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Spatial Suitability Analysis for Sustainable Urban Growth Using the AHP-GeoTOPSIS Model. A Case Study in Guelma, Algeria

Imen Guechi, Halima Gherraz (both: Oum el Bouaghi),
Djamel Alkama (Guelma), Ayoub Korichi (Medea), all Algeria*

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Contents

* Imen Guechi, Ph.D. (corresponding author) and Halima Gherraz, Ph.D., Department of Architecture, Laboratory of Evaluation of Quality in Architecture and In-built Environment, University of Arbi Ben M'hidi, Oum El Bouaghi, Algeria; Prof. Djamel Alkama, Professor, Department of Architecture, University of Guelma, Guelma, Algeria; Ayoub Korichi, Ph.D., Institute Mohamed Hadjouti Kasr El Boukari, Medea, Algeria. – Emails: guechi.imen@gmail.com, halima.gherraz@gmal.com, dj.alkama@gmail.com, ayoubkori @gmail.com.

Summary

As urbanisation continues to expand globally, the demand for land for urban purposes is on the rise. Without proper management, valuable land that could be utilised for more profitable endeavours, such as agriculture, runs the risk of being underutilised. Additionally, certain urban developments have the potential to pose threats to both the environment and the well-being of local residents. Therefore, it is imperative to conduct land suitability analyses before progressing with urban planning initiatives. The primary objective of this paper is twofold. Firstly, it aims to propose scenarios for sustainable urban growth locations in Guelma, with a focus on minimising the consumption of agricultural land and preserving high-potential forested areas. Secondly, this research contributes to the existing literature by introducing a hybrid methodology that combines GIS (Geographic Information System), GeoTOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), and AHP (Analytic Hierarchy Process) for the purpose of selecting suitable urban growth sites in the Guelma region.

In this study, we employed a combination of AHP and TOPSIS methods to conduct the analysis. Ten criteria and constraints were established for the study, utilising spatial data acquired through GIS. These criteria include proximity to forests, soil fertility, land use and land cover (LU/LC), distance to rivers, a Normalised Difference Vegetation Index (NDVI), distance to the urban centre, proximity to roads, population density, a Digital Elevation Model (DEM), and slope. The analysis revealed that approximately 19.47 square kilometres of the Guelma region's land area are most suitable for urban land use. The findings of this study hold significance in terms of mitigating potential urban instability and guiding the government's decisions regarding sustainable urban development.

Keywords: Urban growth, land suitability, Guelma, Algeria, AHP-GeoTOPSIS model, GIS, Remote sensing.

Zusammenfassung

Räumliche Eignungsanalyse für nachhaltiges Stadtwachstum unter Verwendung des AHP-GeoTOPSIS-Modells. Eine Fallstudie in Guelma, Algerien

Mit der anhaltenden globalen Urbanisierung steigt die Nachfrage nach Land für städtische Zwecke stetig an. Ohne angemessene Bewirtschaftung besteht das Risiko, wertvolles Land, das für profitablere Unternehmungen wie Landwirtschaft genutzt werden könnte, zu wenig oder falsch zu nutzen. Darüber hinaus bergen bestimmte städtische Entwicklungen das Potenzial, sowohl die Umwelt als auch das Wohlergehen der örtlichen Bevölkerung zu gefährden. Daher ist es unerlässlich, vor der Umsetzung städtischer Planungsmaßnahmen eine Bodentauglichkeitsanalyse durchzuführen. Das Hauptziel dieses Papiers ist zweigleisig angelegt. Erstens zielt es darauf ab, Szenarien für nachhaltige städtische Wachstumsstandorte in Guelma vorzuschlagen, wobei der Schwerpunkt auf der Minimierung des Verbrauchs landwirtschaftlicher Flächen und der Erhaltung hochwertiger bewaldeter Ge-

biete liegt. Zweitens trägt diese Forschung zur bestehenden Fachliteratur bei, indem sie eine hybride Methodik einführt, die GIS (Geografisches Informationssystem), GeoTOPSIS (Technik zur Ordnung der Präferenz nach Ähnlichkeit zur idealen Lösung) und AHP (Analytischer Hierarchieprozess) kombiniert, um geeignete Standorte für städtisches Wachstum in der Region Guelma auszuwählen.

In dieser Studie haben wir eine Kombination aus AHP- und TOPSIS-Methoden für die Analyse verwendet. Es wurden zehn Kriterien und Beschränkungen festgelegt, wobei räumliche Daten aus GIS verwendet wurden. Diese Kriterien umfassen die Nähe zu Wäldern, Bodenfruchtbarkeit, Landnutzung und Landbedeckung (LU/LC – Land Use and Land Cover), Entfernung zu Flüssen, einen sog. „Normalised Difference Vegetation Index" (NDVI), die Entfernung zum städtischen Zentrum, Nähe zu Straßen, Bevölkerungsdichte, Digitales Höhenmodell (DEM) und Geländeneigung. Die Analyse ergab, dass zirka 19,47 Quadratkilometer der Landfläche der Region Guelma am besten für städtische Nutzung geeignet sind. Die Ergebnisse dieser Studie sind in Bezug auf die Minderung möglicher städtischer Instabilität von Bedeutung und dienen zur Orientierung der Regierungsentscheidungen hinsichtlich nachhaltiger städtischer Entwicklung.

Schlagwörter: Städtisches Wachstum, Bodentauglichkeit, Guelma, Algerien, AHP-GeoTOPSIS-Modell; GIS; Fernerkundung.

1 Introduction

Urbanisation and land consumption are two pivotal processes driving significant changes in land use and land cover which, in turn, characterise the growth and sustainability of urban areas. There is a growing interest in understanding the dynamics of land use and land cover change, which are influenced by various factors including urban planning, social dynamics, and economic forces (Wang and Murayama 2018). The unsustainable expansion of urban areas, often at the expense of green spaces and natural resources, has sparked widespread concern and ignited fervent discussions regarding the critical elements and potential solutions in land use planning (Weber et al. 2006; Potschin 2009; Walter and Stützel 2009; Schetke et al. 2010; Terzi and Bölen 2012). As cities continue to grow, they increasingly strain the eco-environment, leading to heightened conflicts between various land use types (He et al. 2017). Spatial planning emerges as a vital tool for achieving sustainable urban development, simultaneously fostering socioeconomic progress while mitigating environmental challenges (Shuaibu and Kara 2019). The realms of planning and sustainability are deeply intertwined and mutually relevant (Jepson 2001).

In contemporary urban planning and policy development, modern tools such as GIS and Remote Sensing have gained significant prominence (Liu et al. 2015). The adoption of GIS and Remote Sensing is driven by several factors, including their ability to incorporate spatial and temporal dimensions for monitoring, controlling, analysing, evaluating, and quantifying urban growth patterns and changes in land use (Liu et al. 2015; Ramachandra et al. 2013). Furthermore, these techniques offer the flexibility to apply both quantitative and qualitative methodologies to discern the root causes, impacts, and current as well as future trends in urban growth patterns (Aithal and Sanna 2012; Al-Chalabi et al. 2013; Shalaby 2012; Yang 2010). By integrating socioeconomic and spatial data, Remote Sensing and GIS techniques enable the analysis of intricate patterns in land use changes. Additionally, mathematical equations such as the Shannon entropy equation and landscape metrics are employed within Remote Sensing and GIS environments to categorise various urban patterns.

Recent advancements in land consumption assessment underscore the necessity for integrated evaluation methodologies, emphasising the creation of multidimensional tools to guide and monitor sustainable land use practices. A significant portion of land use policy decisions is made through spatial planning and zoning, involving the delicate balancing of sectoral interests and competing priorities to arrive at viable solutions (Cerreta and De Toro 2012).

In recent years, numerous studies have focused on the suitability analysis of land use and land cover for sustainable urban growth in various cities, regions, and countries, such as Trikomo, Cyprus (Kara and Akçit 2021), Abuja, Nigeria (Shuaibu and Kara 2019), Seremban, Malaysia (Aburas et al. 2017), and Famagusta (Kara and Doratli 2021) in Northern Cyprus. Among these, Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) have been the most widely employed methods for assessing land-use suitability for urban growth (Aburas et al. 2015). MCDA involves the analysis of a set of criteria, assigning priorities or weights to these criteria (Zopounidis and Pardalos 2010). Notably, over 80 percent of studies in this domain have utilised the Analytic Hierarchy Process (AHP) to determine criterion weights (Lu et al. 2007).

The Analytic Hierarchy Process (AHP), introduced by Saaty (1987, 2008), is a well-established multi-criteria technique that seamlessly integrates with GIS-based tools to assess suitability (Laskar 2003; Pareta and Jain 1992; Parry et al. 2018). For instance, Bathrellos et al. (2017) used AHP and GIS to develop a multi-hazard map for urban growth suitability in Greece's northeastern Peloponnesus. Ramadan et al. (2021) employed AHP in conjunction with geospatial models to create alternative scenarios for urban development zones in Egypt's Ismailia Governorate. Similarly, Hassan et al. (2020) utilised the Analytical Hierarchy Process (AHP) and Geographic Information Systems (GIS) to analyse and select suitable urban growth zones on Kuwait's Failaka Island.

In this study, we opted for the combined use of AHP and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) due to AHP's status as one of the most widely used Multi-Criteria Decision-Making (MCDM) methods, offering several advantages (Saaty 2008). AHP is scalable and adaptable to various decision-making challenges, thanks to its hierarchical nature. TOPSIS, on the other hand, serves as a practical strategy for addressing real-world multi-criteria decision-making complexities. TOPSIS aids decision-makers in structuring issues, analysing and comparing different solutions, and ultimately ranking them (Chang et al. 2012).

Numerous studies conducted globally have focused on evaluating land suitability for urban development, employing Geographical Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) methods. These studies consider a wide array of sustainability criteria, including environmental, social, and economic factors, as well as regulatory policies (Shah et al. 2020; Parvez and Islam 2020; Yang et al. 2021; Luan et al. 2021; El Sayed 2018). Among the methodologies employed, the Analytical Hierarchy Process (AHP), introduced by Saaty in 1987 (Saaty 1987), has emerged as a prominent choice due to its capacity to discern areas suitable and unsuitable for urban development, notwithstanding concerns about subjectivity and time constraints. For instance, in 2021, a study in Indonesia's Mamuju district applied GIS and AHP to provide guidance for development in areas prone to natural disasters like floods, landslides, and earthquakes (Anastasia et al. 2021). Similarly, a recent investigation in Turkey's Eskisehir province employed AHP to pinpoint optimal locations for sustainable urban development (Delíry and Uyguçgíl 2020). Additionally, several studies in Indian cities have integrated AHP with geophysical and socio-economic criteria to evaluate land suitability for urban development (Parry et al. 2018; Anugya et al. 2017).

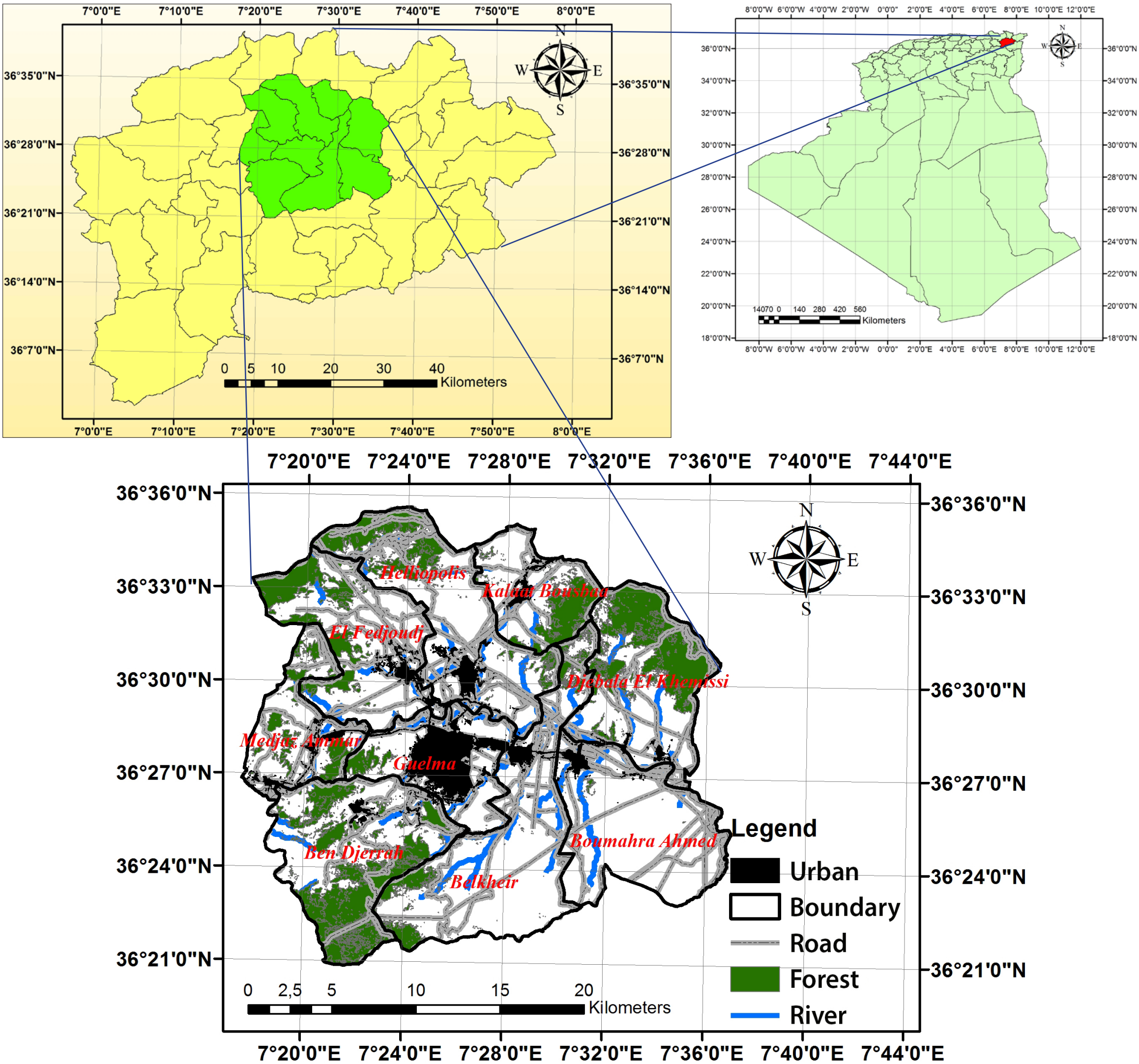
In the literature, researchers have either utilised one of these methods in isolation (Kara and Doratli 2021; Kara and Akçit 2021; Deliry and Uyguçgil 2020; Aburas et al. 2017) or combined methodologies other than GIS-TOPSIS and AHP (Xu et al. 2021; Ramadan and Effat 2021) for sustainable urban growth suitability analysis. TOPSIS is employed in our study to analyse and categorise suitable land, facilitating the prioritisation of regions with the highest suitability for sustainable urban development. While TOPSIS and AHP-GeoTOPSIS methods are widely applied in site suitability studies for urban and peri-urban agricultural land (Ustaoglu et al. 2021; Fatih and Sari 2021; Artikanur et al. 2022), their use in sustainable urban growth analyses is relatively limited. Therefore, this study bridges the gap by integrating TOPSIS with GIS and AHP, resulting in more precise site selection decision-making. To our knowledge, this integrated approach has not been previously employed to determine suitable locations for sustainable urban growth, considering local criteria such as socioeconomic factors, natural resources, and land use.

Guelma, like many medium-sized cities in Algeria, grapples with the challenges posed by rapid and extensive urban growth, which have led to notable land use and land cover (LU/LC) transformations. This urban expansion has brought about significant spatial and environmental changes. Given Guelma's strategic location in the heart of the region, it attracts neighbouring communes (Guechi and Alkama 2017; PDAU 2013). Consequently, the city has witnessed substantial impermeable growth, often at the expense of agricultural and forested lands (Guechi et al. 2021). The reduction of vegetation and its replacement with impermeable surfaces, such as asphalt and concrete, can be directly attributed to urban growth dynamics, resulting in environmental and social repercussions (Mitchell 2011).

The primary objective of this paper is two-fold: firstly, to propose scenarios for sustainable and viable urban growth locations in Guelma, with a specific emphasis on limiting the consumption of agriculturally valuable lands and preserving high-potential forested areas. Secondly, we aim to contribute to the existing body of literature by introducing a hybrid methodology that combines GIS, GeoTOPSIS, and AHP for the selection of urban growth sites in the Guelma region. The findings of this study are anticipated to play a crucial role in preventing future urban instability and offering valuable insights for the government's initiatives in urban sustainable development.

2 Study Area

Guelma is situated in the northeastern part of Algeria, approximately 60 km south of the Mediterranean Sea (36°27′43″N – 7°25′33″E) and at an elevation of 305 meters above sea level. Geographically, it serves as a meeting point and a crossroads, connecting the industrial hubs in the North (Annaba – Skikda) with the trading centres in the South (Oum



Source: Own design

Figure 1: Location map of the study area

El Bouaghi and Tébessa), while also maintaining proximity to the Tunisian border in the East. Encompassing an area of 3,686.84 square kilometers, the province of Guelma had an estimated population of 494,079 inhabitants by the end of 2009, with 2 percent of this population concentrated in the provincial capital. The average population density in this region is 132 individuals per square kilometer. Our study area comprises Guelma's communes, which are centrally located within the Guelma province and include the provincial capital of Guelma, as well as the municipalities of Bendjarah, Belkhair, El Fdjouj, El Heliopolis, Mjaz Amar, Djballa Khmissi, Boumahra, and Kalat Bousbae (Figure 1).

From the perspective of sustainable urban growth, Guelma, like other cities, grapples with an array of economic, social, and environmental challenges. These include urban expansion encroaching on land with high agricultural potential, escalating traffic congestion in the city centre, and other associated issues. It is undeniable that urban growth has given rise to a multitude of challenges within the built environment (Guechi 2018).

3 Methodology and Materials

The aim of this study was to identify a suitable location for long-term urban growth. To achieve this objective, the following procedures were employed: Firstly, diverse datasets and defining criteria for assessing urban growth suitability were established. Subsequently, a multi-criteria decision analysis, based on Geographic Information Systems (GIS) and integrating the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), was conducted.

This integrated model is crucial for addressing the complexities inherent in multi-criteria spatial decision-making when determining areas for future urban expansion. Here, GIS functions as a powerful spatial analysis tool, AHP is utilised to calculate the weightings assigned to various criteria, and TOPSIS is applied to rank and prioritise suitable areas. The amalgamation of GIS, AHP, and TOPSIS brings about significant advantages, particularly in fields such as land use management assessment, as demonstrated by previous studies (Oztürk and Batuk 2011; Barrios et al. 2016; Jozaghi et al. 2018).

3.1 Data Collection

A data table was meticulously crafted to compile pertinent socio-economic and environmental information from diverse sources, encompassing remotely sensed satellite data and thematic maps, all tailored to align with the research goals. In the lead-up to the data analysis phase, a series of preprocessing techniques were applied to refine both raster and vector datasets. These techniques included mosaicking, projection, resampling, and subsetting, each contributing to the data's readiness for comprehensive analysis. Table 1 in this paper furnishes a comprehensive overview of the data harnessed for the spatial analysis. Given the pivotal role of data availability in this study, the authors resorted to generating specific datasets that were otherwise unobtainable from official sources, underlining the significance of these data in fulfilling the study's objectives.

Data	Data type	Data source
– Satellite images 1990; 2000; 2020	– Raster	– United States Geological Survey (USGS)
– Digital Elevation Model (spatial resolution 30 m)	– Raster	– United States Geological Survey (USGS)
– Roads	– Vector	– Open Street Map (OSM)
– Number of the population 2008	– Statistics	– General Census of Population and Housing (GCPH 2008)

Source: Own compilation

Table 1: Data utilised in the spatial analysis

3.2 Criteria Selection for Sustainable Urban Growth

This study aims to perform a comprehensive land suitability analysis for future sustainable urban growth. The approach adopted involves defining specific criteria, applying the Analytical Hierarchy Process (AHP) for weighting these criteria, classifying them into ten distinct suitability classes, and generating a weighted overlay map (WOL) to provide an overall view of land suitability. Achieving sustainable urban growth necessitates the careful consideration of various socio-economic and environmental factors. Notably, topographical factors, such as slope and elevation (Delíry and Uyguçgíl 2020; Santosh et al. 2018), the proximity to residential, commercial, and industrial areas (Chen 2016; Abdelkarim et al. 2020; Hassan and Nazem 2016), and the presence of essential infrastructural elements like road networks (Delíry and Uyguçgíl 2020; Zhang et al. 2021), exert significant influence on the suitability of urban locations. Furthermore, it is imperative to prioritise the preservation of natural resources, which entails identifying areas suitable for development and those requiring conservation efforts (Hassan and Nazem 2016; Dipeolu and Ibem 2020). The criteria employed in this study are derived from a thorough literature review and encompass slope, elevation, road networks, urban agglomeration, fertility, NDVI, and land cover.

In order to identify the areas, best suited for future urban expansion while ensuring sustainability, it is essential to take into account a range of environmental and socio-economic criteria, as underscored in previous research (Aburas et al. 2017; Chen 2016). For the purpose of this study, ten distinct criteria were carefully selected to assess land suitability, as detailed in Table 2. To standardise all the factor suitability maps, a ranking and scoring method was applied, with suitability levels spanning from 1 to 10. A higher score signifies a lesser degree of constraint or a greater level of suitability. The resulting maps, illustrating these suitability scores, are presented in Figure 3.

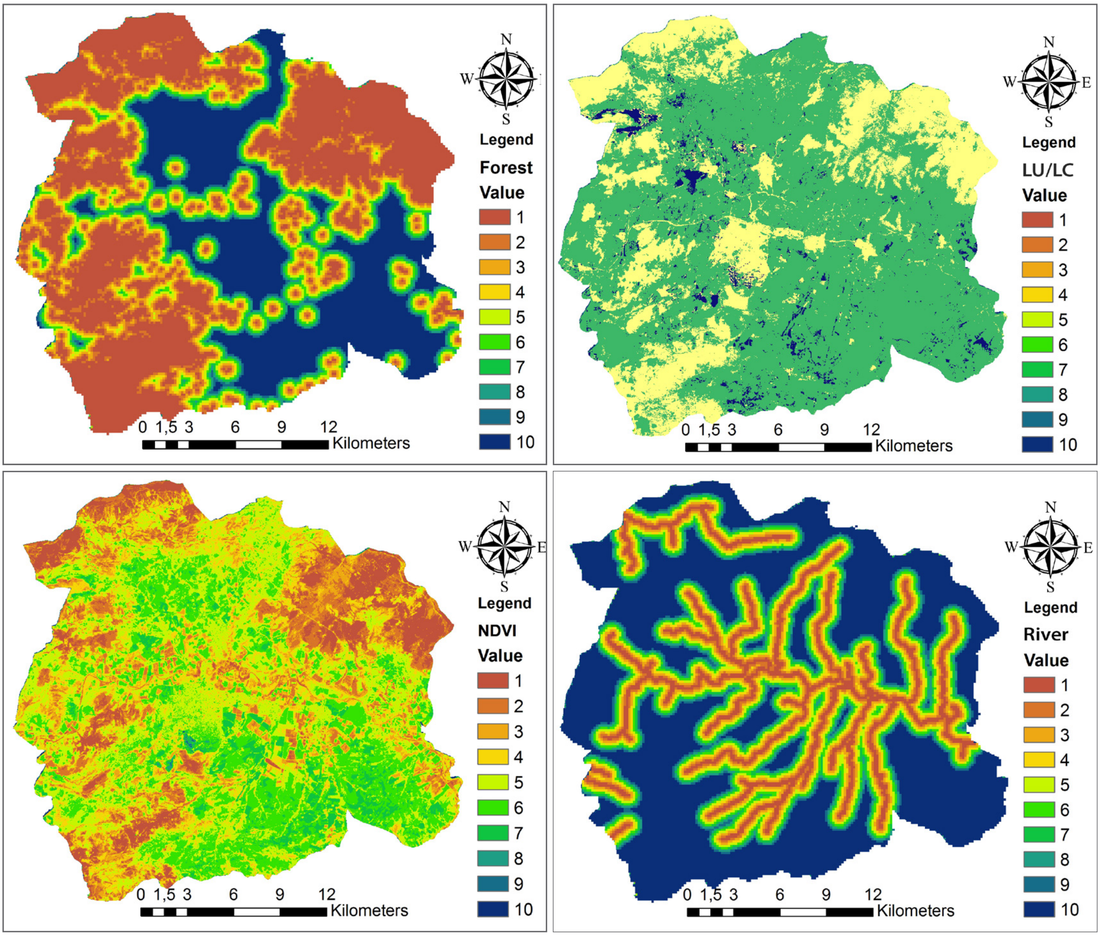
3.2.1 Environmental Criteria

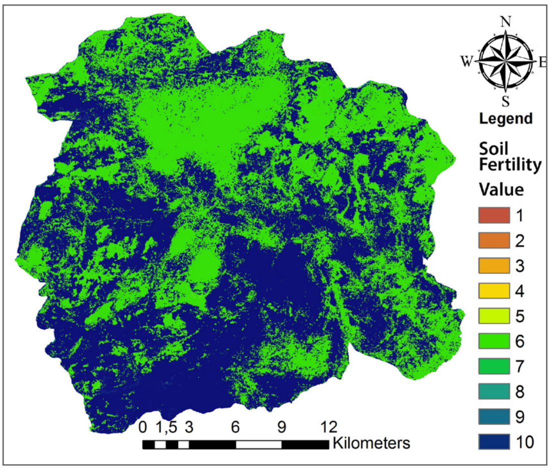
Undoubtedly, the environment takes precedence as the cornerstone of sustainable development. Within the context of our specific case study, the imperative is to safeguard agricultural and forested lands against unwarranted land-use alterations. To effectively achieve this goal, we employ a comprehensive set of strategies and considerations (see Table 2 and Figure 2):

Suitability scale	Sustainable urban growth									
	Environmental criteria					Socio-economic criteria				
	Distance to forest (m)	Soil fertility	LU/LC	Distance to river (m)	NDVI	Distance to urban centre (m)	Distance to roads (m)	Population density (pop/km^2)	DEM	Slope (%)
1	D <100	691 – 768	Forest; urban	D < 100	-0.04 – -0.02	D < 300	D > 900	> 26	1264.5 – 1392	46.26 – 51.40
2	100 – 200	–	–	100 – 200	-0.03 – -0.01	300 – 600	800 – 900	–	1137 – 1264.5	41.12 – 46.26
3	200 – 300	537 – 614	Agri-Land	200 – 300	-0.01 – 0.01	600 – 900	700 – 800	–	1009.5 – 1137	35.98 – 41.12
4	300 – 400	460 – 537	–	300 – 400	0.01 – 0.03	900 – 1200	600 – 700	1 – 3	882 – 1009.5	30.84 – 35.98
5	400 – 500	–	–	400 – 500	0.03 – 0.04	1200 – 1500	500 – 600	–	754.5 – 882	25.70 – 30.84
6	500 – 600	–	–	500 – 600	0.04 – 0.06	1500 – 1800	400 – 500	–	627 – 754.5	20.56 – 25.70
7	600 – 700	–	–	600 – 700	0.06 – 0.08	1800 – 2100	300 – 400	–	499.5 – 627	15.42 – 20.56
8	700 – 800	–	–	700 – 800	0.08 – 0.10	2100 – 2400	200 – 300	–	372 – 499.5	10.28 – 15.42
9	800 – 900	–	–	800 – 900	0.10 – 0.11	2400 – 2700	100 – 200	–	244.5 – 372	5.14 – 10.28
10	D > 900	0 – 76.8	Barre-Land	D > 900	0.11 – 0.13	D > 2700	D < 100	4	0 – 244.5	0 – 5.14

LU/LC … Land Use and Land Cover; – NDVI … Normalised Difference Vegetation Index; – DEM … Digital Elevation Model

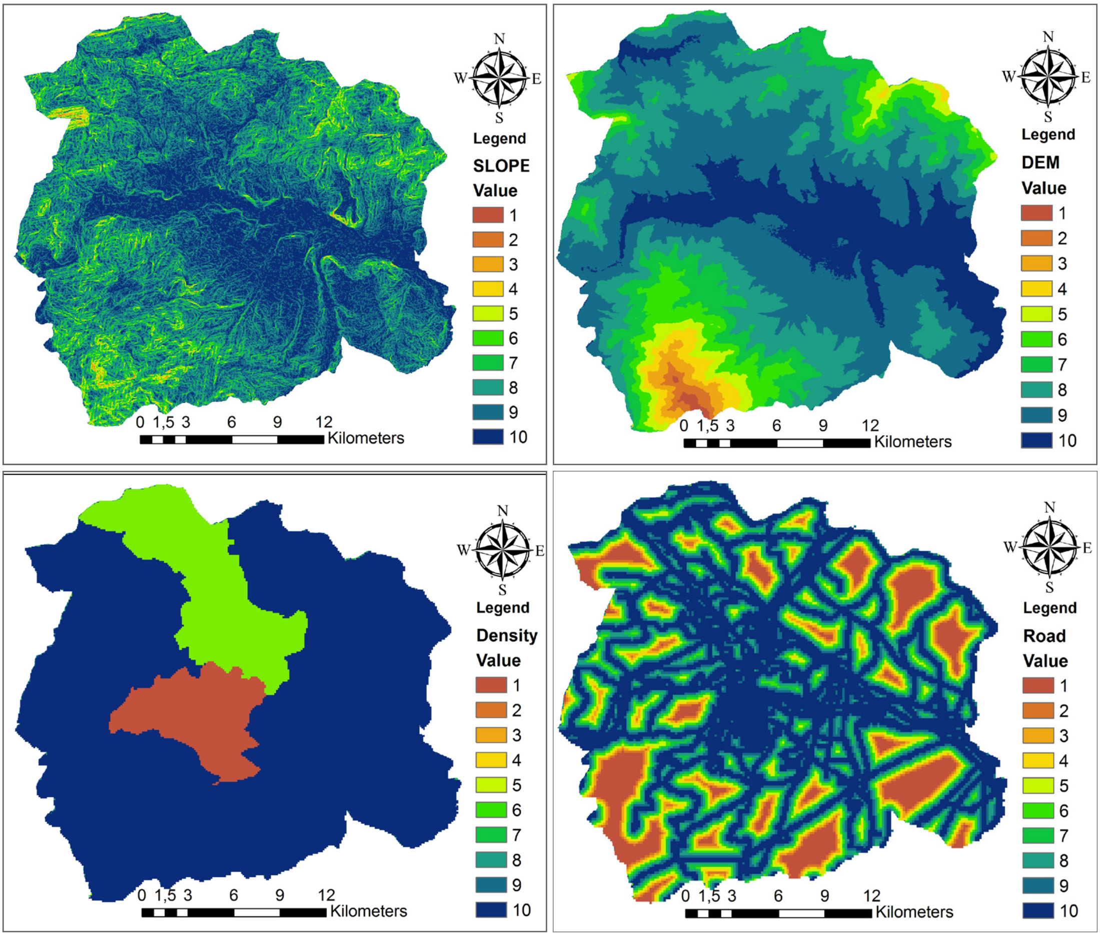
Table 2: Suitability scale of criteria for sustainable urban growth in Guelma

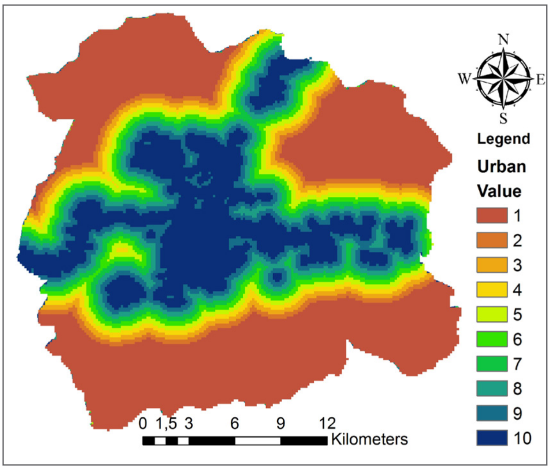




Source: Data calculated by the authors. Own design.

Figure 2: Environmental criteria used in the AHP-GeoTOPSIS method





Source: Data calculated by the authors.
Own design.

Figure 3: Socio-economic criteria used in the AHP-GeoTOPSIS method

- Preservation of agricultural and forested lands: Foremost in our mission is the preservation of agricultural and forested lands, shielding them from detrimental land-use changes. This entails maintaining a respectful distance to safeguard these invaluable natural resources.
- Mitigating agricultural impacts: A pivotal element involves minimising any adverse effects on agricultural lands while simultaneously curbing urban development encroachment into forested areas.
- Avoidance of river streams and fertile zones: We advocate for a judicious approach by avoiding river streams and regions known for their high fertility. This strategy is integral to the protection of ecologically sensitive areas.
- Significance of land cover analysis: A critical component within the realm of urban planning is the scrutiny of land cover. Delving into the various land cover categories reveals significant constraints that inform urban planning decisions. For instance, it underscores the imperative that agricultural and forested lands, along with established urban areas, remain invulnerable to alterations.

This comprehensive approach ensures that urban development aligns harmoniously with the principles of sustainability, upholding a steadfast commitment to preserving and protecting critical environmental assets such as agricultural and forested lands.

3.2.2 Socio-economic Criteria

The goal of the economic and social aspect is twofold: to reduce development expenses and to align with the preferences of the population. This is accomplished through a focus on the following factors (see also Table 2 and Figure 3):

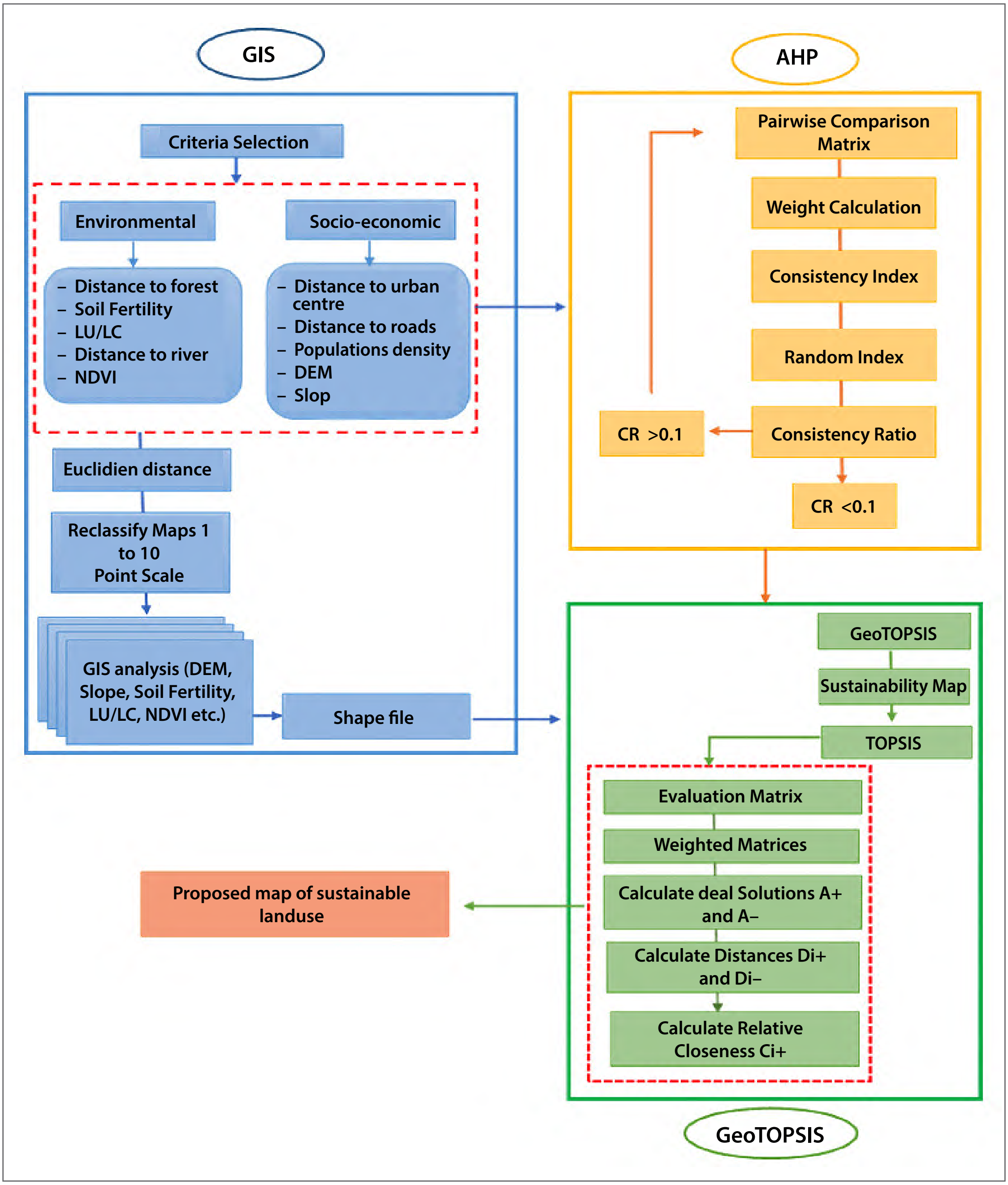
- Proximity to urban centres: Opting for locations in close proximity to urban centres.
- Avoidance of high population density areas: Steering clear of areas with high population density.
- Accessibility via roads: Ensuring accessibility through the presence of nearby roads. This is critical for the exchange of goods, ease of access, connecting rural regions, and providing primary residential routes.
- Utilising a digital elevation model (DEM) and slope maps: Leveraging digital elevation models (DEM) and slope maps to avoid steep and rugged terrain.

This approach aims to strike a balance between economic viability and meeting the social preferences of the population, ultimately contributing to sustainable urban development.

After the choice of the criteria, we applied the GIS-AHP-TOPSIS model, which is presented in the flowchart in Figure 4

3.3 AHP method

In this study, the weighting in the TOPSIS analysis was determined through the implementation of the “Analytic Hierarchy Process” (AHP) method. The primary objective of an AHP analysis is twofold: to establish the precedence of various criteria and to assess



Source: Own design.

Figure 4: The flowchart of the study

their relative importance. Moreover, the AHP incorporates the concept of consistency to compute overall weights and assess the consistency of priorities. To ensure the consistency of weights and priorities, the AHP methodology provides a consistency ratio, which should ideally be less than 0.1. Expert Choice software was employed for the precise calculation of the weight assigned to each criterion, and the results are presented in Table 3.

3.4 GeoTOPSIS

The "GeoTOPSIS", an extension of the "TOPSIS" method introduced by Hwang and Yoon in 1981, is seamlessly integrated into an open-source QGIS plugin named "Vector MCDA". This tool stands out as the most suitable choice for capturing the intricate nature of systems. It harnesses vector data to execute a suite of multi-criteria analysis algorithms, where each geographic entity serves as a distinct option, often referred to as a "geo-alternative". Each algorithm meticulously assesses and processes these geographical attributes as criteria, ultimately yielding preference indices as outputs, as detailed by Rocchi et al. in 2015.

Building upon the foundation of the TOPSIS model, GeoTOPSIS seamlessly applies algorithms involving ideal points, resulting in the generation of maps that vividly depict the arrangement of numerous geographical possibilities. The assignment of weights to criteria can be achieved directly or through the application of the Analytic Hierarchy Process (AHP) methodology, as elucidated by Rocchi et al. in 2015.

3.5 TOPSIS method

The TOPSIS technique is a distance computation that allocates the best option to the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. These distances are factored into a similarity index, which will be sorted to determine the best options. The calculation steps of the TOPSIS method are:

The Euclidean norm was used to make the matrix D dimensionless. The dimensionless matrix obtained is referred to as N_D.

$$r_{ij} = \frac{r_{ij}}{(\sum_{i=1}^{m} r_{ij}^{2})^{\frac{1}{2}}} \quad (j = 1, \ldots \ldots \ldots, n) \tag{1}$$

The following equation is used to build a normalised weighted decision matrix:

$$V = N_D * W_{n*n} \tag{2}$$

Following that, ideal positive (A_i^+) and ideal negative (A_i^-) alternatives were determined:

$$A^+ = (y_1^+, y_2^+, \ldots \ldots y_n^+) \tag{3}$$

$$A^- = (y_1^-, y_2^-, \dots\dots y_n^-) \tag{4}$$

$$y_1^+ = \begin{cases} \max_{y_{ij}}; \text{ if j is a benefit attribute (benefit)} \\ \min_{y_{ij}}; \text{ if j is a cost attribute (cost)} \end{cases}$$

$$y_1^- = \begin{cases} \max_{y_{ij}}; \text{ if j is a benefit attribute (benefit)} \\ \min_{y_{ij}}; \text{ if j is a cost attribute (cost)} \end{cases}$$

Then, the following equation was used to calculate the distance between the values of each alternative using the positive ideal solution matrix and the negative ideal solution matrix.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (y_i^+ - y_{ij})^2} \quad (i = 1, 2, \dots, m) \tag{5}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_i^-)^2} \quad (i = 1, 2, \dots, m) \tag{6}$$

Calculate the value of choice for each option using the equation below.

$$C_i = \frac{D_i^-}{(D_i^- + D_i^+)} \quad (i = 1, 2, \dots, n) \tag{7}$$

$$\text{Where: } 0 \le C_1^+ \le 1 \quad i = 1, 2, \dots, m$$

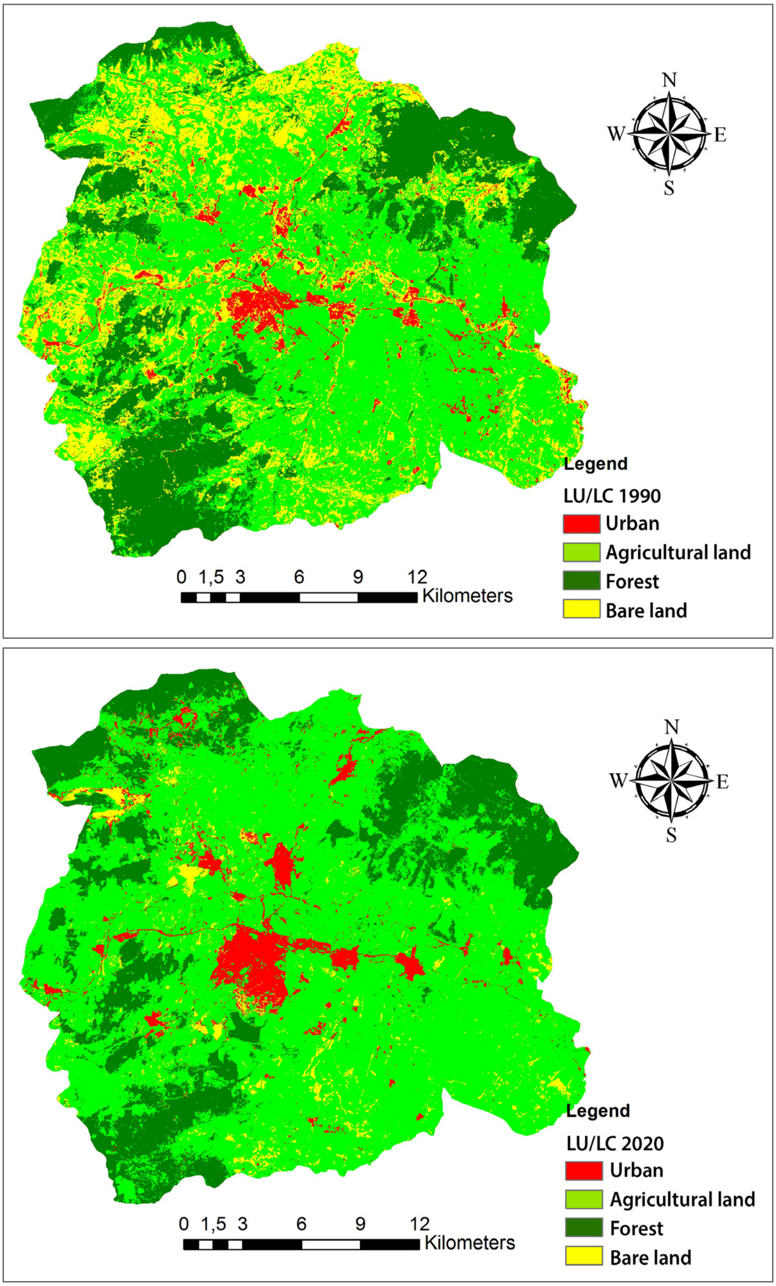
This option's value is the last value that is used to order or prioritise all of the options that have been considered. The higher the priority value of the alternative selected, the higher is the value of C_i.

4 Results

4.1 Detecting Changes

In this study, change detection analysis for Guelma was conducted using Landsat 7 and Landsat 8 satellite images, employing a supervised classification approach. The results of the urban land cover classification for the years 1990, 2010, and 2020 are visually represented in Figure 5.

Figure 5 illustrates the Land Use/Land Cover (LU/LC) maps of Guelma's municipal region. Over the past three decades, there has been a pronounced urban expansion within the municipal cluster of Guelma. This growth is particularly concentrated in the Guelma municipality itself, which stands out as notably larger in comparison to the surrounding municipalities. Guelma is recognised as one of Algeria's cities that play a pivotal role in delivering essential urban services. These functions exert an influence on both the neighbouring communes and the remaining communes within the province, as highlighted by (GUECHI et al. 2021).

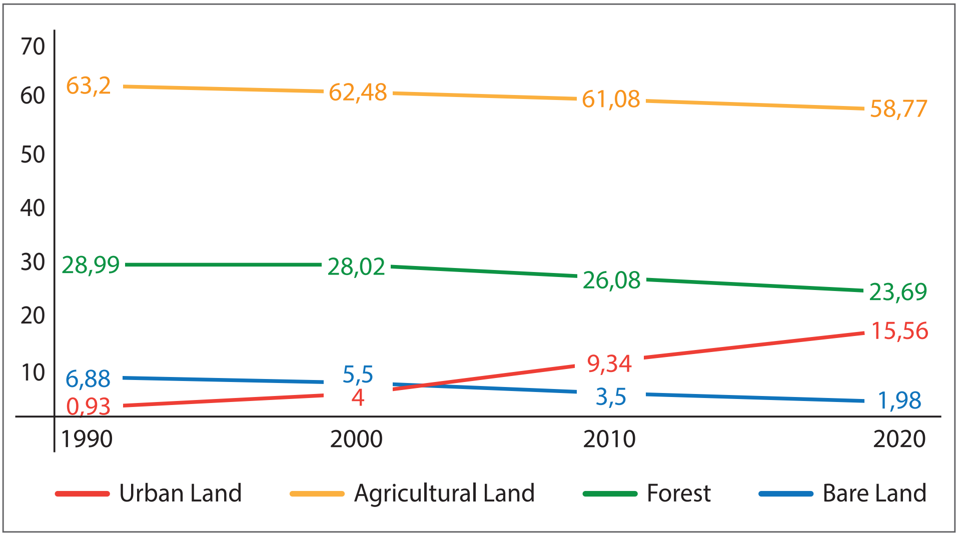


Source: Data calculated by the authors using Landsat 7 and Landsat 8 satellite images. Own design.

Figure 5: The geographic LU/LC (land use/land cover) maps of Guelma's municipial region in 1990 and 2020

To gain a deeper insight into the process of urbanisation within the municipalities of Guelma throughout the research period, calculations were performed to assess the areas covered by various land uses, along with their fluctuations. The outcomes of these calculations are visually presented in Figure 6.

Within the urbanised region, there is a discernible upward trend, with urban land cover increasing from 0.93 percent in 1990 to 15.56 percent in 2020, as indicated in Figure 6.



Source: Data (in percent) calculated by the authors using Landsat 7 and Landsat 8 satellite images. Own design.

Figure 6: Land cover change in Guelma from 1990 to 2020

Conversely, the areas dedicated to bare land, farmland, and woodland have experienced reductions. The extent of barren land has decreased from 6.88 percent in 1990 to 1.98 percent in 2020. Agricultural land has also seen a decline from 63.2 percent in 1990 to 58.77 percent in 2020. Furthermore, forested areas have contracted in size, diminishing from 28.99 percent in 1990 to 23.69 percent in 2020. These observations suggest a direct correlation between the growth of urban land cover and the reduction in green cover, particularly in recent years.

4.2 The Weights Calculated Using the AHP Method

Table 3 presents the weights and consistency ratios (CR) for the main criteria (environmental and socio-economic criteria) and their respective sub-criteria in an Analytic Hierarchy Process (AHP) analysis. Here’s an analysis of the results:

- *Environmental Criteria:*
- The main environmental criterion is assigned a weight of 0.50, indicating its equal importance with socio-economic criteria.
- The consistency ratio (CR) for this main criterion is 0.00, which is ideal, indicating perfect consistency in the pairwise comparisons.
- *Sub-criteria under Environmental Criteria:*
    - Distance to forest: This sub-criterion carries a weight of 0.176, signifying its significance within the environmental criteria. The CR of 0.07 suggests a reasonable level of consistency in the comparisons related to this sub-criterion.
    - Soil fertility: Also with a weight of 0.176, this sub-criterion holds similar importance to distance to forest. The CR of 0.07 indicates a good level of consistency.
    - Land Use/Land Cover (LU/LC): With a weight of 0.06, this sub-criterion is relatively less important within the environmental criteria.
    - Distance to river: This sub-criterion has a weight of 0.032, indicating a lower level of significance.
    - NDVI (Normalized Difference Vegetation Index): With a weight of 0.05, NDVI holds moderate importance among the environmental sub-criteria.

- *Socio-economic Criteria:*

  The main socio-economic criterion is also assigned a weight of 0.50, reflecting its equal importance with the environmental criteria.

  The consistency ratio (CR) for this main criterion is 0.05, which is below the threshold of 0.10, indicating acceptable consistency.
- Sub-*criteria under Socio-economic Criteria:*
    - Distance to urban centre: This sub-criterion carries the highest weight among all sub-criteria at 0.216, signifying its significant influence within the socio-economic criteria. The CR of 0.05 suggests a reasonable level of consistency in the comparisons related to this sub-criterion.
    - Distance to roads: With a weight of 0.179, this sub-criterion is also highly important within the socio-economic criteria. The CR of 0.05 indicates a good level of consistency.
    - Population density: This sub-criterion holds relatively less weight at 0.026, indicating its lower significance.
    - DEM (Digital Elevation Model): With a weight of 0.049, DEM is moderately important within the socio-economic sub-criteria.
    - Slope: This sub-criterion has a weight of 0.036, suggesting a relatively lower level of importance.

In summary, these results reveal the relative importance and consistency of each criterion and sub-criterion in the AHP analysis. The weights assigned to each sub-criterion are indicative of their impact on the overall decision-making process. The low values of the consistency ratio (CR) (Table 3) generally indicate acceptable consistency in the pairwise comparisons made during the AHP analysis, enhancing the credibility of the results.

Main criteria	Weights	CR	Sub-criteria	Weights	CR
Environmental criteria	**0.50**	**0.00**	Distance to forest	**0.176**	**0.07**
			Soil fertility	**0.176**	
			LU/LC	**0.060**	
			Distance to river	**0.032**	
			NDVI	**0.050**	
Socio -economic criteria	**0.50**		Distance to urban centre center	**0.216**	**0.05**
			Distance to roads	**0.179**	
			Population density	**0.026**	
			DEM	**0.049**	
			Slope	**0.036**	

Source: Calculation by the authors

Table 3: Main weights and sub-criteria weights and values of the consistency ratio (CR)

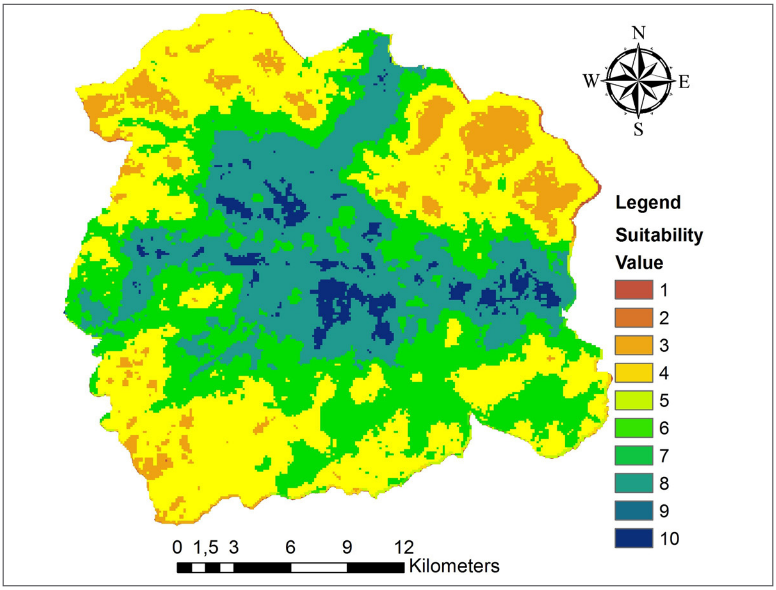
4.3 Determining the Suitability of Future Urban Growth by GeoTOPSIS

Once the weights for each criterion were established, the GeoTOPSIS method was employed to assess the significance of future urban expansion within each location. Leveraging its integration with a Geographic Information System (GIS), the GeoTOPSIS approach enabled the visualisation of ranking results using the conventional TOPSIS methodology.

In this particular scenario, we transformed the raster map into points to evaluate the priority of each point within the Guelma region. Subsequently, we associated these points with all attributes pertaining to the criteria used in the analysis. As a result, a comprehensive map depicting priorities for future sustainable urban growth was generated, as illustrated in Figure 7.

The results of the analysis reveal a spectrum of suitability scores for each raster cell, ranging from the lowest to the highest values, which span from 1 to 10. While the study identified favourable regions for sustainable urban expansion distributed across the research area, a notable concentration of these areas was observed in the central region near major roadways, as depicted in Figure 7. It's evident that land suitability gradually decreases as one moves from the urban centres towards the periphery, particularly in forested regions. Notably, Guelma, Bel Khair, El Boulis, Boumahra, Mzaz Amar, El Fdjouj, and Djballa Kmissi emerge as the regions boasting the highest suitability for future urban expansion. Collectively, these areas comprise a substantial portion of the overall highest suitability area, with percentages ranging from 3.08 percent to 32.33 percent.

These findings underscore the importance of strategic site selection for sustainable urban growth, with a focus on regions that offer the highest suitability scores and potential for responsible expansion.



Source: Calculation by the authors. Own design

Figure 7: Urban suitability map for the Guelma region (the higher the value of the suitability scores on a scale from 1 to 10 the higher is the urban suitability)

4.4 Ranking Suitable Urban Growth Land by TOPSIS Method

The urban growth suitability map for the Guelma district was generated using the Geo-TOPSIS technique, followed by the application of the TOPSIS method to rank alternative suitable locations within the region with the highest suitability. This ranking was based on the criteria weights obtained through the AHP approach. The initial step involved converting the raster map into a polygon map, and subsequently, the Zonal Statistics function in ArcGIS was applied to extract the multi-values of criteria within the suitability regions, as presented in Table 4.

Finally, the TOPSIS model's equation was employed to determine the ranking of future urban growth lands. In this ranking process, a total of 68 polygons representing the most suitable urban areas were utilised, as depicted in Figure 8. The key considerations for selecting suitable urban land include proximity to the urban centre and roads, as well as lower values for elevation and slope susceptibility. Additionally, it is essential for these areas to be situated at a distance from forests and agricultural lands, while also possessing good soil fertility.

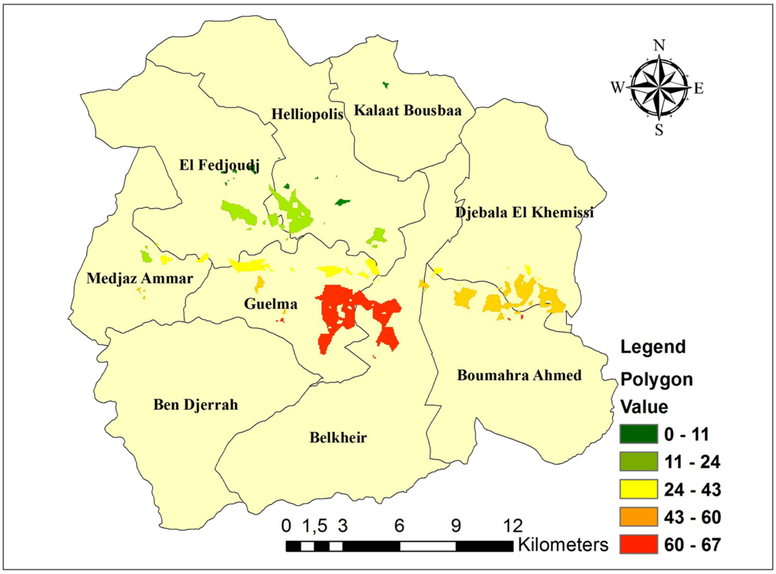
These steps and considerations collectively contribute to the identification and prioritisation of areas that are most conducive to responsible and sustainable urban growth within the Guelma district.

The provided Table 4 presents the results of the analysis, where various criteria and their associated weights (W) are used to assess the suitability of different locations

PHS	Sustainable urban growth									
	Environmental criteria					Socio-economic criteria				
	Distance to forest (m)	Soil fertility	LU/LC	Distance to river (m)	NDVI	Distance to urban centre (m)	Distance to roads (m)	Population density (pop/km²)	DEM	Slope (%)
W=	**0.176**	**0.176**	**0.06**	**0.032**	**0.05**	**0.216**	**0.179**	**0.026**	**0.049**	**0.036**
P1	10	10	10	10	5	10	10	10	8	10
P2	10	4	3	10	6	9	10	10	9	10
P3	8	10	10	9	6	10	10	10	9	10
P4	10	10	10	3	6	10	10	10	9	10
P5	10	4	10	9	6	10	10	10	9	10
P6	10	4	3	1	6	10	10	4	9	10
P7	10	10	10	4	5	10	9	10	9	9
…										
…										
P68	10	10	10	1	6	7	10	10	9	10

Source: Calculation by the authors. – PHS .. Polygon of the highest suitability

Table 4: The decision matrix – TOPSIS for sustainable urban growth



Source: Calculation by the authors. Own design

Figure 8: Polygons of the highest quality for future urban growth in the Guelma region

(P1 to P68) for sustainable urban growth. The analysis considers both environmental and socio-economic criteria, with each location receiving a suitability score for each criterion. Here's an analysis of the results:

– *Environmental Criteria:*
  - Distance to forest (in meters): This criterion has a weight (W) of 0.176, indicating its importance within the environmental criteria. All locations (P1 to P68) score high (10) in this criterion, suggesting that they are generally far from forests, which is favourable for environmental preservation.
  - Soil fertility: With the same weight of 0.176, this criterion also receives high scores (10) across all locations, indicating that they generally have good soil fertility.
  - Land Use/Land Cover (LU/LC): This criterion has a weight of 0.06 and is less influential within the environmental criteria. Scores for LU/LC vary but generally favour urban growth.
  - Distance to river (in meters): Given a weight of 0.032, this criterion exhibits varying scores across locations, with some locations scoring lower (1 to 4), indicating proximity to rivers, which may not be ideal for urban growth.
  - NDVI (Normalised Difference Vegetation Index): With a weight of 0.05, NDVI scores consistently high (6 to 10) across all locations, indicating good vegetation cover.

– *Socio-economic Criteria:*
  - Distance to urban centre (in meters): This socio-economic criterion carries the highest weight of 0.216. All locations receive high scores (9 to 10), suggesting their proximity to the urban centre, which is favourable for urban growth.
  - Distance to roads (in meters): With a weight of 0.179, this criterion also receives high scores (9 to 10) across all locations, indicating good accessibility via roads.
  - Population density (population per km²): Given a weight of 0.026, population density scores vary but generally favour urban growth.
  - DEM (Digital Elevation Model): This criterion, with a weight of 0.049, generally receives high scores (8 to 10), suggesting that locations have favourable elevation for urban development.
  - Slope (%): With a weight of 0.036, slope scores are generally low (9 to 10), indicating that locations have low slopes, which is suitable for urban growth.

In summary, the analysis shows that all locations (P1 to P68) generally exhibit favourable conditions for sustainable urban growth based on the criteria and weights assigned. These results highlight the suitability of various areas within the study region, with considerations for both environmental preservation and socio-economic factors such as accessibility and proximity to urban amenities.

To rank the suitable sustainable urban growth in the Guelma region with the TOPSIS method, the procedures outlined in the methodology section were followed. Table 5 shows the (Euclidean) distances between the positive (D_i^+) and negative (D_i^- ideal points. Next, the alternative future urban lands were ranked using the C_i values obtained, as shown in Table 5.

The provided table presents the results of the analysis, including the positive D_i^+, negative (D_i^-, and their sum ($D_i^+ + D_i^-$), as well as the computed C_i values. Here's an analysis of the results:

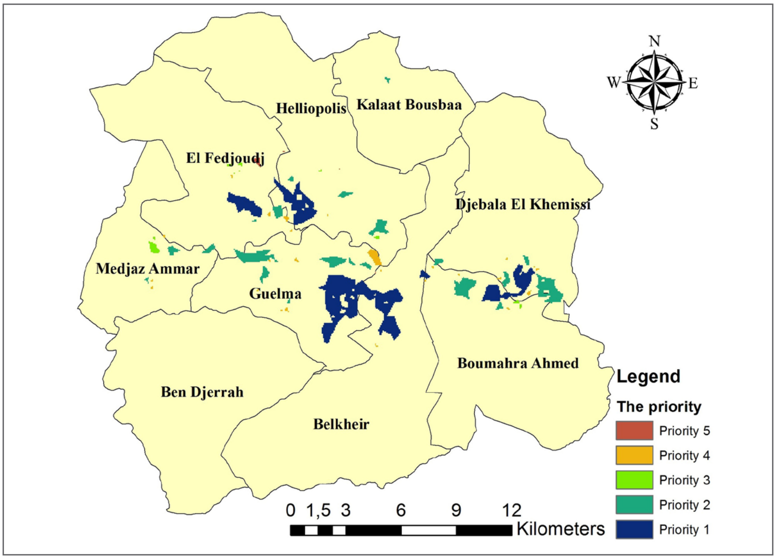
PHS	D_i^+	D_i^-	$D_i^+ + D_i^-$	C_i
P1	0.00131646	0.02005466	0.02137111	0.93840022
P2	0.01539643	0.01162244	0.02701887	0.43016003
P3	0.00478057	0.01828635	0.02306692	0.79275209
P4	0.00491924	0.02014988	0.02506911	0.80377302
P5	0.01390805	0.01441117	0.02831922	0.50888295
P6	0.01655444	0.01346802	0.03002246	0.44859812
P7	0.00483952	0.01991647	0.02475599	0.80451119
…				
…				
P68	0.01045463	0.01860478	0.02905941	0.64023251

Source: Calculation by the authors.

Table 5: Calculation of (D_i^+), (D_i^-) and C_i

In summary, the C_i values indicate the suitability of each location for sustainable urban growth, with higher C_i values suggesting stronger suitability. Locations like P1, P3, P4, P7, and P68 stand out as strong candidates, while P2, P5, and P6 are also suitable but to a slightly lesser degree based on the criteria considered in the analysis.

Using the GIS, the ranking results of suitable urban growth are shown in Figure 9.



Source: Calculation by the authors. Own design.

Figure 9: Priority of the highest suitability for sustainable urban growth in the Guelma region (the highest priority is priority 1)

Based on Figure 9, it is evident that the most favourable or the top choices for future urban expansion in the Guelma region are concentrated within the communes of Guelma, Belkhair, and El Boulis, with some additional areas located in El Fedjouj. These areas appear to have the highest suitability for sustainable urban growth based on the criteria and analyses conducted. Therefore, these communes and specific areas within them are recommended as the prime locations for future urban development in the Guelma region.

5 Discussion

The discussion of the results presented in this study provides valuable insights into the suitability of different areas within the Guelma region for sustainable urban growth. Here's a comprehensive discussion based on the findings:

5.1 Land Cover Changes and Urban Growth

The analysis of land cover changes over the past three decades, as shown in Figure 5, reveals a significant increase in urban land cover in the Guelma municipal grouping. This expansion is particularly concentrated in the municipality of Guelma, signifying its importance as a centre for urban services and growth. The substantial urban growth observed has implications not only for the municipality itself but also for the surrounding communes and the broader region.

5.2 Environmental Concerns and Socio-Economic Considerations

Sustainable urban development necessitates the preservation of agricultural and forested lands, as highlighted in this study. Factors such as maintaining a safe distance from forests, avoiding river streams, and considering land cover types are crucial to minimise environmental damage associated with urban expansion. The findings emphasise the importance of integrating environmental criteria into urban planning processes to protect valuable natural resources.

Proximity to urban centres, accessibility via road networks, and population density are socio-economic factors that influence urban growth suitability. These factors impact the cost of development, residents' access to essential services, and overall urban liveability. The results underscore the need to strike a balance between economic development and environmental preservation.

5.3 Multi-Criteria Decision Analysis (MCDA) and Identification of Suitable Areas

The study employed a multi-criteria decision analysis (MCDA) approach, combining Geographic Information System (GIS), Analytic Hierarchy Process (AHP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. This integrated approach allowed for a comprehensive assessment of various criteria and their relative importance in determining suitable locations for urban expansion.

The Analytic Hierarchy Process (AHP) is a versatile method that can be effectively integrated with other techniques such as linear programming and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). It provides an efficient approach to tackle complex decision problems, particularly in determining the weights for suitability criteria. AHP offers a well-structured methodology for calculating these weights and standardising criteria. As indicated by Zhang et al. (2015), AHP stands out as a superior method for weight calculation compared to alternatives because it allows for the measurement and resolution of discrepancies within the system when dealing with competing criteria.

The effectiveness of AHP in weight determination has been widely recognised in the literature and has found extensive applications in land suitability modelling, as demonstrated by studies such as Pilevar et al. (2020), Ramya and Devedas (2019), Kazazi Darani et al. (2018), Pramanik (2016), and Mosadeghi et al. (2015).

However, it's important to acknowledge that AHP has its limitations, as noted by Park et al. 2011. It relies on questionnaire surveys to establish relative weights, which can be time-consuming in technical applications. Additionally, due to the aggregation of results, there is a potential for compensation between high scores on some criteria and low scores on others. Other drawbacks include potential biases in stakeholder perspectives, concerns about result repeatability, and subjectivity in assigning weights to suitability criteria.

On the other hand, TOPSIS is a compensatory aggregation technique that utilises linear functions, such as the arithmetic mean (Bandura 2008), which is a common method for developing composite indicators. Its primary advantage lies in its simplicity and ease of replication. However, TOPSIS tends to overlook imbalances between sub-indicators and the composite index, which can lead to variations in the prioritised list (OECD et al. 2008). To address this issue, approaches like the Constant Elasticity of Substitution (Mazziotta and Pareto 2013) can be employed to calculate distances between ideal and anti-ideal solutions, helping to mitigate the problem.

In summary, both AHP and TOPSIS offer valuable tools for multi-criteria decision-making, with AHP excelling in terms of its capability to address discrepancies in competing criteria, while TOPSIS offers simplicity and ease of replication. Careful consideration of their respective strengths and limitations is essential when selecting the most appropriate method for a given decision problem.

Based on the analysis, specific communes within the Guelma region were identified as highly suitable for future urban growth. Communes such as Guelma, Belkhair, El Boulis, and El Fedjouj emerged as prime candidates for sustainable urban development. These areas scored highest in terms of meeting the defined criteria, indicating their potential to accommodate urban expansion while minimising negative impacts on the environment.

The findings of this study hold significant implications for urban planning and policy-making in the Guelma region. They provide valuable guidance for decision-makers in identifying appropriate locations for future development, thereby preventing urban sprawl that encroaches upon agricultural and forested lands. By prioritising areas with higher suitability scores, the government can make informed choices to promote sustainable urban growth and address the challenges associated with rapid urbanisation.

While this research has provided valuable insights into urban growth suitability in the Guelma region, it is essential to acknowledge that the findings may not directly apply to other regions with different urbanisation patterns and socio-economic conditions. The Guelma region has its unique characteristics and challenges, and the proposed AHP-GeoTOPSIS method's effectiveness may vary in different contexts. To adapt and apply this methodology to other regions, several considerations should be taken into account.

Firstly, different regions have distinct socio-economic dynamics, land use patterns, and environmental factors. It's crucial to tailor the criteria and weights used in the AHP-GeoTOPSIS method to match the specific context of the region under study. Conducting local stakeholder consultations and expert opinions can help refine the criteria and their relative importance.

Secondly, the availability and quality of data can vary widely between regions. Researchers should assess the data sources and ensure that they are relevant, up-to-date, and reliable for the specific region. In some cases, additional data collection efforts may be necessary to fill data gaps.

Thirdly, the AHP-GeoTOPSIS method may need adjustments to suit the characteristics of the target region. Different regions may require variations in the selection of criteria or alternative multi-criteria decision analysis methods based on their unique needs and challenges. Additionally, regional variations in governance structures, policies, and regulations can significantly impact the applicability of the proposed method. Researchers should consider the local policy environment and engage with local authorities to ensure alignment with regional development goals. Lastly, some regions may have specific environmental or cultural preservation requirements that must be integrated into the suitability analysis. These factors may not be present in the same way in all regions and should be considered accordingly.

In summary, while the AHP-GeoTOPSIS method presented in this study offers a valuable framework for assessing urban growth suitability, its successful application in different regions depends on contextualisation, data availability, methodological adaptation, policy alignment, and consideration of unique environmental and cultural factors. Researchers and urban planners should approach the adaptation of this method to new regions with careful consideration of these factors to ensure its effectiveness and relevance.

5.4 Future Directions

This research contributes to the growing body of knowledge on sustainable urban planning. Future studies in this area can build upon the methodologies used here and incorporate additional criteria, including climate resilience, social equity, and cultural preservation, to further refine the selection of suitable urban expansion sites.

In conclusion, the study's integrated approach to assessing urban growth suitability in the Guelma region provides a valuable framework for addressing the complex challenges of balancing economic development with environmental preservation. The identified communes offer a starting point for strategic urban planning that aims to achieve sustainability while meeting the evolving needs of the population and the region as a whole.

5.5 Potential Limitations and Their Impact on the Study's Outcomes

It is important to acknowledge several potential limitations that may impact our study's outcomes and the broader applicability of our findings. First, our research is regionally specific to the Guelma region in Algeria, limiting its generalisability to other areas with distinct characteristics. Data limitations, including quality and accuracy issues, could affect the precision of suitability assessments. Subjectivity in assigning criteria weights introduces potential bias, and our study offers a snapshot of suitability, not accounting for long-term changes. The absence of stakeholder engagement and the exclusion of cultural and climate factors further constrain the study's scope.

These limitations underscore the need for careful consideration and adaptation when applying our methodology to different regions and emphasise the importance of ongoing data validation, stakeholder involvement, and dynamic suitability assessments in urban planning processes.

6 Conclusion

Over time, the ongoing expansion of urbanisation poses a significant challenge to the capacity of available land to meet the demands of urban growth. Therefore, it is imperative to incorporate environmental and socio-economic factors into urban land management practices from the early stages of the planning process to ensure the long-term sustainability of cities. Balancing the need to accommodate current requirements while mitigating the impact of human activities represents a complex issue that necessitates innovative solutions. It becomes evident that there exists an imbalance between urban expansion and sustainability, driven by factors such as a lack of suitable locations, financial constraints, and underutilisation of information technology.

In this study, we propose the AHP-GeoTOPSIS method for assessing land-use suitability for sustainable urban growth. This approach leverages the strengths of both the AHP and TOPSIS methodologies. The integrated model, combining GIS, AHP, and TOPSIS, provides a valuable tool for analysing areas conducive to urban growth. This method adopts a multi-criteria approach to problem-solving, which is then further refined and prioritised within a hierarchical framework. The model utilises ArcGIS for spatial data analysis, AHP to determine criteria weights, and TOPSIS to evaluate and rank the selected alternatives or parcels.

A total of 10 criteria were identified and employed in this research to assess the suitability of urban land use in the Guelma region for sustainability. The analysis revealed that approximately 19.47 square kilometers of land in the Guelma region are highly suitable for urban land use, with notable percentages in various communes, including 32.33 percent in Guelma commune, 15.51 percent in Boulis, 15 percent in Belkhair, 13.87 percent in

Djballa Khmissi, 10.53 percent in Boumahra, 8.79 percent in El Fdjouj, and 3.08 percent in Mjaz Amar. This study underscores the importance of focusing on macro-urbanisation rather than micro-urbanisation for the future urban growth of Guelma, urging consideration beyond the Intercommunal Group of Guelma.

The findings of this research hold significant implications for urban planners and local governing bodies in meeting the future needs of the population. Similar studies could be extended to other cities to quantify urban sprawl and assess the extent of environmental impact resulting from urbanisation. Future research endeavours in this domain should consider employing high spatial and spectral resolution satellite imagery to enhance the precision of planning and development initiatives.

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