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APPLICATION OF GEOMATIC TOOLS FOR THE DIACHRONIC MONITORING OF LANDSCAPE METRICS IN THE NORTHEASTERN ALGERIAN HIGHLANDS, CASE OF THE CITY OF SETIF

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Summary

Geomatic tools could be used efficiently for urban development planning. The problem of the study lies in the extensive land use of terrains that are now suitable for heavy construction which slows down the development of new facilities. Furthermore, the authorities are forced to plan future settlements around Setif, at a distance of 8 to 12 kilometers from the city limits, threatening the long-term viability of construction and the ring of farmland that connects them to the core city. This must be done during the planning stage based on a diachronic analysis of all the natural and physical factors/parameters. The main objective of this research is to explore the application of landscape metrics to the analysis and monitoring of urban growth in the city of Setif, north-east of Algeria. For this purpose, our research paper uses Geographic Information System (GIS) and Remote Sensing (RS) techniques based on Principal Component Analysis (PCA) and the Angle Mapper Algorithm (SAM) target method for the analysis of urban land planning and sustainable urban planning of Setif. In the result of these analyses we propose suitability/buildability maps with more suitable construction sites. The research method is based on a 17-year time series dataset compiled from the Sentinel 2A and Landsat imagery between 2004 and 2021. Additionally, we used a cadastral Vs geotechnical overlay to estimate soil capacity. This work proves again that the integration of RS and GIS techniques allows for scientific identification of the lands suitable for urban development (LAUP).

Keywords

LAUP • GIS • RS • PCA • Sentinel 2A • Landsat

1. Introduction

The success of the land artificialization strategies constitutes a crucial aspect for the stakeholders involved in the territorial architecture. A comprehensive analytical framework, combined with a quantitative modelling techniques of urbanized spaces, is necessary for a thorough understanding of the concepts, tools, and knowledge related to urban planning This framework should also account for the natural and physical conditions. The city can be viewed as a specific urban system with economic and social characteristics, corresponding to interactive functions within and beyond its limits [Wu 2008]. These urbanized spaces form a puzzle vector aggregation composed of nested heterogeneous elements [Mckinney 2006]. Thus, this structure complicates the planning of urban and peri-urban areas [Weber 1995]. By redesigning landscape structures, disrupting the ecological continuities, and isolating natural ecosystems, urban sprawl raises concerns among policy makers and researchers. Urban growth can be compared to an intermittent and/or continuous fluctuation between the continuous expansion of the already existing urban and the conversion of new distant spaces. The urbanization of intra-urban vacant spaces takes place through the creation of new isolated fragments or through the continuous expansion of the original urban spot. Consequently, Liu et al. [2010] distinguish three types of urban expansion: 1) edge expansion; 2) the outlying, and 3) infilling (Fig. 1).

The application of geomatic tools for the assessment of the evolution of earth landscape and land management gives interesting results in regard to both natural and anthropogenic factors [Hamad et al. 2018]. Remote sensing can provide earth observation information for interface discrimination, especially in difficult terrain where field surveys are hard to carry out. The GIS and RS techniques are often used together by several researchers in natural hazard assessment [Hadji et al. 2014b, Zahri et al. 2016, Dahoua et al. 2017a, b, El Mekki et al. 2017, Rais et al. 2017, Anis et al. 2019, Ncibi et al. 2020a, b]. They are very useful for geological [Hadji et al. 2014a, Tamani et al. 2019], geotechnical [Achour et al. 2017], hydrogeological management [Hamed et al. 2014, Demdoum et al. 2015, Mokadem et al. 2016], as well as for natural hazards mitigation [Hadji et al. 2013, Mahdadi et al. 2018], and disaster management [Hadji et al. 2017a, b, Mouici et al. 2017, Manchar et al. 2018].

The municipality of Setif is experiencing exponential urbanization at the expense of agricultural land. Moreover, new settlements are planned to surround the city, which could negatively affect the sustainability of land management and the harmony of the physical and natural environment. The support of geomatics tools such as GIS and remote sensing could be very useful to provide smart solutions to urbanization problems in the highland region.

Spatial metrics have aroused great interest among researchers and planners concerned with the urban environment. They are used for the diachronic monitoring of the patterns that organize the urban and peri-urban landscape [Fu and Chen 2001] and/or for the evaluation of the spatio-temporal process of urbanization of cities [Herold et al. 2002]. The suitability of this technology for the fields of architecture and urban planning has been extensively discussed in the scientific literature. Thus problems of scale, spatial resolution of data and the validity of classifications have been widely addressed [Herold et al. 2003]. Remote sensing provides indicators whose accuracy depends on the spatial resolution of the sensors [Skupinski et al. 2009]. Individual objects can appear compact or aggregated, and the spatial measures derived from these images are determined more by the shape of the pixels [Milne 1991]. Multiple classifications of the same region using different classes depend on how these classes are defined. Thematic quality relies on the difference in contrast between the classes and on the resolution of the sensor: the lower the spectral separability of the objects, the less accurate the land cover mapping [Anderson et al. 1976]. The accuracy of a classification is also connected to the number of classes considered. The choice of the nomenclature to classify the remote sensing images must therefore be made according to the spatial resolution of the sensor and the number of thematic classes required to generate the spatial metrics.

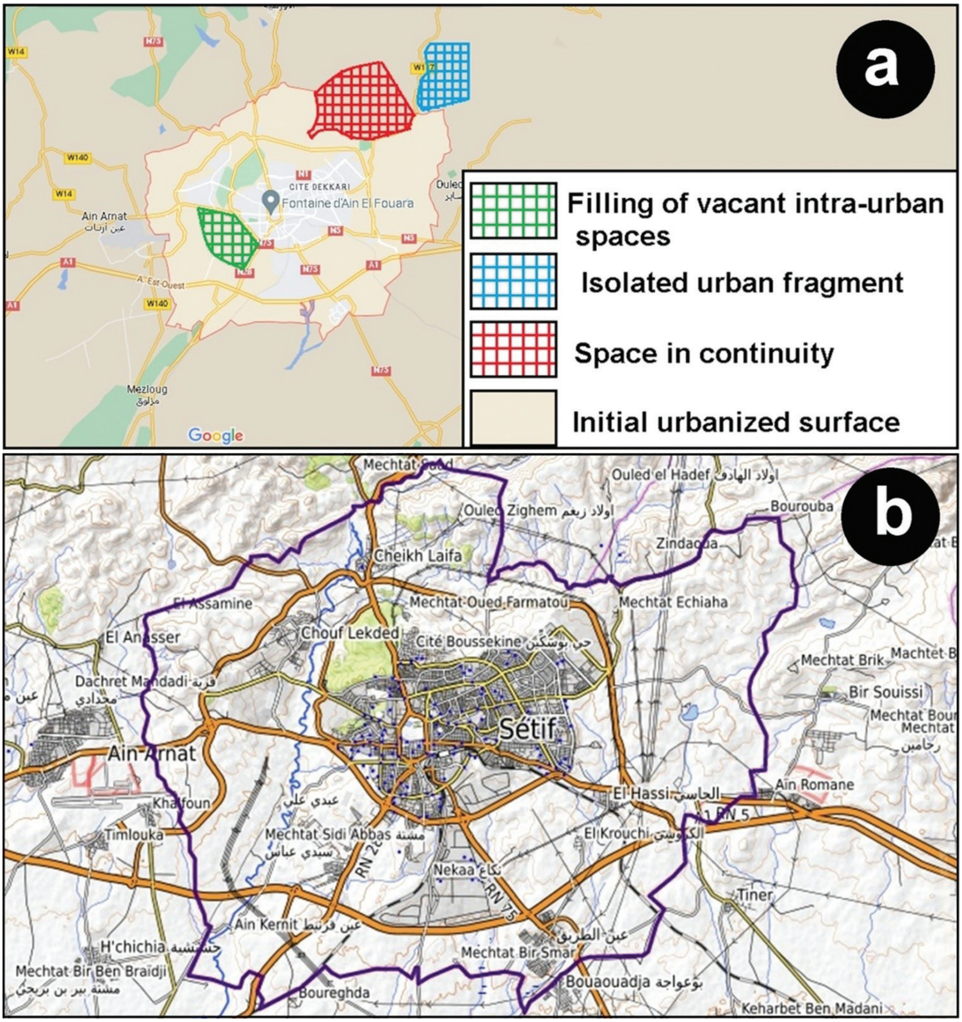

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Fig. 1. a) types of urban expansion. b) urban development plan of Setif municipality

Thus, a rough classification into two main types of land cover, including artificial surfaces and non-artificial surfaces, is a priori suitable for high-resolution imagery. According to Herlod et al. [2005], this heterogeneity is determined by the spatial resolution of the data, the extent of the study area and the nomenclature used to map land cover. The aim of this article is to explore the use of landscape metrics for the analysis of the urban spot and its evolution, based on a series of satellite images of Setif taken over a period of 17 years (2004–2021) (Fig. 2).

Source: Authors' own study

Fig. 2. Panoramic view of the western part of the city of Setif

2. Study area

Setif is the capital city of the province of Setif. It is located 276 km northwest of the capital Algiers (Fig. 3). The province of Setif covers an area of 6500 km^2 and has a population of 1,800,000. This administrative wilaya has the second-largest population, after the capital Algiers. The Setif province's capital, where 300,000 inhabitants dwell, has become a major economic center. The realization of the Setif tramway has transformed the downtown traffic plan, and served the case of the main avenue of the city 'Avenue du 8 Mai 1945'. It has become an essential element of the public space in the city. The Setif province is classified as a zone IIa (medium seismicity), characterized by a tectonic activity that manifests itself in earthquakes of more or less high magnitude [Karim et al. 2019]. The design and implementation of the expansion of the city must take into account the seismicity of the region and respect the regulations in force. The history of the region's social fabric can be divided into following periods: 1) The pre-colonial era that was characterized by a stable and harmonious social fabric and a self-sufficient economy. 2) The colonial era that was characterized by a dualistic and discriminatory society, and an economy that was dependent on the colonialist metropolis. The post-colonial period that was characterized by an economy of a primacy of urban capital and the opposition between towns and the countryside. The dark decade that was characterized by a multifaceted restructuring resulting from the security situation.

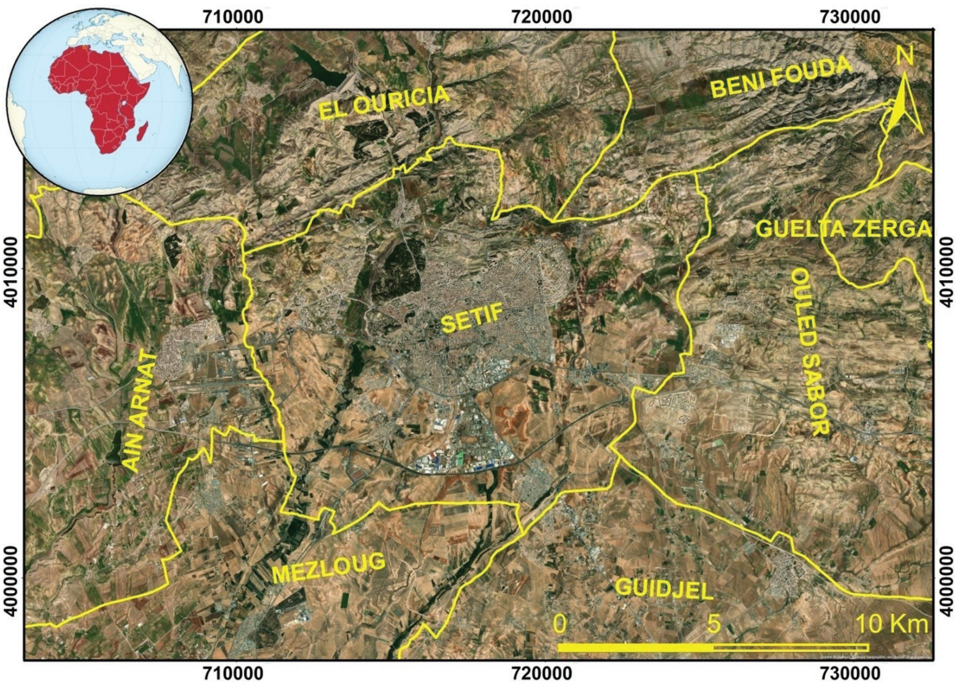

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Fig. 3. Location of study area against the neighboring administrative municipalities

3. Material and methods

3.1. Data acquisition

Since our study focuses on large-scale land cover analysis, the use of high spatial resolution optical images is more appropriate. To cover the entirety of the study area, we used high spatial resolution imagery provided by the ETM+7 (Enhanced Thematic Mapper) sensor of the Landsat 7 TM satellite with a spatial resolution of 30 meters (Table 1) [Angal et al. 2010]. The Landsat 7 images were acquired on 15/07/2004, 22/08/2006, 24/04/2009, 22/08/2012, 28/06/2005, 26/10/2018, and 19/01/2021 to monitor the development and the evolution of Setif city during the period of 2004–2021. This series of images was mostly taken at a time of year when the probability of obtaining sharp and contrasting images is the highest [Demaze 2010]. We applied radiometric calibrations and atmospheric corrections (pre-processes) to these scenes. Seven ETM+7 images were acquired from the United States Geological Survey 'USGS' (http://earthexplorer.usgs.gov), as primary remote sensing data, which we used the same geometric correction: radiometric calibration, atmospheric correction (FLAASH), and the land sat gap-fill preprocessing of the images.

Table 1. General characteristics of the used sensor

Satellite/ sensors	N° and width of the spectral bands (µm)	Domain	Spatial resolution (m)	Size of the scene
Landsat 7 / ETM +7	1: 0.45 to 0.52 2: 0.52 to 0.60 3: 0.63 to 0.69 4: 0.76 to 0.90 5: 1.55 to 1.75 6: 10.4 to 12.5 7: 2.08 to 2.35 8: 0.51 to 0.90	Blue (visible) Green (visible) Red (visible) Near infrared Mid-infrared Thermal infrared Far infrared Panchromatic	30 m × 30 m 30 m × 30 m 30 m × 30 m 30 m × 30 m 30 m × 30 m 60 m × 60 m 30 m × 30 m 15 m × 15 m	170 × 185,2 km

3.2. Data processing

Among multiple treatments available (PCA, BR and MNF…) we have chosen the minimum noise fraction method (MNF) [Green et al. 1988]. This algorithm consists of two consecutive data compression operations. The first is based on an estimation of noise in the data as represented by a correlation matrix. This transformation decorrelates and rescales the noise in the data, by variance. At this stage, the information about band noise has not been taken into account. The second operation includes the original correlation and creates a set of components that contain weighted information about the variance across all bands in the raw data set [Soulaimani et al. 2014].

3.3. Classification

We applied the supervised classification Spectral Angle Mapper algorithm method (SAM). This classification method allows rapid mapping by calculating the spectral similarity between the image spectra and reference reflectance spectra [De Carvalho and Meneses 2000, Schwarz and Staenz 2001, Hunter and Power 2002].The reference spectra can either be obtained from laboratory or field measurements or extracted directly from the image. SAM measures the spectral similarity by calculating the angle between the two spectra, treating them as vectors in dimensional space [Van der Meer 2006]. Small angles between the two spectra indicate high similarity and large angles indicate low similarity.

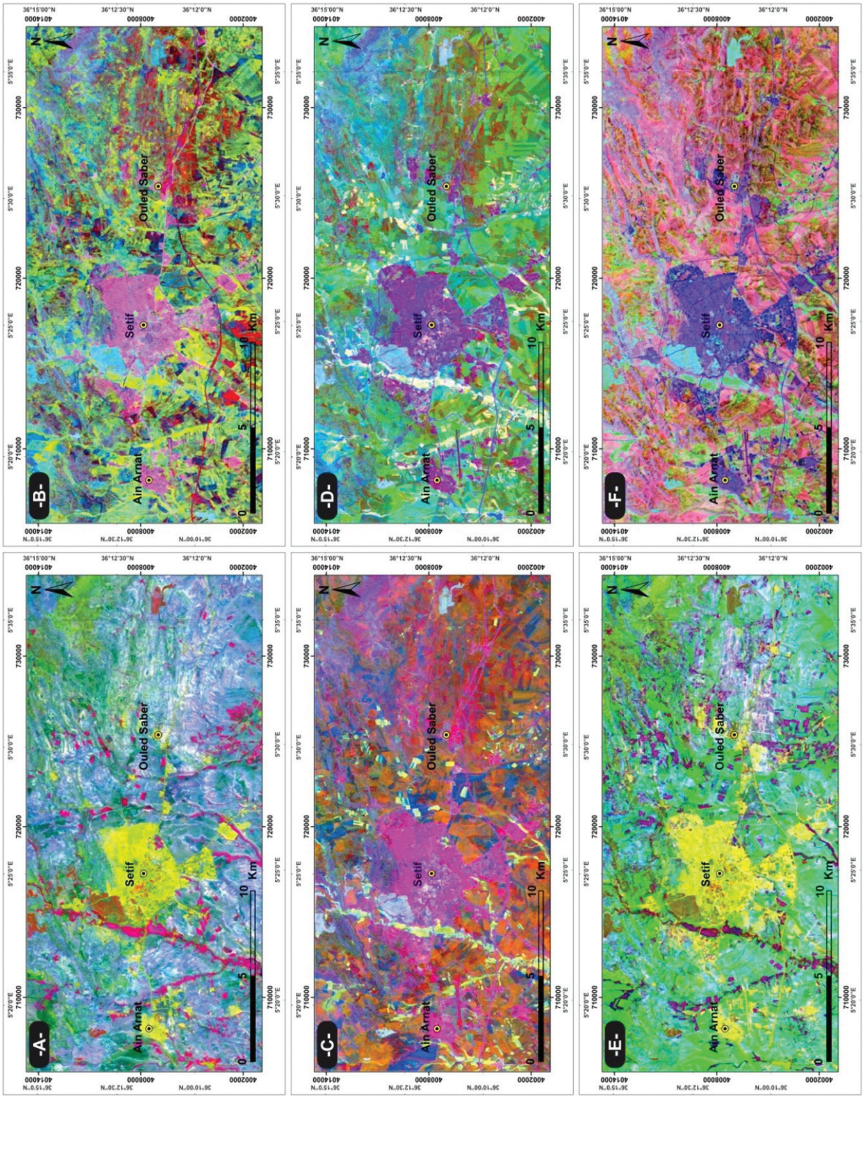

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Fig. 4. False-color composite of the MNF '2004 to 2021' (R: MNF3 – G: MNF2 – B: MNF1)

4. Results and discussion

Our results demonstrate that satellite RS is a valuable tool to generate information for urban area mapping even at parcel level. Sentinel 2-A images were good enough to generate the integral land use/land cover.

The methodological processing of high-resolution satellite data using ENVI software has successfully generated the cadastral layer with a full matching of geo-referenced POS-PDAU plans. We effectively used the multi-Criteria evaluation of urban land suitability analysis. We selected several models to evaluate the sensitivity of the factors at both the city and parcel level. The urban land suitability analysis does not demand micro-level classification, therefore a broader classification of land use and land cover has been adopted. Due to the high spatial resolution satellite image, it was possible to create a cadastral layer or parcel boundary layer .

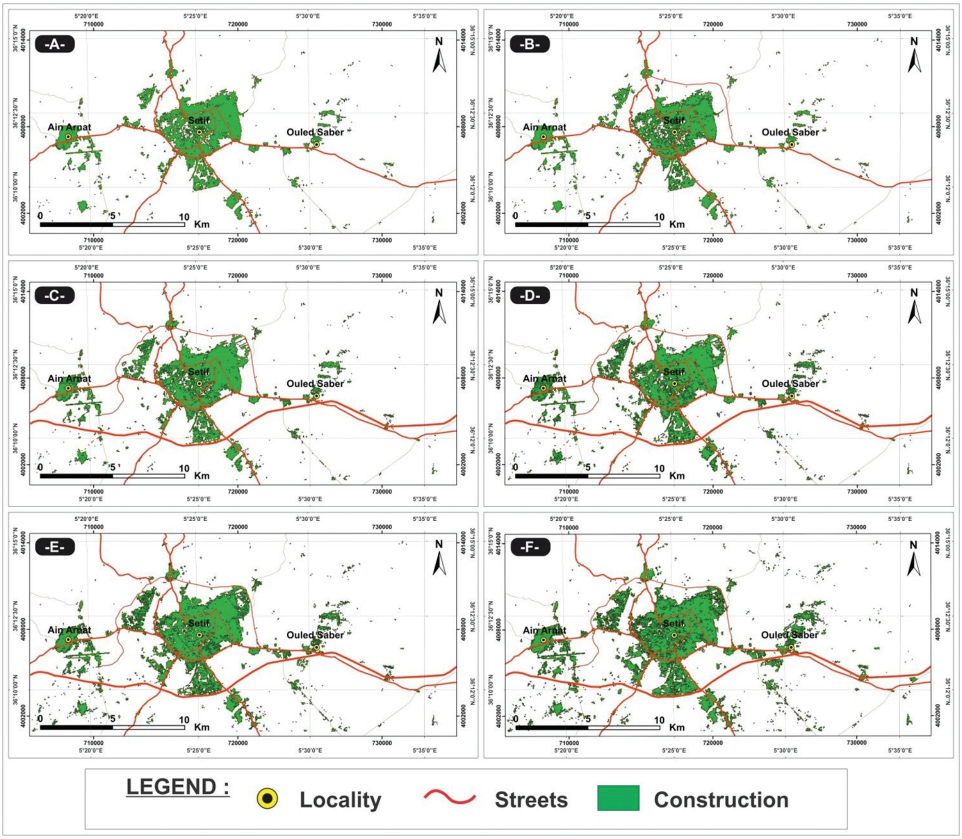

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Fig. 5. Distribution of build-up areas (2004–2021), obtained by the SAM target method

As an experiment, the use of false-color combinations (R: MNF 3 – G: MNF 2 – B: MNF 1) proved its ability to discriminate buildings in our study area (Fig. 4). Several locations were used as references to extract the spectral signatures of buildings from the false-color images.

The results of the supervised classifications SAM Target (Fig. 5), on the scenes used based on the already extracted spectral responses, show an exponential expansion of the study area in the period of 2004–2021. The build-up area reaches approximately 16768522.7 square meters. The build-up areas grow in all directions, mainly along the east-west axis.

The comparison of the plans of build-up areas from the period of 2004–2021 on the Territorial Development Master Plan (PDAU) shows the intentional non-compliance on the geographic scale marked in Figure 6.

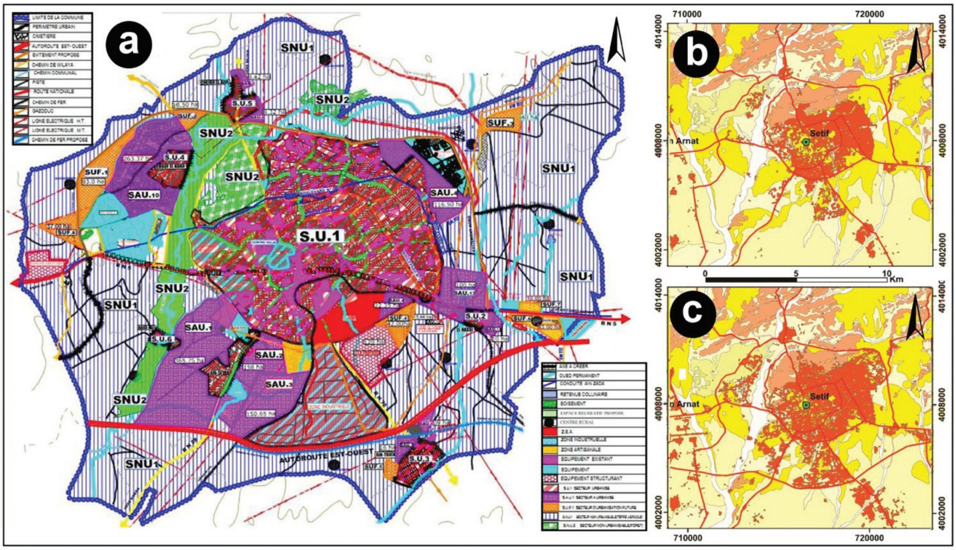

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Fig. 6. Comparison of the a) PDAU, with b) the build-up area in 2004 and c) the build-up area in 2021

5. Conclusion

Finally, it can be concluded that the use of RS and GIS techniques for spatial planning is a powerful analysis and visualization tool for the assessment and monitoring of urban development. The generated data and thematic map express the usability of Sentinel 2A multi-spectral data for effective and rapid mapping of the land-use and land cover features. Our case study (Setif city) has presented a typical problem that the policy makers and urban planners have to face, involving mainly the identification of land suitability for urban development at a cadastral level using geomatics tools. Our aim was to produce suitability/ buildability maps for the correct selection of construction sites. This must be decided in the planning stage based on the RS/GIS technology combined with the diachronic monitoring of the expansion of Setif (over a period of 17 years in our study) to see the build-up main axis. Once the build-up axis and the geotechnical properties of the site are known, it will be very easy to plan and adopt the appropriate construction modes, and to select the correct construction site according to the requirements of the planning stage.

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