DETECTING CHANGES IN LAND OCCUPATION AND USE (BETWEEN 1984-2021) USING "GEE" AND GIS TOOLS: FOCUS ON THE GREEN STRUCTURE OF THE FUTURE METROPOLIS OF ANNABA (NORTH-EAST ALGERIA)

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ABSTRACT

Annaba, Algeria’s fourth largest city, has acquired national and international importance due to its openness to the Mediterranean Sea. Over the last ten years, its rapid sprawl has continued to exacerbate the situation, leading to increased consumption of space, particularly green structures. The main objective of this study is to assess changes in land use and land cover (LULC) over the last 30 years, focusing on the green structure of the future metropolis.

Google Earth Engine (GEE) was used to explore land cover classification using the random forest algorithm. A spatial model of the main changes in land cover between 1984, 2004 and 2021 was also generated.

The principal drivers of land use change are human activities and urbanization, including fires and land clearing. The spatial pattern of change is mainly due to inappropriate investment policy and uncontrolled urbanisation. This is explained by the main results of the land use conversion processes between 1984 and 2021. The comparison shows a decline in forests and green land, mainly due to conversion to urbanised land, cropland, bare land or other land. Similarly, bare land and other types of land declined over the 1984-2004 period in favour of urbanised or cultivated land. Furthermore, it compromises any possibility of sustainable development at a time when we are facing climate change.

Keywords: Annaba, Google earth engine, Green structure, LULC, Random forest, Urban growth

Introduction

As a result of urbanisation, it is estimated that around 54.5% of the world’s population lives in cities. This figure is expected to rise to 66% by 2050 (UNITED NATIONS, 2014). Between 2000 and 2030, urbanised areas will increase due to the lack of urban regulation and the rapid development of countries (Bhatta,
2010), which has led to a mismatch between the city and its green structure: every day, green spaces disappear in favour of grey spaces and concrete. The disappearance of natural landscapes, biodiversity and agriculture has particularly affected local people, who are faced with the loss of their familiar landscapes. The green structure has been completely disrupted, if not destroyed. The consequences of this phenomenon will inevitably affect the socio-economic and physical dimensions of the urban environment. The result is pressure on resources, ecological degradation, changes to the local climate and an increase in the urban heat island effect (Fashae et al., 2020), in particular the absence and retreat of green networks due to the disruption of green structures. Green is often used as a structuring element of the city, including the green belt, the green promenade, recreational spaces and lawns, urban parks and sports fields (Kerbouch, 1998). The green structure also includes agriculture, agroforestry, forestry, natural areas (valuable areas and landscapes as well as protected ecosystems) and uncultivated land. It is also the link between urban and rural areas (Banzo, 2007).

The importance of green spaces in cities has been recognised for decades. Integrated into overall green structures, they have been the subject of international studies, particularly in the last ten and fifteen years (Giacché, 2008). Green structures in cities are very important and must be taken into account. More than a response to a social or cultural demand, they meet an environmental need, particularly in the face of climate change (Long & Tonini, 2012). They help to reduce changes in the local climate by creating a cooling effect and providing fresh air. Several studies have demonstrated the role of green spaces in reducing the high temperatures, which is caused by the urban heat island effect, by maintaining a cooler temperature. This cooling effect often extends beyond the boundaries of these areas (Gherraz et al., 2020; Kim, 1992; Hassan et al., 2021).

Research and studies on green spaces in Algeria, especially in certain Mediterranean cities, often focus on the appropriation, management and practice of green spaces (Aouissi, 2015).

Recently, a number of studies have used digitisation, especially Geographic Information Systems (GIS) and remote sensing for different topics such as urban sprawl (Guechi et al., 2021; Saouli et al., 2020; Lin et al., 2020), since urbanisation and urban expansion are among the main catalysts of land use and land cover change with temporal and spatial impacts on green structures and impacts on biodiversity (Aguejdad et al., 2016). Today, if we want to curb the invasion and disappearance of these vital elements, the use of remote sensing and GIS is highly topical and relevant, especially for monitoring the evolution of green components in the face of urbanisation and sprawl. The use of digitisation to study the decline or deterioration of green structures and their impact on the environment and ecosystems in the context of urban growth can contribute to the formulation of sustainable strategies for the future development of our cities.

Annaba, Algeria's fourth-largest city, is recognised at national level as a "future metropolis" (SNAT, 2030) and bears an international importance due to its openness to the Mediterranean. It lies at the crossroads of various economic, industrial and tourist centres, as well as natural resources such as the future Edough National Park, the Fezzara Lake Ramsar site and the Boukhmira wetland. As a result of the population explosion and rural exodus (625,689 inhabitants according to the RGPH 2008, 759,1374 in 2030), the town is currently undergoing a number of transformations and it is experiencing a high rate of demographic growth, particularly in rural areas. As a result, the environment has been affected and all sectors, especially green spaces, have been particularly consumed (Noui, 2009). Annaba is seriously affected by urban heat islands, air pollution and increased noise pollution (Dahech & Sainia, 2019), which has a negative impact on sustainability and quality of life. Increasing urbanisation is leading to a considerable artificialisation of the natural soil of its territory. This desire for urban expansion overrides any ecological concerns (Zennir, 2019).

Remote sensing and GIS are innovative tools for decision-makers, particularly for achieving sustainable development. The objectives of this work are as follows:

- To study the main factors leading to rapid change, focusing on the green structure;
- To avoid hasty measures which reduce green areas under the pretext of urbanisation needs.
- Provide local decision-makers with a plan for the future of green structures to avoid their encroachment and deterioration.
- Emphasise the restoration of sites that can contribute to the reconstruction of the green structure.
- Propose the conversion of certain abandoned areas into green spaces in order to preserve the green structure and its links with other green spaces.

Diachronic approaches make it possible to identify and quantify changes in land use, occupation and the state of the green structure in response to these changes. This also provides a better understanding of the spatio-temporal changes that the green structure has undergone over time in relation to patterns of urbanisation and urban sprawl (Saouli et al., 2021).

The use of GIS as a decision support tool and the application of remote sensing techniques are now widely recognised as highly relevant for monitoring and managing land cover and land use change (Mering, 2008; Diédhiou et al., 2020). These techniques have demonstrated their ability to provide up-to-date spatial information on these changes. We have developed a framework for regular monitoring of changes using new open source geospatial technology platforms such as Google Earth Engine (GEE). Google Earth Engine (Zurqani et al., 2018; Lin et al., 2020; Liu et al., 2020; Pérez-Catiliac, 2023) is a useful platform for exploring land cover classification and spatial patterns of major changes. In terms of accuracy, the Random Forest classification algorithm, known for its efficiency, provides higher results than other classification algorithms (Tsai & al., 2018).

**Description of the study area**

**Geographical location of the study area**

Annaba is located in the extreme northeast of Algeria, on the southern coast of the Mediterranean, between the northern latitudes of 36°36’ and 37°05’ and the eastern longitudes of 07°17’ and 07°49’. It has an area of 1,439.20 km² and it is bounded by the following geographical features:

- To the north: the Mediterranean Sea;
- To the south: the Wilaya of Guelma;
- To the east: the wilaya of El Taref;
- To the west: the wilaya of Skikda.

The geographical peculiarity of the future metropolis lies in the fact that it is located between brutal reliefs: a territory with a landscape of plains, mountains, hills and coasts: a large part of this Mediterranean metropolis is developed on the plains, which represent 18.08% of the territory, or 255 km². The northern part of the future metropolis is dominated by the extensive Edough mountains, which surround the city. These mountains occupy 52.16% of the wilaya’s territory, with a surface area of 736 km². The hills and foothills occupy 25.82% of the total area or 365 km² (ANDI, 2013). It also has a fairly dense hydrographic network, consisting of Lake Fetzara (fresh water), which extends over 18,670 ha, and the Oued Seybouse with a length of 127.5 km (Figure1).
The area defined for this study covers approximately 526.25 km². It is made up of the following municipalities Annaba, El Bouni, Sidi Ammar, El Hadjar, El Berda, Beraheb, Oued El Aneb and the new town of Draa Erich. The region is characterised by plains 25 metres above sea level. The highest elevation is Mount Edough, the future national park, at around 1,000m. The plains extend mainly to the west, east and south, while the mountains and hills lie to the north and partly to the south. The study area contains the most densely populated communes, with three of the seven varying between 1,000 inhabitants/km² and 5,000 inhabitants/km² (ONS 2008). However, the other three have average densities that vary between 100 km² and 500 km². The remaining commune has a low density of 70 inhabitants/km².

**Climatic conditions**

The Mediterranean climate is characterised by the synchronisation of a period of minimum rainfall, the hottest summer months, mild or cool winters and maximum rainfall in autumn or spring. Climate change and water stress over the last decade have affected the Mediterranean basin, particularly the southern region from Egypt to Morocco (Symonds, 2021). The green structure is linked to a number of climatic requirements, including solar radiation, thermal requirements for its development and water for its essential growth. Various authors agree that summer water stress, linked to climate change, is the main factor limiting the development of vegetation and the maintenance of green structures (Seguin, 2010).

The Annaba region is characterised by a sub-humid climate, rainy in winter, hot and humid in summer, with a maximum average of 32°C in August and a minimum average of 6.58°C in January. The study area is the wettest region in the country with an average rainfall of about 670 mm per year. However, it should be noted that most of the winter precipitation, in particular 70% of the total annual precipitation (i.e. more than 460 mm), falls between October and February (Figure 02). The climatic characteristics of the area have been strongly influenced by the morphology expressed by the three natural entities: Mount Edough, Lake Fetzara and the Mediterranean Sea. The geographical distribution of rainfall shows that the Edough Mountains are the source of precipitation in the area with more than 800 mm of annual average. This justifies the floristic richness of this part and especially the plant density.

![Graphique climatique - Annaba](www.climatsetvoyages.com)

*Figure 02. Average rainfall variation over Annaba (Period: 1991 - 2020)*

Source: [www.climatsetvoyages.com](www.climatsetvoyages.com)
Annaba’s green structure: historical origin

Historians, travellers and admirers of the town and landscape of Annaba, such as Ibn El Hawkel and El Idrissi, have pointed out that the origin of the green spaces can be attributed to place names. Bled El Anneb, known as the "town of jujubes", was renowned for its abundance of agricultural produce: vines, olives, jujubes, tomatoes, etc., which reflected the prosperity, beauty and charm of the town. The cultivation of gardens, orchards and crops played an essential role in the emergence of a promising industry.

The transition from agriculture to industrialisation led to major spatial changes in the urban area and its surroundings. Despite these changes, the integration of green spaces persists. This integration is based on different urban typologies such as shopping centres, avenues, boulevards, etc. The organisation respects the principles of urban composition, emphasising the openings and appropriate alignments resulting from Hausmannian avenues. Urban development accelerated in the post-colonial city, but land-use planning failed to ensure its preservation. The expansion of the city is encroaching on agricultural and natural green spaces. Conservation is generally weak or absent, particularly in expanding urban areas such as ZHUNs (new urban housing areas) and town centres. Annaba has historic green spaces with exceptional plants. Two of the city’s seven gates have been transformed into green spaces: the Calypso Garden was created in the 1883 Porte de la Marine, and the Porte des Caroubiers leads to a seafront promenade adorned with acacias and flowers in full bloom. However, these facilities are relatively small in relation to the size of the city and its industrial character, in contrast to its glorious past when it had vast gardens, earning it the nickname "the gardens of Algeria" (Noui, 2009).

Annaba’s green structure: environmental and social importance

The green structure has always attracted the interest of urban regions and communities because of its many advantages. From an economic point of view, it is attractive because many cities depend on their distinctive environment, particularly the green landscape (green and blue structure), to enhance their attractiveness.

Increasing urbanisation has had an impact not only on the size and quantity of cities, but also on the surrounding natural environment, including green and blue spaces and ecosystems. Green structures, a fundamental element of urban infrastructure, have a significant impact on the environment and quality of life. Residents express a constant desire for these essential elements, not only for recreation and fitness, but also for social interaction with others. They also act as a deterrent to crime, violence and aggression (Sushinsky et al. 2017).

New York, in the United States, with its Central Park, where the majority of the 115,000 or so people who visit it every day come for a variety of activities. Physical, like running, walking, cycling or rollerblading, or social, like getting closer to friends or nature, or cultural, like attending a concert, reading - or simply relaxing. For them, Central Park is an invaluable resource (https://assets.central-parknyc.org/pdfs/about/The_Central_Park_Effect.pdf). The woods and parks of Paris express the same importance and are very popular. As well as bringing together people from different social backgrounds, ethnic groups and generations, they foster a sense of belonging.

Algeria, a developing country, and in particular the coastal town of Annaba, is in turn accumulating the consequences of uncontrolled urbanisation, with ecological (pollution, fragmentation, etc.), socio-economic and other consequences. Brown functions often consume green resources and degrade their processes (Andersson et al 2014), at a time when everyone is campaigning for a sustainable city.

A population renowned for frequenting blue spaces such as beaches, but which, since the COVID19 pandemic, has changed its destination, moving towards outdoor spaces, including green forest structures, gardens, etc. So much so that they believe that using the forests of the future, Edough National Park is a condition of well-being, health and even recovery (opinions gathered during the COVID19 pandemic).

Quality and quantity can play an important role in encouraging social interaction and increasing opportunities for interaction between...
the woodland environment and people can have an impact on human health due to the undeniable benefits of trees and vegetated surfaces (Bolon et al 2018). The growth of urban areas and changes in land use have affected the quality and quantity of green spaces. It should be noted that digital strategies are an effective and informative approach to provide baseline data on a topic, that of the green structure discussed in this study. GIS is therefore an essential decision-making tool for professionals, researchers and local authorities. The whole world is competing to develop a high-performance digital future, with the aim of managing resources efficiently.

Materials and Methods

This study investigates land use change between 1984 and 2021 and its impact on the green structure of the study area using remote sensing technology. Land use classification and accuracy assessment were performed in Google Earth Engine GEE. The GEE platform benefits from a high-performance computing infrastructure that provides the computing capacity for data preparation and the systematic creation and training of a large number of classifiers and algorithms. The use of machine learning algorithms enables cloud computing to efficiently test different basic classifiers and their combinations as well as to train the whole with a wide range of spectral, spatial and temporal bands from satellite imagery at very high spatial resolution. GEE provides access to satellite and other ancillary data, cloud computing, and algorithms that enable the storage and processing of large amounts of data (in the megabyte range) for analysis and decision making (Kumar & Mutanga, 2018).

Methodological approach

The data processing for this study is summarised in the flowchart in (Figure 3). Firstly, the study selected a Landsat composite image with cloud removal for the years 1984, 2004 and 2021 respectively. The spectral indices (SAVI, NDVI, NDBI and NDWI) were calculated by supervised classification using the Random Forest "random tree", which is a decision tree algorithm (Richards, 2022). The RF "random forest" is a set of random trees defining classes with a majority vote to stop the final classes. It is one of the most widely used algorithms for land cover classification from remote sensing data (Sasikala et al., 2015). It naturally handles both regression and classification. Therefore, RF was used to generate the classification maps in this study.

![Figure 03. Flowchart of the method followed in data processing](image-url)
The aim of this study is to investigate the effects of land use and land cover (LULC) change, and in particular to detect disturbances in green structure caused by rapid urbanisation. These disturbances lead to fragmentation, which in turn affects the ecosystem and disrupts its stability and sustainability.

**Image pre-processing**

The use of image archives already available on the GEE platform, some of which have already been pre-processed (cloud removal, georeferencing, Top of Atmosphere (TOA), surface reflectance), has enabled us to extend the database to higher resolution datasets.

In addition, GEE allows us to carry out rapid analyses using Google's IT infrastructure, which provides online datasets in almost tangible time. The collection of surface reflectance images used in our case is as follows: Landsat 5 (for 1984 and 2004) and Landsat 8 (for 2021). They were chosen to classify the land cover of a perimeter made up of 8 zones defined at the level of the future metropolis. The data sources for this study are summarised in the table below:

<table>
<thead>
<tr>
<th>Data layer</th>
<th>Source</th>
<th>Spatial resolution (m)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 5 surface reflectance</td>
<td>GEE Dataset (USGS)</td>
<td>30</td>
<td>1984</td>
</tr>
<tr>
<td>Landsat 5 surface reflectance</td>
<td>GEE Dataset (USGS)</td>
<td>30</td>
<td>2004</td>
</tr>
<tr>
<td>Landsat 8 surface reflectance</td>
<td>GEE Dataset (USGS)</td>
<td>30</td>
<td>2021</td>
</tr>
<tr>
<td>Administrative Boundaries</td>
<td>PDAU Annaba</td>
<td>-</td>
<td>2008</td>
</tr>
<tr>
<td>1:10 000 Topo-map</td>
<td>PDAU Annaba</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Socio-economic and, demographic data</td>
<td>PDAU Annaba</td>
<td>-</td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td>Statistical yearbook (RGPH)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climatic data</td>
<td>PATW Annaba ONM</td>
<td>-</td>
<td>1990-2005</td>
</tr>
</tbody>
</table>

**3.3. Land cover classes**

The types of land cover defined for the study have been divided into 5 classes (urbanized land, cultivated land, forest land and green spaces, water surfaces, bare soil and other land) (Table 2)

<table>
<thead>
<tr>
<th>Land cover classes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urbanized land</td>
<td>Residential areas, roads and industrial zones.</td>
</tr>
<tr>
<td>Cultivated land</td>
<td>Agricultural or wasteland lands...</td>
</tr>
<tr>
<td>Forest land and Green Spaces</td>
<td>Forestland and urban green areas.</td>
</tr>
<tr>
<td>Water surfaces</td>
<td>Wadis, lakes, dams,...</td>
</tr>
<tr>
<td>Bare soil and other</td>
<td>Unused or difficult to use land, including rock and bare soil (land from land clearing, fire...</td>
</tr>
</tbody>
</table>

**Assessment of classification accuracy**

Multiple factors contribute to the accuracy of image classification. The accuracy assessment process allows the analyst to compare the pixel values of a selected raster layer with reference pixels. These reference pixels have well-defined classes (Sader, 1995). Verification of the accuracy of the land cover classification maps created involves the use of high-resolution imagery from Google Earth and Bing Maps, as well as a historical description of the study area.

Stratified random sampling was used to identify approximately 400 reference points in 1984, 2004 and 2021, respectively. Each land use class had a maximum of 70 reference points. To assess the accuracy of the results, a confusion matrix was calculated for the land use map, based on the producer’s accuracy, the user’s accuracy, the overall accuracy, the kappa...
coefficient and the F1 score. To balance the overall performance of the producer and user against the classifier, the F1 score was calculated (Congalton & Green, 2009).

Figure 4 shows the land cover classification maps for the years 1984, 2004 and 2021, which were generated using supervised random classification. The Random Forest classifier achieved exceptional overall accuracy for the study area, with rates of 90% (1984), 93.34% (2004) and 93.23% (2021). The Kappa accuracies for 1984, 2004 and 2021 were 0.86, 0.90 and 0.86 respectively, as shown in Table 05. For each year, user and producer classification accuracies for each category ranged from 60% to 98%. Classification accuracies for water were consistently high each year due to its distinct characteristics, while built-up areas and bare land exhibit low accuracies. The F1 score is a value between 0 and 1, calculated by combining the accuracy of the producer and that of the user. A higher F1 value indicates lower classification accuracy.

**Detection of land use change**

In order to promote sustainable urban development and help decision-makers to take appropriate action, the detection of land use change is based on spatial models. This is an essential step in understanding the land use and land cover (LULC) process, especially with regard to the green structure, which is considered an essential element in achieving sustainable development. For this purpose, it is necessary to calculate the gain and loss of vegetation cover according to equations (1)-(3):

\[
\text{Kgain} = S_b S_a \quad (1) \\
\text{K0} = S_{bi} = S_{ai} \quad (2) \\
\text{Kloss} = S_a K_0 \quad (3)
\]

Sa and Sb denote the type of land cover at the beginning and end of a given period. Sai and Sbi indicate the areas where the type of land cover is identical and unchanged at the beginning and at the end of the given period.

**Results**

**Land cover classification and accuracy assessments**

The land cover classification maps for 1984, 2004 and 2021 are presented in Figures 4(a), 5(b) and 5(c), respectively. A supervised random classification method was used to produce the classification maps. The RF classifier achieved an overall accuracy of 90.09% (1984), 90.31% (2004) and 88.43% (2021), with corresponding Kappa accuracies of 0.88 (1984), 0.89 (2004) and 0.86 (2021), as shown in Table 4. The accuracy range for the user and producer is between 80% and 100% for each year and class. The accuracy of the water classification was high in each year because it is easily distinguished from other classes on the basis of its reflectance ratio. On the other hand, built-up areas and bare land showed low accuracy. Initial results indicate that urbanisation is intensifying and encroaching on green forests and agricultural land. The increase in residential, commercial and industrial activities has led to urban development that extends as far as the future Edough Mountains National Park and the agricultural plains. Expansion has also spread to neighbouring communes such as El Bouni, Sidi Amar and El Hadjar, as well as to the entire coastal strip. The construction of the new town of Draa Erich to the west destroyed part of the forest and farmland to make way for a predominantly mineral town meeting the needs of growth and the urgent demand for housing. The original state of the green environment has deteriorated considerably, with adverse effects on the flora surrounding Lake Fezzara, a "Ram-sar site".
Table 04. Accuracy assessment of classified maps LUC for the years 1984, 2004, and 2021

<table>
<thead>
<tr>
<th>Land cover classes</th>
<th>Year 1984</th>
<th>Year 2004</th>
<th>Year 2021</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>User's accuracy</td>
<td>Producer's accuracy</td>
<td>F1 Score</td>
</tr>
<tr>
<td>Accuracy Assessment</td>
<td>49.53 %</td>
<td>72.11 %</td>
<td>60.82 %</td>
</tr>
<tr>
<td>Urban area</td>
<td>93.36 %</td>
<td>95.34 %</td>
<td>94.35 %</td>
</tr>
<tr>
<td>Forest</td>
<td>94.8 %</td>
<td>99.57 %</td>
<td>97.23 %</td>
</tr>
<tr>
<td>Water</td>
<td>94.25 %</td>
<td>80.03 %</td>
<td>87.14 %</td>
</tr>
<tr>
<td>Agricultural area</td>
<td>87.01 %</td>
<td>91.94 %</td>
<td>89.47 %</td>
</tr>
<tr>
<td>Bare land</td>
<td>90%</td>
<td>93.34%</td>
<td>93.2%</td>
</tr>
<tr>
<td>Kappa coefficient</td>
<td>0.86</td>
<td>0.90%</td>
<td>0.86%</td>
</tr>
</tbody>
</table>

Land use changes between 1984 and 2021

Table 5 summarises the results of the changes in land use. It shows the area of land cover and how it has changed in the study area over the last 37 years. The most significant trend in land use change is the decrease in forest and green space of 43.98 km², followed by bare land of 5.64 km². By contrast, built-up land in all other categories increased by 23.45 km².

Comparing the last period to the initial period for each land cover type; urban land, cropland and water experienced an increase in the rate of land cover change, with increases of 30.13%, 12.53% and 14.81% respectively. However, between 1984 and 2004, the land cover of forests and green spaces decreased by 18.46% and that of bare soil by 20.84%. Between 1984 and 2021, there will be a 23.78% decrease in forests and green spaces and a 10.77% decrease in bare ground.
In general, urbanized and cultivated areas have steadily increased over the period from 1984 to 2021. Whereas, forest land and green spaces have considerably decreased. Bare land and others showed a similar tendency decreasing between 1984-2004 and 2004-2021 (Figure 05).

The urbanised area increased by 13.84 km² between 1984 and 2004, and by 9.62 km² between 2004 and 2021. Above all, it accumulated 23.45 km² over the entire period. Aquatic areas increased by 6.47 km² between 1984 and 2004, and by 4.91 km² between 2004 and 2021. In total, the increase is 11.38 km² between 1984 and 2021. The increase in water surface area corresponds to changes in the lake's water level, resulting from winter inflows in a temperate climate.

The decrease in the surface area of the lake occurs after a summer season characterised by severe weather conditions, particularly in August, resulting in the evaporation of water and the absence of contributions to the water table. The area of cultivated land increased by 24.84 km² between 1984 and 2004, but decreased by 10.32 km² between 2004 and 2021. For bare soil and other land classes, there has been a fluctuation in area, with a decrease of 10.92 km² between 1984 and 2004, followed by an increase of 5.27 km² between 2004 and 2021. The decrease in area coincides with the restoration of land for agriculture, forestry or
urbanisation, while the increase is associated with burnt or cleared land.

**Spatial models of land use change: green change**

Figure 06 shows land use and land cover change (LULC) for the periods 1984-2004 and 2004-2021. The most significant change is the decline in forestland and green spaces transformed into farmland and urban development. Over the last 37 years, the study of changes in land cover and land use has revealed that forests and green spaces, farmland and urbanised land are the types of cover that have undergone changes. Urbanised land has undergone a notable change, resulting in a significant advance in urbanisation, particularly for the periods 1984-2004 and 2004-2021.

Analysis of the changes revealed the following results: a gain of 11.4 km² of forestland and green spaces compared with a loss of 55.5 km² between 1984 and 2021. The gain in forestland and green spaces was transferred from cultivated or bare land and other land. The loss of forests and green spaces, which amounts to 55.5 km², is lost in favour of urbanised land or transferred to farmland, bare land or other land (burnt, cleared, etc.). The area of forest and green space loss is particularly marked in the north (Annaba commune) and east (El Bouni commune), as well as in the south (Sidi Amar and El Hadjar communes) and along the NR 44 beyond Oued El Aneb. It corresponds to an extension of urbanised land.

This expansion has spread to the slopes and mountains of the Edough, damaging the picturesque green ridges of El Bouni and the Sidi Amar mountains, which were once lush woodlands containing mastic trees. The transfer of growth to Oued el Aneb via its new town of Draa Erich has destroyed forests, green spaces and cultivated land, and the urbanisation process is continuing. These areas are mainly located in the foothills of the Edough and on the Oued el Aneb plains. Between 1984 and 2021, cultivated areas underwent a reorganisation that resulted in a significant loss of farmland, covering an area of 37.24 km². Continued urbanisation has contributed to this loss. On the other hand, a transfer of forests and natural green spaces (Figure 7) resulted in a gain of 41 km².

The reduction is more concentrated in the communes of El Bouni, Sidi Amar and Berrahel, and in the new town of Dra Erich, respectively. These areas have benefited from major housing, infrastructure and business park programmes. The urbanised area has expanded significantly in the central urban zone of Annaba, as well as in neighbouring communes. Expansion has
mainly taken place along the north-south axis, particularly in the communes of El Bouni, Sidi Amar and El Hadjar. The area has also expanded westwards, along the RN 44, and in the communes of Oued Aneb, Draa Erich and Treat. The urban area has contracted and spread along the NR44 national road.

Discussion

The importance of green structure in changes of land use between 1984 and 2021

In 1984, the study area was dominated by cultivated land (198.28 km²), accounting for 37.75% of the total area, followed by forest and green space (35.21%), bare land (9.97%), urbanised land (8.74%), and water (8.31%). According to the comparison, in 2021, coverage of forest and green space decreased to 26.85%, while cultivated land slightly increased to 40.54%. The study showed that there was a reduction in coverage of forest and green space between 1984-2004 and 2004-2021, due to the conversion of these areas to urbanised land, cultivated land, bare land, or other uses. Several studies have shown that this transformation emerged adjacent to the Edough slopes (Mebirouk, 2012), where a substantial portion of the city’s forestry is located. Likewise, between 1984 and 2004, the percentage of bare soil and other types of land declined by 20.64% and then slightly increased by 12.73% between 2004 and 2021.

Annaba, like other major cities in Algeria, is experiencing uncontrolled development that is damaging both farmland and forests. After initiating the development of the intensive belt agriculture described by Von Thünen, the city is now causing its decline through changes in land use (Nemouchi & Zeghiche 2021), which are also limiting the movement of species. These environments offer multiple ecosystem services that depend significantly on human activities, particularly land use. Our analysis focused on changes in land use and land cover, enabling us to assess the physical and structural changes within the future metropolis. Urbanisation has spread well beyond the study area, leading to uncontrolled land consumption and urban sprawl. This has led to a reduction in agricultural land, with a high level of artificialisation (Zennir, 2019). Rapid urbanisation has transformed the city into a vast conurbation. The future metropolis continues to expand at an alarming rate, with its urban centres and immediate suburbs developing rapidly (Aguejdad, 2009).

The confrontation between industry and agriculture has had a significant impact on land use. Thousands of hectares have been lost to industrialisation. Almost all the land in demand has been used for intensive agriculture (Saidi, 2012). This rapid expansion has had a negative impact on the quality of the environment, particularly through the reduction of the green structure. The growth of the future city runs counter to many principles of sustainable development, such as the preservation of natural and agricultural areas, which are now a concern of public authorities worldwide (Robert, 2016).
Some areas of vegetation have been destroyed by fire, contaminated by pollution or cleared for farming. The result is a significant reduction in the vegetation cover of these lands. Not to mention the damage caused to agricultural land, which has been downgraded and urbanised. Thousands of hectares of fertile land have been ruined by concrete. It should be noted that the use of the spatial model has made it possible to identify changes in the main types of land use. The results showed a reduction in forests and green spaces. Cultivated land and expansion, particularly of built-up land, are the main land-use change processes in the study area, also generating fragmentation.

![False colour composite FCC of the used satellite imagery (1984 and 2021)](image)

**Conclusion**

The approach based on the study of changes in land occupation and use has made it possible not only to visualise but also to assess the state of the green structure in the face of the advance and extension of urbanisation. Over the last 37 years, the green structure has been hampered by a reduction and fragmentation of green cover in the face of excessive growth in grey cover. The share of forests and green spaces has fallen from 35.21% in 1984 to 26.85% in 2021. The proportion of cultivated land rose from 37.75% in 1984 to 40.53% in 2021. The proportion of bare land fell from 9.97% in 1984 to 8.90% in 2021. The proportion of urbanised land rose from 8.74% in 1984 to 13.22% in 2021.

Urbanisation has generally advanced in several directions, mainly northwards, climbing the slopes of the Edough and invading forestland, southwards and south-westwards, consuming cultivated land, and westwards along the RN 44 towards Draa Erich, the future new town of Moustapha Ben Aouda. The grey cover swallows up farmland and woodland. Urban masses mask and often erase the green masses. A progressive decline and rarefaction characterise the evolution of the green structure between 1984 and 2021, which lost 55.5% of forestland and 37.24% of cultivated land in the face of urban expansion of 30.49%.

This study shows the importance of spatial remote sensing and geographic information systems for monitoring and understanding the rapid expansion of urban and suburban areas, and assessing their impact on neighbouring ecosystems. Satellite classification has attracted a great deal of interest and has most often been used to provide information on environmental losses (forests and green spaces, cultivated land, etc.) in the face of urbanisation. This study is important because it provides an effective methodology for the temporal classification of land use and the detection of changes. It focuses on the relationship between green structure and urbanisation over time. Google Earth Engine is therefore used to classify Landsat satellite images in order to track changes in land use in the areas studied from 1984 to 2021. A multi-temporal remote sensing database was instantly available via the GEE data library and cloud computing environment, which offers free access for these scientific purposes.
Analysis of the images in GEE showed that Annaba, as well as the selected areas, experienced a dramatic change in land use over this period. User and producer accuracy has always been above 80% for classified images. Overall accuracy and Kappa values ranged from 93.32% to 93.34% and from 0.86 to 0.93 respectively. The results showed that over the last 30 years (1984-2021), Annaba has seen a 23.70% decrease in forests and green spaces and a 10.77% decrease in bare land. There has been an increase in urbanised land (51.07%), cultivated land (7.32%) and water surfaces (26.07%) in the study area.

The dramatic change in "LULC" land use and occupation is due to a number of factors, including socio-economic considerations, such as increasing urbanisation due to demographic expansion and persistent demand for housing, infrastructure and facilities, poor political decisions (relating to economic promotion, town planning, etc.) that neglect environmental parameters and the sustainable development of regions, as well as physical aspects.

The increase in urbanised areas at the expense of forests and farmland shows that efforts to promote sustainable development and above all to preserve ecosystems, particularly green structures, are still far from achieving their objectives in the absence of rigorous monitoring.

Continuous monitoring of the green structures of cities and their sustainability, by regulating urban growth and sprawl, and demographic pressures on the environment and ecosystems.

The use of Google Earth Engine and the classification of satellite images contribute to the development of a land use and occupancy policy; it is an important example for other environments that could be confronted with similar phenomena and evaluate their development models. Future studies should continue to improve the accuracy of the classification.

Such an approach can lead to the measurement and qualification of the green structure on a global scale as well as on smaller scales. This ecological component is considered essential for the balance of ecosystems and the sustainability of territories, particularly for societies that express a constant need for these vital elements in the face of urban stress and climate change (temperature peaks, for example).

References


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