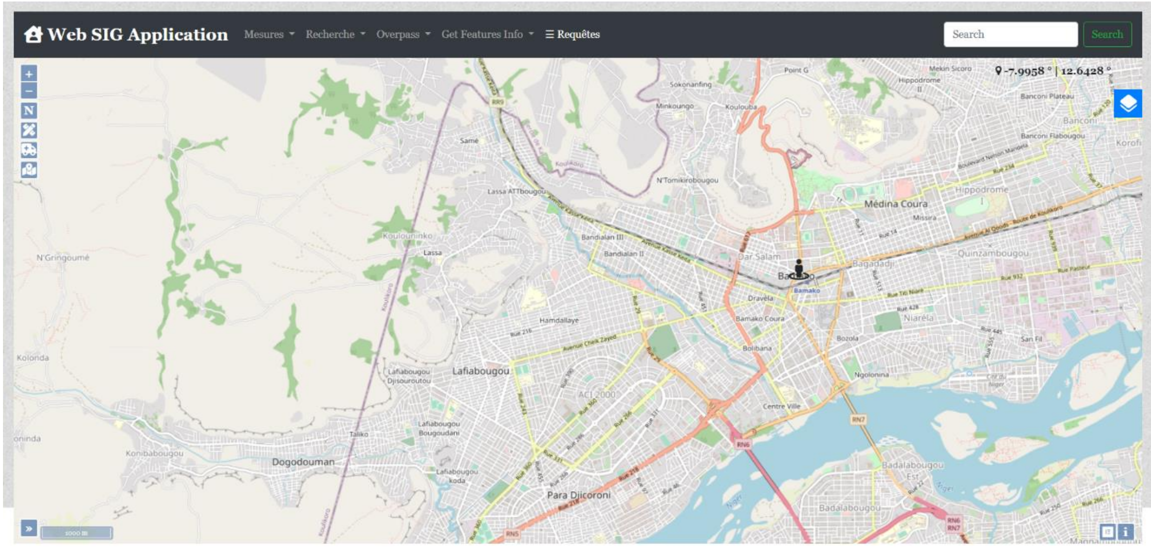

Figure 6Web GIS interface

IV. RESULTS

IV.1 TO MONITORING THE EVOLUTION OF URBANISATION

For the classifications, three (03) clusters are needed to distinguish urban areas from non-urban areas for Sentinel-2 images and five (05) clusters for ALOS images, the number of clusters is obtained after a few trials. These clusters reflect the diversity of surface conditions. Subsequently, all classes representing the urban area were merged to form the urban class, while the others were grouped to form the non-urban class. In total, the land cover classes were reduced from 5 to 2. While this clustering operation degrades the semantic accuracy of the nomenclature, in exchange, each constructed class inherits a higher spatial reliability (i.e. less confusion).The clusters are as follows:

Table 3 Grouping of the classes in the classification

	Sentinel -2	**ALOS**	**Clustering**
Non-urban class	Water	Water	Non-urban
	Vegetation, Bare soil, Hills	Vegetation	
	-	Hills	
	-	Bare ground	

After the clustering of the classes, we proceeded to the evaluation of the classifications. The results of the quality assessment of the resulting map are presented in theTable 3.

Table 4 Confusion Matrix ALOS Image 2009

Cl_Va	C_1	C_2	C_3	C_4	C_5	Tot	Us_Ac	Kap
C_1	23	3	0	0	0	26	0.885	-
C_2	0	102	6	12	10	130	0.785	-
C_3	0	3	106	1	3	113	0.938	-
C_4	0	14	0	113	38	165	0.685	-
C_5	0	2	0	18	47	67	0.701	-
Tot	23	124	112	144	98	501	0	-
Pr_Ac	1	0.823	0.946	0.785	0.480	0.0	0.780	-
Kapp	-	-	-	-	-	-	-	**0.712**

Classes 1, 2, 3, 4 and 5 correspond to water, hills, vegetation, buildings and bare ground respectively. After grouping into two classes, we obtain an overall accuracy of 83.43%.

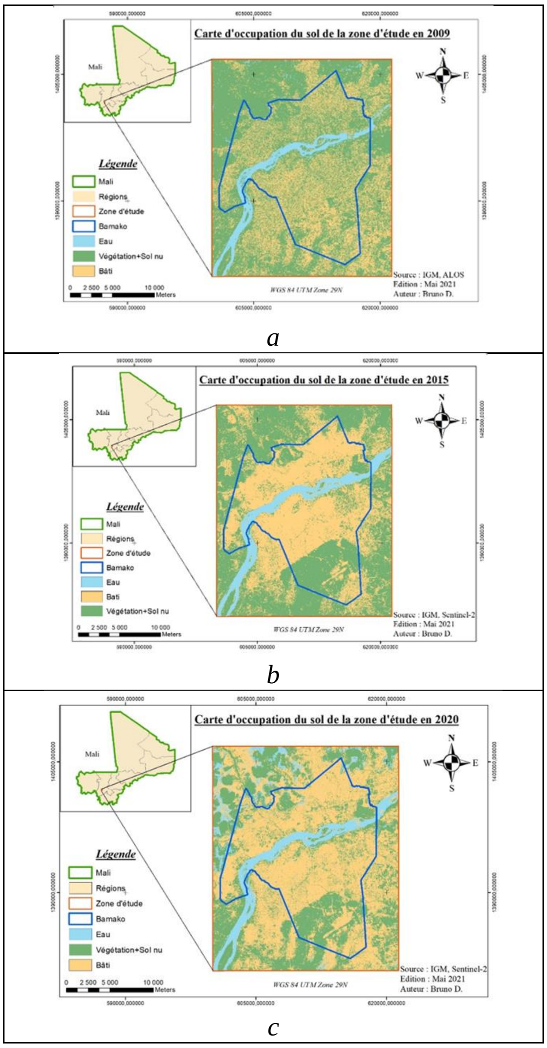

Figure 7 Land cover map of the study area (a: 2009; b: 2015; c: 2020)

Table 5 Confusion Matrix Sentinel-2 Image 2015

Cl_Va	C_1	C_2	C_3	Tot	Us_Ac	Kap
C_1	30	0	0	30	1	-
C_2	0	159	61	220	0.723	-
C_3	0	3	245	248	0.988	-
Tot	30	162	306	498	0	-
Pr_Ac	1	0.981	0.801	0.0	0.871	-
Kapp	-	-	-	-	-	**0.765**

Classes 1, 2 and 3 correspond respectively to C_1=water, C_2=built-up areas and C_3=vegetation + hills + bare ground. After grouping into two classes, the overall accuracy of the classification does not change and remains at 87%

Table 6 Confusion Matrix Sentinel-2 Image 2020

Cl_Va	C_1	C_2	C_3	Tot	Us_Ac	Kap
C_1	27	18	1	46	0.587	-
C_2	0	173	12	185	0.935	-
C_3	0	27	242	269	0.900	-
Tot	27	218	255	500	0	-
Pr_Ac	1	0.794	0.949	0.0	0.884	-
Kapp	-	-	-	-	-	**0.793**

Classes 1, 2 and 3 correspond respectively to water, buildings and vegetation + hills + bare ground. After grouping into two classes, we obtain an overall accuracy of 89%.

A minimum overall classification accuracy of 78% was obtained for the different images (Table 4) and the Kappa index has a minimum value of 71% (Table 4), which are acceptable values for classification
Once the classifications were validated, the areas of each class were calculated and the results are shown in **Error! Reference source not found.**

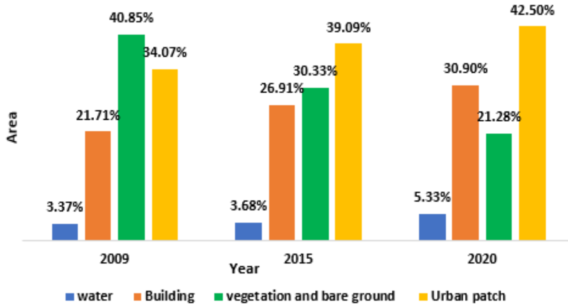

Figure 8 Area of the different classes and their evolution

Through the **Error! Reference source not found.**, we note the growth in the surface area of buildings over the different years, from 22% in 2009 to 27% in 2015 and 31% in 2020, to the detriment of vegetation and zero soil, which fell from 41% to 30% and then to 22%. Water, being mainly constituted by the Niger River in 2009 and 2015 to which small water reservoirs are added in 2020.

The evolution of the urban area over the years studied shows that urbanization has expanded more in the area from 2009 to 2015 with a rate of

5.02% than from 2015 to 2020 with a rate of 3.41%. For buildings a rate of 5.19% from 2009 to 2015 and a rate of 3.99% from 2015 to 2020.

From these facts, we observe on the **Error! Reference source not found.** the annual progression rates of each class. The built-up area is growing at a rate of 0.84% per year and the urban area is growing at an annual rate of 0.77%.

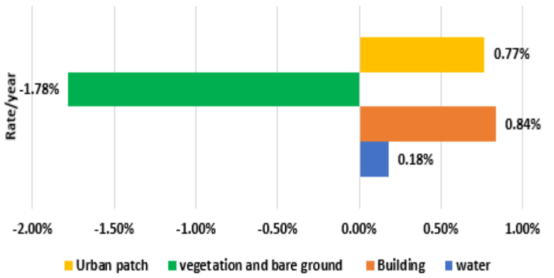

Figure 9Annual progression rate

IV.1.1 Forecast of Urban patch

By calculating the correlation coefficient between the evolution of the built-up area and the urban patch, we obtain a percentage of 99.88%, which implies that the evolution of the built-up area and the urban patch are strongly dependent to the point where one of the class can be seen through the other.

By carrying out a twin analysis of the "building" and "urban patch"with respect to the year (**Error! Reference source not found.**), we can see the evolution of the built-up area in relation to that of the urban patch: this is the notion of "building density". Depending on the year, we have a "fairly dense", "more or less dense" and "dense" urban area. The combination of these data with the data shows us that the evolution of the built-up area and the urban area are correlated with the evolution of the population.

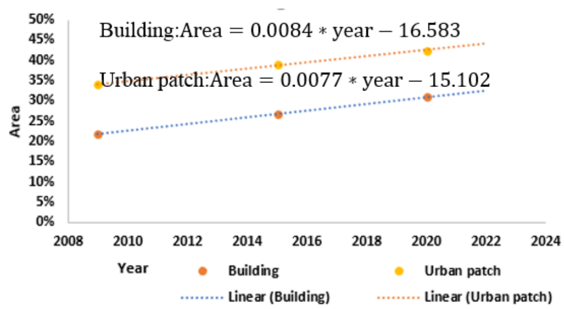

Figure 7Correlation diagram of the built-up area and urban patch

Table 7Surfaces forecast of building and urban patch

Year	2025	2030	2035	2040
Building	42.70%	46.90%	51.10%	55.30%
Urban patch	49.05%	52.90%	56.75%	60.60%

IV.2 URBAN GIS OF THE MUNICIPALITY OF COMMUNE III

The linking of shapefiles and tables allowed us to perform complex analyses and queries and therefore makes the GIS efficient. **Error! Reference source not found.**shows the relational schema obtained after linking the shapefiles and tables.

IV.2.1 Identification of illegally erected buildings

Spatial analysis by reverse query using the Completely_within algorithm identified those illegally constructed buildings that encroach on the right-of-way of public domains (here roads) (**Error! Reference source not found.**).

Our web GIS has several functionalities including incident reporting, geolocation, distance and area measurement, coordinate determination, location searches, road searches and map control (reorder, turn map layers on or off, zoom in or out at a graphical scale).All layers are overlaid on top of each other and interactive (click for attribute table information).

Accessible on all browsers, on Android phones from a URL link and easy to manipulate, this prototype allows real participation from all those who use it and goes beyond the basic functions of a web GIS through its incident reporting functionality.

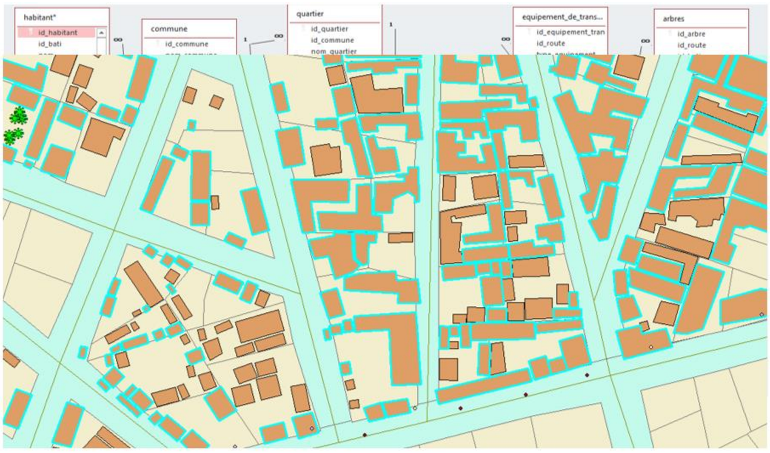

Figure 12Buildings encroaching on the road

V. CONCLUSION

The spatio-temporal study on the evolution of the urban patch class in Bamako and surroundings between the years 2009, 2015 and 2020 from satellite data was carried out. Temporal masks were developed on the classified images to allow their use in the study of urban dynamics.

The introduction of an intermediate year in our analysis allowed us to assess the importance of urban dynamics in the study area. The results showed that for the whole study area, this growth was maintained: 0.77% between 2009 and 2020.

The integrated remote sensing approach applied to the study of urban growth allows information to be obtained in a spatial context that promotes informed decision-making in terms of land use planning and environmental preservation. This approach was used in this work to detect urban forms from satellite images and to quantify the spatio-temporal dynamics of these forms.

The GIS prototype produced in the framework of this work constitutes a real decision-making tool, although it is not complete. It opens the perspectives for the enrichment of pre-existing information and the elaboration of other more specific information, in order to provide planners and managers of the urban environment with updated georeferenced cartographic documents, which can be used directly as a working and decision-making tool.

Its improvement, success and sustainability can only be guaranteed by updating the database, which could only be done by the relevant departments of the municipality.

Acknowledgements

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