A comprehensive study of using remote sensing and geographical information systems for urban planning

Hafsa Ouchra, Abdessamad Belangour, and Allae Erraissi

***Abstract*— For urban planners, the demographic surge has become a nightmare. Indeed, rapid population growth has pushed cities to expand at an unprecedented rate. This put a lot of pressure on urban planners to create new open spaces or rejuvenate old ones. As a result, in addition to strategic thinking and public participation, they rely on geographical remote sensing-based data collecting, analysis, and forecasting. Monitoring and comprehending its spatial evolution is still an important element in any approach to sustainable urban development. Local governments lack the necessary instruments, which can be updated on a regular basis, to act successfully in spatial planning and development. Spatial remote sensing and geographic information systems (GIS) provide options to tackle these challenges. One of the primary uses of spatial remote sensing is the detection of changes in land use and land cover. It is a time series comparison of satellite images. The goal of our research is to demonstrate the importance of remote sensing, specifically satellite images, in understanding urban forms, spatial planning, and monitoring the evolution of the built environment, as well as to highlight an overview of geographical data analysis methods and to present some remote sensing applications.**

***Index Terms*— Remote sensing, Geographic Information Systems (GIS), Urban sprawl, Satellites images, Urban planning, Land use.**

I. INTRODUCTION

The urban environment is characterized by the complexity and heterogeneity of its surface. The objects vary greatly in size, density, and diversity [1]. Cities, in general, undergo extensions and changes due to urban development. The study of urban growth is a branch of urban geography that focuses on cities and towns in terms of physical and demographic expansion [2].

Urban planning and management always require reliable and up-to-date information for effective decision-making. Satellite images contribute to this update and are an interesting source of information for monitoring urban development. They have the advantage of providing a global view of the environment [1]. The first uses of Landsat, Sentinel, Spot, etc. images were to study the expansion of cities, quantify and monitor the progression of urban areas at the expense of rural areas [1].

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Change detection methods rely mainly on spatial remote sensing and GIS for the acquisition, processing, and exploration of spatiotemporal data. GIS facilitates the modeling and prediction of different scenarios and their evaluation [3]. This approach allows understanding the process of urban sprawl through the identification of the different changes of occupation and land use taking place in urban and peri-urban territories [3]. This approach can help local authorities to act effectively in spatial planning, with a view to the sustainable development of territories with less impact on the environment [3, 4].

This paper is organized as follows: Section II presents a background of urban planning; Section III describes urban remote sensing. Earth observation data for urban planning is cited in section IV. Section V presents approaches to remote sensing data analysis; Section VI is an overview of satellite remote sensing software tools and finally, in section VII we draw a conclusion.

II. BACKGROUND

Urban geography is the study of urban areas in terms of population concentration, infrastructure, economics, and environmental impacts. This study has attracted the interest of a wide range of experts [2].

In recent decades, the analysis of urban growth from different perspectives has become a primarily performed operation for many reasons. Before we study the role of remote sensing for urban planning and before we present the different methods of geospatial data, we need to have a general idea of the urban ecosystem, urban growth, and urban planning.

A. Urban Ecosystem

It is a hybrid system that integrates physical, natural, artificial, social, economic, ecological, environmental, infrastructural, and institutional subsystems. These urban ecosystems are the consequence of urban development, which has resulted in the creation of rapid industrial centers and the blossoming of residential colonies, and which has also become a center of economic, social, cultural, and political activities [2]. must have at least one of these basic components [5]:

B. Urbanization Process

Urbanization, in general, is the process of growth in the proportion of the population residing in urban places. This process is characterized by greater population growth within the city as well as by the migration of people from outside, mainly rural, areas to cities [6]. The process of urbanization also involves an increase in the number of urban bangs. Agricultural land is continuously converted to urban uses in the process of urbanization around the world. As a result, rural areas are becoming urbanized as their economies become less and less dependent on agriculture [6].

C. Urban Development

It is the development and reorganization of urban space. This urban growth considers both the demographic growth of cities, the spatial extension of cities, and the multiplication in time and space of the number of cities. Urban growth only makes sense if one of these three criteria is met [7].

D. Urban Planning

It is the process of developing and designing urban areas. This process encompasses the use of open land, air, water, and the built environment, including buildings, transportation, and economic and social functions. The emerging challenges are sustainable, inclusive, compact, resilient, and smart urban development. To effectively prepare cities to meet these challenges, short- and long-term strategies are essential [8].

III. GEOGRAPHIC INFORMATION SYSTEM (GIS)

Today, the fields of application of image processing are very numerous. The main domains, which have allowed image processing to develop are the military, medical, industrial, multi-media, and geospatial domains. The geospatial field is currently an effervescent field. The tools and data are now easily accessible and available to citizens and organizations who wish to harness the power of geospatial analysis.

Fig. 1. The components of GIS [9]

Geographic Information System (GIS) make it technically feasible to integrate large amounts of data collected by various sensors as a computer system to capture, store, query, analyze and display geospatial data that describes both location and attributes of spatial features [10].

It is also provides planners with unprecedented opportunities to manipulate their information in an almost infinite number of ways, as it is an indispensable tool for resource management, emergency planning, crime analysis, public health, land records management, precision agriculture, and many other areas. GIS operations include data acquisition, data management, data query, vector data analysis, raster data analysis, and data display. Geospatial data is spatially referenced and can be vector or raster [10].

A Geographic Information System (GIS) [9] comprises hardware, software, and data that are integrated to capture, store, analyse, and display all kinds of geographically tagged information as shown in Fig. 1.

A. Hardware

A computer system's hardware is employed for data storage and processing. The computer's size is determined on the kind and nature of GIS. A small size GIS necessitated the use of a small personal computer, but a big scale corporate GIS necessitated the use of a larger computer to support the GIS. Other hardware components, such as a plotter and printer for producing maps, are also necessary in GIS. Scanners and a digitizing table are also required for scanning and digitizing the map. Field data is also collected using the GPS receiver [11].

B. Software

In GIS, software is utilized to store, analyze, and display geographical information data. The GIS has a range of tools for querying, managing, and transferring data as well as satellite imaging data. GIS software often includes a cad system for sketching and measuring purposes [11].

C. Data

Data is the most crucial aspect of GIS. The information is gathered from the residence and a commercial data source. To assist organize and manage data, most GIS applications use a DBMS to establish and maintain a database. The data in the GIS is presented in two formats. Geographical or geographical data, as well as spatial data attributes Spatial data is information that has a distinct geographical location in the form of a set of coordinates. Maps, charts, scanned drawings, import cad data, GPS receiver data, and satellite imaging data are all sources of spatial data. Attribute data are descriptive pieces of data that contain information about a certain area. Computer-stored data, databases, and messaging data are the sources of attribute data [11].

D. People

Without users, GIS technology cannot be applied. This user creates and decides on assistance tools for real-world challenges. Some people took the effort to learn how to utilize these tools efficiently. Other users simply require certain responses to their users. As a result, in order for users to make the best use of GIS, it is required to spend in workstation training [11].

E. Methods

GIS success is dependent on a well-planned implementation plan and company. What are the distinct organizational frameworks and operational practices? Using the new GIS technology necessitated the hiring of employees to use the new technology [11].

IV. REMOTE SENSING AND URBAN PLANNING

A. Importance of Remote sensing for urban planning

Remote sensing, and in particular satellite imagery, is arousing great interest among the computer science community, who seek to give machines the ability to recognize their environment through the classification of satellite images. The satellites provide images of the Earth that are collected, analyzed, and processed for civilian and military purposes. Indeed, satellite images have many applications in the fields of meteorology, oceanography, fishing, agriculture, biodiversity, geology, cartography, land use planning, war, etc. The classification of satellite images aims to transform the images into usable information rather than having the image of a place.

The information provided by remote sensing analysis can help inform the planning process to promote sound land management. Time series satellite imagery can play a critical role in observing growth patterns. Therefore, sound urban planning and sustainable management of urban growth are critical to human, economic, and environmental well-being during periods of high growth [12].

B. Satellite Remote sensing and GIS applications

Remote sensing and GIS can contribute to many tasks in the field of urban planning [12]:

- Land use planning and sustainable development.
- Land market development and monitoring.
- Infrastructure planning.
- Informing stakeholder communities.
- Facilitating inter-city and intra-departmental collaboration through information sharing.
- Environmental and resource planning, including farmland conversion and preservation of cultural sites and areas of historic value.

C. Challenges for Urban Planning

There are many barriers that limit the use of spatially explicit land use information that can be derived from remote sensing. Perhaps the most common barriers are limited access to and availability of satellite imagery, the level of technical expertise required to use the data beyond visual interpretation, and the costs associated with developing and maintaining large geospatial databases. Implementation of development strategies and satellite data is often unavailable to project managers engaged in planning [12].

V. EARTH OBSERVATION DATA

Earth observation (EO) data give quantitative information that is temporally and spatially more consistent than traditional land-based surveys [8]. They allow the derivation of a variety of physical, climatic, and socio-economic indicators to support urban planning and decision-making. Generally, EO data offer many opportunities for mapping and monitoring urban areas [13, 14].

They are increasingly available but are often not easily accessible to key actors in urban planning and decision-making. Earth observation is modern science, which studies the evolution of the earth's environment, using remote sensing data such as satellite images and aerial photographs [2].

A. Types of GIS Data

a) *Vectorial data types*: are employed in nature to express discrete properties. It is the best surface representation approach in SIG and has a multi-layered architecture that represents the point, line, and polygon [9]. Vectorial data types employ a hierarchical structure to describe information from sources such as highways, rivers, cities, lakes, and park boundaries. The vectorial data model makes it simple to extract contour, interpolation, élévation, and other features. The translation of matricial data into vectorial data is shown in Fig. 2 [15].

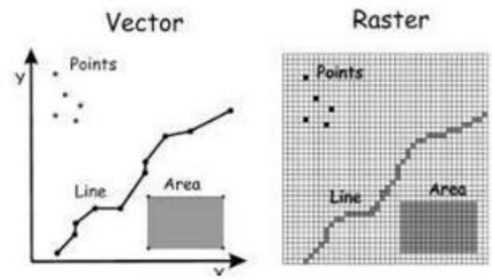

Fig. 2. Vector vs Raster Data [9]

b) *Raster data formats:* are grids of rows and columns with pixel color values recorded in each cell and contiguous attribute values [15]. They are used to properly represent geographical data about real-world items such as aerial pictures, scanned maps, and remote sensing data. They are the best method for expressing two-dimensional spatial elements including lines, regions, and networks [9].

B. Aerial photography

Aerial photography has a very long archive of data, while satellite remote sensing for earth observation started in 1972 with the first launch of the Landsat satellite [2].

Aerial photography has long been used as a tool for urban analysis [12]. They provide information that can significantly improve the efficiency of planning and management of cities and towns. They are also relatively inexpensive, accurate, reliable, and can be obtained at any desired scale, but they are not useful for large metropolitan areas [16]. That's why, today, not only the aerial photographsthat are available but also the satellite sensors dominate more and more many fields of application, including urban analysis.

C. Satellite data

Information derived from remote sensing can help describe and model the urban environment, leading to a better understanding that benefits applied urban planning and management [17]. A report published by NASA highlighted the fact that advances in satellite-based land surface mapping are contributing to the creation of much more detailed urban maps, providing planners with a much deeper understanding of the dynamics of urban growth and sprawl, as well as related land management issues [2].

Numerous technical improvements have led to earth observation satellites, such as the advanced Landsat (TM and ETM+), SPOT, and Indian Remote Sensing (IRS) LISS sensors, which are second-generation satellites. Since 1999, there has been a third generation of earth observation. Fig. 3 shows other satellite remote sensing applications.

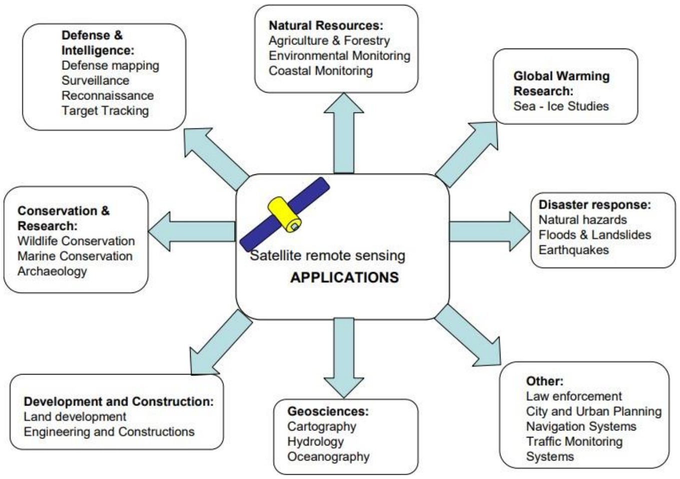

Fig. 3. Remote sensing and GIS applications [18]

Satellites with very high geometric resolution (IKONOS-2, QuickBird-2, OrbView-2, GeoEye-1, Cartosat, etc.). This has led to an increasing number of urban applications using remotely sensed data since the requirements for the desired level of detail can be met either by airborne or satellite sensor systems [2]. Each of these satellite data is different in spatial, spectral, and temporal resolution. Table 1 shows the characteristics of some satellites [19].

TABLE I. OVERVIEW OF SOME SATELLITE DATA

Satellite data	Waveband	Spatial resolution (m)	Temporal resolution
Formosat -2[20]	Multi-spectral, Panchromatic	1.5-6	Daily
Quickbird [21]		1- 4	3-4 days
Landsat [22]		15-60	16 days
IKONOS [23]		0.8-4	2-3 days
Spot-5 [24]		2.5-10	2-3 days

VI. REMOTE SENSING DATA APPROACHES

New strategies also had to be developed for efficient information extraction. Jabari and al [25], Pelletier and al [26], Firozjaei and al [27], and many approaches to remote sensing classification, particularly satellite pictures, have been introduced by D. Jawak and al [28], including pixel classification, object-oriented classification, and CNN classification. The classical pixel-based classification is no longer the best methodology applied when using third-generation images with high spatial resolution. Therefore, object-oriented approaches or sub-pixel analysis, for example, have proven to be better in many cases [2].

TABLE II. Difference between PBC and OOC

Attributs	Classification approaches	
	Pixel-based classification	Object-oriented classification
Spectral/Color	✓	✓
Form/Shape	X	✓
Area/Size	X	✓
Texture	X	✓
Content	X	✓

A. *Pixel-based classification*

Pixel-based methods are based on pixel-by-pixel classification of remotely sensed images, using the combined spectral responses of all pixels in the training set for a given class to decide whether different pixels can be grouped together to have similar features [29]. This approach is very effective for low spatial resolution data but it is not ideal for high resolution satellite data because it cannot distinguish surface features that have different objects with the same spectral characteristics. There are two types of classification methods: supervised and unsupervised.

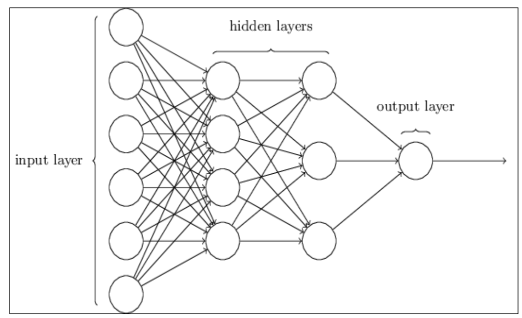

Fig. 4. Neural Network architecture [30]

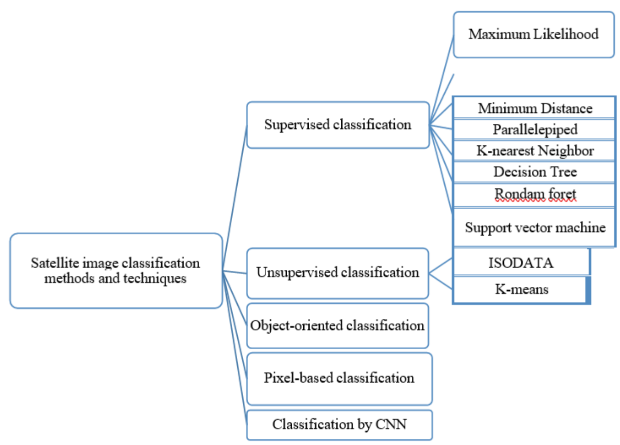

Fig. 5. Satellite image classification methods and techniques [31]

- Unsupervised Classification

It is based on grouping pixels into a number of spectral classes. The spectral classes are manually labeled into the classes of interest [29]. Iterative Self Organizing Data Analysis Technique classification is the most commonly used method in remote sensing. It is an unsupervised learning method that creates a predefined number of unlabeled clusters in an image and requires several parameters that control the number of clusters and iterations to be performed. ISODATA uses the cluster- busting technique to label complex classes [32].

- Supervised classification

It is based on the selection of representative pixels for each of the desired classes and then the execution of one of the classification algorithms that label the pixels of an image as information classes. Maximum likelihood classification is the most common supervised method in the literature [29].

Generally, ISODATA and Maximum Likelihood Classification methods are the most common methods applied for pixel-based analysis. A simplified illustration of the image satellite classification methods is shown in Fig. 5.

B. Object-based classification

This type of analysis uses image classification methods that pass the classification through image objects, which are pre-established after a segmentation process. Segmentation is an image processing operation that aims to divide an image by grouping pixels (Objects) according to predetermined criteria [33].

According to D. Jawak and al [28], Xiaoxia and al [34], the process of this approach is as follows:

- Object-based methods are based on the object-oriented classification that initially performs segmentation of the entire image into consistent groups of pixels that are called segments.
- The user then creates a set of classification criteria based on their prior knowledge.
- Then, the classifier is chosen to assign each segment to the appropriate class according to a set of defined rules.

It is an unsupervised technique in object-based classification if decisions are made based on the degree of similarity to class definitions that are described by one or more conditions. When class assignments are based on statistical calculations between the image objects to be classified and the training set such as the K-NN method, the method is said to be supervised [29].

In this method K-NN, the spectral distance between two pixels is utilized to assess variation and determine class similarity. It is a non-parametric method, its principle is that the class of a new sample pixel is based on the distance between the k nearest sample points in the feature space [32].

The advantage of this approach is to improve the accuracy of the classification because it uses all spectral, spatial, contextual and textual information as shown in this table 2, but this approach faces a limitation which is the segmentation error.

C. Convolutional neural network-based classification

Researchers often use statistical modeling and machine and deep learning algorithms, including convolutional neural networks (CNN), recurrent neural networks (RNN), and generative adversarial networks (GAN) [35, 36]. These methods offer new strategies for addressing complex geospatial data analysis tasks [30, 26]. The capacity to learn sophisticated hierarchical features from multiple data sources allows deep learning methods to extract meaningful spatial and temporal patterns and infer information about the physical domain of urban areas and more abstract variables related to the socio- economic conditions and quality of life of their inhabitants [8].

This approach is more suitable for remote sensing image classification, especially hyperspectral and satellite image time series (STIS) classification [26]. The latter is an ordered set of images of the same scene acquired at different dates. This type of data provides rich information on the temporal evolution of the studied area and combines high temporal, spectral, and spatial resolutions that allow to closely follow the vegetation dynamics [26].

Generally, methods based on convolutional neural networks such as RNN, TempCNN, etc., have also been used to analyze and detect urban changes [26]. A simplified illustration of the neural network architecture is shown in Fig. 4.

The advantage of this approach is that deep learning methods such as RNN, CNN, TempCNN ... in general outperform traditional classification algorithms, such as RF because they do not treat temporal features. But the limit that meets this approach is the processing time because these methods are longer to train. This approach is based on neural networks.

VII. Conclusion

Spatial remote sensing and geographic information systems (GIS) provide options to tackle these challenges. One of the primary uses of spatial remote sensing is the detection of changes in land use and land cover. It is a time series comparison of satellite images. The goal of our research is to demonstrate the importance of remote sensing, specifically satellite images, in understanding urban forms, spatial planning, and monitoring the evolution of the built environment, as well as to highlight an overview of geographical data analysis methods and to present some remote sensing applications.

This study also depicts the urban ecosystem and the role of remote sensing in urban planning, as well as some remote sensing and GIS applications, and provides a brief overview of various geospatial image processing approaches such as object-oriented classification, pixel-based classification, and CNN classification. Many scientific works aim to discover approaches to satellite image processing for better urban planning, and many researchers have discovered that CNN and object-oriented classification algorithms and methods are the only ones that work, and they have obtained better classification results in terms of accuracy.

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