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A Study of Urban form Mutations through Geomatics -Case Study: Oued Zenati Town-

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Abstarct

Understanding and managing the growth of the urban environment is critical for addressing the issue of sustainability, which is becoming increasingly important in all disciplines. The current study focuses on a Tellian city (in the north-east of Algeria) with an agricultural vocation and is intended to be exhaustive because it incorporates both spatial remote sensing tools and geographer-developed macroform indicators. It is divided into three sections, the first of which is a survey of the literature on remote sensing and studies of urban forms using macroform indices. The second section summarizes the case study and describes the techniques used for this goal. In the third section of this research, we present and discuss the outcomes of applying macroform indices to the case of Oued Zenati city using remote sensing photos. More specifically, we examine the various values of the indices adopted and attributed to each primary figure of the city of Oued Zenati during the three periods. The results indicate that the urban form of Oued Zenati town is positioned in the field of less compact sinuous linear forms

Key words: urban form, Oued Zenati, remote sensing, macroform indicators.

INTRODUCTION

Urbanization is a global concern and a type of environmental change that has a direct impact on people's daily life. Currently, urban regions house 57 % of the world's population, and the annual population growth rate in urban areas is approximately 1.84% per year (United Nations Human Settlements Programme, 2022). Understanding and managing the changing urban environment is necessary for tackling sustainability, which is becoming increasingly important in practically all disciplines (P. Newman, J. Kenworthy 1999 and C. Wu, A.T. Murra, 2003). While European towns are increasingly emphasizing the need of avoiding urban sprawl in order to maintain the landscape and biodiversity (E. Banzhaf, V et al,2009), this issue is spreading in Algerian cities uncontrollably, despite the legislation in place (national and regional development plans, local urban plans, land use plans, etc.). In fact, while urban growth can be characterized in terms of population growth or economic activity in cities, the processes of urban development are more complex than one might expect. Many views consider sprawl to be a pattern of urbanization rather than a change process in which sprawl occurs and policy must intervene (C. Couch et al 2005). In thriving urban regions, there is a clear link between overall urban development in terms of societal transformation and economic growth on the one hand, and physical urban expansion on the other. In contrast, in decreasing urban regions, sprawl is frequently shaped by government and municipal policy regulations rather than market factors (H. Nuiss, D. Rink, 2003). Although no single technology can assess urban sprawl or population increase in real time, remote sensing and its associated data can follow urban growth rates as quickly and over broad areas as possible. Tracking changes in urban areas requires the use of this technology, which has become indispensable not only for obtaining synoptic views related to land use for map revision and environmental and agricultural monitoring, but also for estimating the severity of fires (T. Meena Laosuwan, 2021; P. Pradabmook, T. Laosuwan, 202; and N.A. Babayeva, R.B. Rustamov, 2014). However, it has a wide range of uses in urban planning (I. R. Hegazy, M. R. Kaloop,2015). Indeed, remote sensing is one of the most effective approaches for studying changes in urban settings (M. İlsever, C. Unsalan, 2012), as it provides the multi-temporal data required for quantitative and qualitative detection of these changes (A. Jenerowicze et al, 2019). Today, satellite photography can be a valuable source of information. Several urban land covers have been detected and mapped with high resolution using remote sensing (H. Afify, 2011), providing an important tool for tracking changes in urban land cover over time (F. Tapiador, J.L. Casanova, 2003). Furthermore, because a city's spatial structure is intimately linked to the shape of

its extensions and the design of its contour, it might disclose its morphological compactness (S. Kaya, P.J. Curran,2006 and, Guerrois 2003) or, on the contrary, its sprawl. Moreover, it is through examining the physical layout that we may deduce the characteristics of a city from its profile. Ignoring social factors and focusing solely on the forms of the urban environment, urban morphology explains the physical and spatial structure of the city by emphasizing the overall arrangement of the urban fabric (A. Dechicha, 2013). As a result, it is not surprising that Le Gales asserted the use of this "urban form" method to capture the freedom cities have to affect their shapes (E. Ducom, 2005). In the same vein, Guérois shows that it is possible to investigate urban forms from the standpoint of urban sprawl by quantitatively studying the urban patch (S. Kaya, P.J. Curran,2006). According to this viewpoint, one can readily differentiate stages of agglomeration extension along transport lines or, on the other hand, its filling in by occupying interstitial gaps, resulting in more compact forms (Guerrois 2003). Nonetheless, this static examination of the built environment's arrangement is simply a snapshot of the evolution of the borders and forms of urban fabrics as they shifted through time (P. Le Gales, 2003). In other words, depending on the physical components of the site, each urban patch experiences progressive deformations throughout time that range from stretching to digitation (S. Kaya, P.J. Curran, 2006). Allain confirms in his book on urban morphology that the effects of the site act in two ways: either by aeration of the urban patch or by contraction, giving rise to complex macroforms such as Marseille and San Francisco in the first case and compact macroforms such as Genoa and Cairo in the second. While this concept of macroforms refers to the geographical organization of the agglomeration as a whole, it also corresponds to the overall image of the agglomeration or metropolis, according to Allain (P. Derycke,1979). While the latter is the outcome of land-use patterns, it has been modified by the sedimentation of cultural and economical interactions over numerous eras, depending on the decisions made by the various actors. Each macroform is thus determined by certain elements that take into account the site in its various contexts: (i) geomorphological (its configuration and constraints, geological, morphological, climatic, and hydrological facts, vegetation, and soil nature) (R. Allain,2004), (ii) geographical (particularly its transport axes) (P. Vennetier,1991) (decisions and choices of the authorities). Under the influence of these several causes, urban growth can occur in "oil patches" with a concentric form or at a digital pace led by transport axes. If the pictorial vocabulary can help with this description of the shape of urban patches (S. Kaya, P.J. Curran,2006), it must nevertheless be founded on a theoretical model that acts as a reference in this area. The interest of this model lies in the fact that it allows one to position oneself without the risk of losing oneself so fast in the vast diversity of the particular characteristics of these spaces by first presenting the general laws and constants regulating the arrangement of urban space (P. Derycke,1979). In this regard, the two methods, Thünenian and fractal, offer complimentary theoretical guidelines.

STUDY AREA

As shown in figure 1 Oued Zenati is located in northeastern Algeria, 39.3 kilometers from Guelma and 449 kilometers from Algiers. It is the municipality's major town and the second most important city in the Guelma wilaya. Its population has consistently increased over the last few decades, particularly between 1998 and 2008, when it increased from 22.502 to 27.441 residents (L. Boulahia et al,2017) at a 2.03% annual growth rate. This geographical location gives it a strategic position, which is reinforced by the national road RN20, which crosses the city's urban fabric from north to south, connecting the wilaya of Guelma to that of Constantine, and the national road RN81, which leads to the Algerian-Tunisian border via Souk Ahras. The dissected mountainous topography of the Atlas Tellien and the wadi that spans this city from north to south have significantly affected its urbanization process. Despite having less forest cover than the region of Guelma, the territory of Oued Zenati has some sections set aside for market gardening and arboriculture. Its cereal vocation is supported in large part by its brown calcareous and occasionally deep soils, as well as its sub-humid and semi-arid environment.

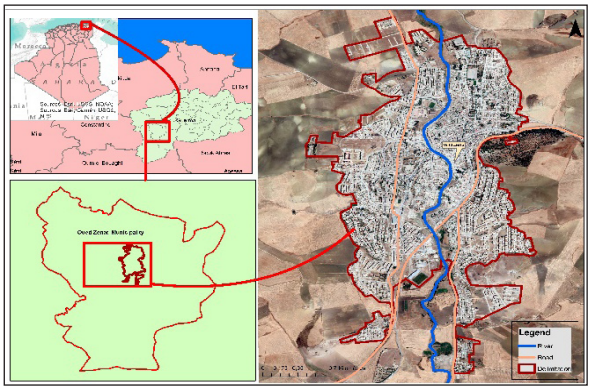


Figure 1. Oued Zenati's delimitation and geographical location

The town of Oued Zenati is located in Guelma Province; the upper-right map shows the location of Guelma Province in eastern Algeria; the lower-right map shows the location of the town of Oued Zenati in Guelma Province; and the left map depicts the urban area of Oued Zenati (Naidja. A, Benmechiche. M, 2021)

METHODS AND MATERIALS

The ultimate goal of studying urban form changes by combining macroform indices with geomatics techniques is to produce a tool that can help to the enhancement of the quality and environmental performance of urban areas, in addition to the aforementioned purposes. As a result, the environmental contribution to sustainable urban development will be strengthened while the economic and social difficulties associated with it are taken into account. Given that this strategy has been used in dry and semi-arid areas in southern Algeria (Dechicha.A, 2003), the current study focuses on a Tellian city (northern Algeria) with an agricultural vocation. As a result, our study is comprehensive and covers both spatial remote sensing technologies and macroform indicators, which we shall discuss further below. It is organized into three sections, the first of which includes a review of the literature on remote sensing and urban form studies using macroform indices. The second section summarizes the case study and describes the techniques used for this goal. In the third section of this paper, we present and discuss the outcomes of applying macroform indices to the case of the city of Oued Zenati using photos from remote sensing. It is a matter of examining the varying values of the indices retained and credited for each elementary figure of the city of Oued Zenati during the three periods

DATA

In order to study the evolution of the fabric of the city of Oued Zenati and the mutations of its urban form, we have used mainly the Geographic Information Systems (GIS) and spatial remote sensing. First, because there were no satellite pictures covering our study area in 1977, we relied on the National Institute of Cartography's topographic map of the city at the time (INC). However, for the years 1999 and 2021, we chose to extract buildings from two Landsat 7 and Sentinel 2 satellite pictures, respectively. Table 1 shows the data used for the extraction of Oued Zeati city's buildigs. These photos are available for download from the Earth Explorer website, the NASA website, and the USGS website. We should mention that the building extraction was accomplished using supervised classification using the maximum likelihood approach and the pixel spectral response. Figure 2 displays The extracted urban built-up land from 1977 to 2021.

Table 1. Data used for the extraction of Oued Zenati city's buildings(Naidja. A and Benmechiche. M, 2021)

Year	Data	Source	Resolution (m)
1977	Topographic map Oued Zenati N7-8 (scale 1/25000)	National Mapping Institute INC.	/
1999	Satellite image	LANDSAT-7 ETM	30
2021	Satellite image	Sentinel2	10

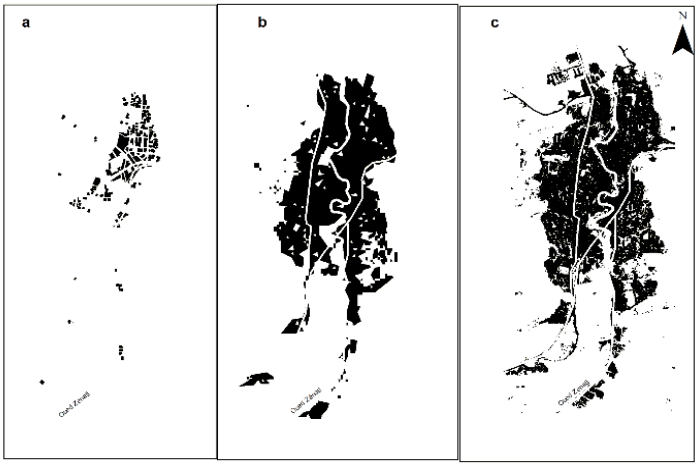


Figure 2. The extracted urban built-up land from 1977 to 2021. (a) Urban built-up land distribution in 1977 ; (b) Urban built-up land distribution in 1999 ; (c) Urban built-up land distribution in 2021

METHOD

The macroform indicators used in this study are connected to the indicators of extent or intensity of land use developed and tested by Guérois (Dechicha.A,2003). Because they lack dimensions and orientation, these indicators do not capture size effects and instead reflect the contour and layout of the shapes, as seen in Table 2. While the compactness of urban forms is frequently characterized by a single favored metric, we agree with Guérois that a mix of many indices is required to arrive at more appropriate classifications (Dechicha.A, 2003). This appears evident to us because each of the six indices listed above is relatively sensitive to all or part of the dimensions of elongation digitation, and indentation used in urban patch analysis and characterization.

Table 2. The macroform indices, (Guérois, 2003; A.Dechicha, 2013)

Indices	Formules	Description
I_1 Perimeter Contortion Index	$I_1 = \frac{4\pi A}{P^2}$ [16,17,]	Ratio between the real surface of the shape (A) and the theoretical perimeter of a circle of the same surface (P). It allows to identify, as opposed to the circle (I1 = 1), elongated and/or indented shapes [25].
I_2 Stretch index	$I_2 = \frac{L2}{L1}$ [16,17,]	Allows to measure the stretch or span of the shape under study by comparing the length of the longest axis (L2) to that of the second longest axis perpendicular to it (L1) [20]. The circle remains the reference figure (I2 = 1 if the two axes are of equal).
I_3, I_4, I_5 Indices of disc filling	$I_3 = \frac{(R)^2}{A}$ [16,17,]	Compares the area of the largest inscribed circle (R) to the area of the figure (A). I3 identifies whether the shape is massive or not.
	$I_4 = \frac{Rci}{Rcc}$ [16,17,]	Allows you to compare the area of the largest inscribed circle (Rci) with that of the smallest circumscribed circle (Rcc). If I4 = 1, the figure is a circle, and the closer I4 is to 0, the more the figure is digited and/or elongated.
	$I_5 = \frac{A}{(Rc)^2}$ [16,17]	Compares the area of the figure (A) to the area of the smallest circumscribed circle (Rc). If I5 = 1, the figure is a circle, and the closer I5 is to 0, the more the figure is digited and/or elongated.
I_6 Digitation index	$I_6 = \frac{1}{(1+D)}$ [16,17]	Constructed from the number of digitation axes. An appendage is considered as a digitation axis if the minimum distance between its extremity and the inscribed circle is greater than the diameter of this circle (D). In the case of a non-digitized shape (Id = 1) the index tends towards 0 when the number of digitation axes increases.
Summary of indices	A : Area of the figure. P : figure's Perimeter. L1 : Length of the longest axis. L2 : Length of the longest axis perpendicular to L1. Rcc : Radius of the circumscribed circle. Rci : Radius of the inscribed circle.	

Guérois identified six simple geometric forms as reference models after addressing the various form indexes (Guerois, 2003). The circle, the flake (a massive circular shape with a highly indented outline in detail), the eight-pointed cross (a highly digitized circular shape), the four-pointed cross (a digitized circular shape), the sinuous line (a more massive linear shape), and the straight line are the primary materializations of these shapes. Fortunately, Guérois created a theoretical reference scale (Table 3) to compare the relative position of these shapes on the value intervals appropriate to each of the indices shown previously in Table 2.

Placing each figure on its own reference scale allows us to characterize each index by a form of "signature," which serves to highlight its sensitivity to particular physical configurations. As a result, our work consists in calculating the six indices mentioned above for the three shapes of Oued Zenati town (extracted via remote sensing) afterward positioning them on the theoretical reference scale of Guérois to draw conclusions not only about the shape of the city but also about its mutations between the three selected dates (1977, 1999, 2021). Subsequentely, by the using of statistic tool (Statistica.7), CPA analysis has been done to determine the correlation between variables and factors.

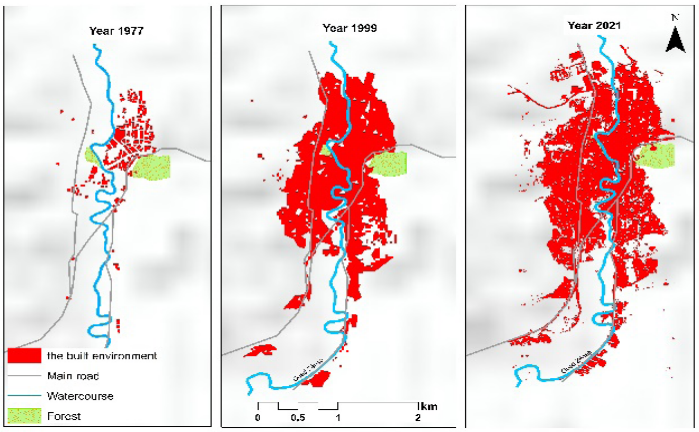
Table 3. Macroform indices calculated for six geometric reference figures (A.Dechicha,2013)

Geometric shape	Description	Values obtained on each index					
		I_1	I_2	I_3	I_4	I_5	I_6
	Circle	1	1	1	1	1	1
	Circular shape, Very indented contour	0.54	0.79	0.78	0.79	0.8	1
	Circular shape, very digitized	0.09	1	-	1	0.45	1
	Circular digitate shape	0.15	1.00	-	1	0.24	1
	Linear sinuous shape	0.10	0.15	0.21	0.15	1	1
	Straight linear form	0	0	-	-	-	1

RESULTS AND DISCUSSION

CHRONOLOGICAL EVOLUTION OF THE URBAN FABRIC

Oued Zenati's urbanization, like that of many other cities around the world, is mostly due to fast population increase and rural exodus. This mainly unplanned, and thus unregulated, urbanization has resulted in the relative devastation of green regions, particularly agricultural areas, and, to a lesser extent, water resources (Boulahia. L,2017 and Naidja.A; Benmechiche.M, 2021). Figure 3 depicts three eras of urban growth as well as three comparatively diverse forms of the city of Oued Zenati, each of which was defined by its unique political, economic, and demographic events, based on remote sensing and supervised categorization.



Year	1977	1999	2021
Built-up area km^2	0.20	2.57	2.94
Built-up area %	11.85	14.40	
Growth rate (%)	53.86	0.65	

Figure 3. Evolution of the urban area of the city of Oued Zenati between 1977 and 2021 (A.Naidja and M. Benmechiche, 2021)

Until 1977: The village grew primarily on the right bank of the Oued, occupying only 0.20 km^2 of land. This growth, caused by the settlers' exogenous action and the locals' endogenous action, has resulted in two forms of fabric: extrinsic

colonial and unplanned self-constructed. We note that since the country's independence (1962) and until 1977, all state socialist efforts focused on the secondary and tertiary sectors, as well as the resulting economic development, have accelerated the urbanization of most Algerian cities, emphasizing the influx of populations in their direction(L. Boulahia,2017, A. Naidja and M. Benmechiche, 2021). Nonetheless, no related reflection took place throughout this period of urbanization that occurred without the introduction of an urban policy as such. This was demonstrated by the fragmented and haphazard construction of cities and a few public buildings.

Until 1999: Following its rapid geographical expansion of nearly 2.57 km^2, the community underwent major transformation (54 %). This linear and egalitarian growth on both sides of the wadi and along the wilaya road CW33 (which leads to Skikda via Bordj Sabat) has resulted in two distinct urban typologies:

- The unplanned fabric: mostly manifested by self-built slums as a result of the large rural exodus to the city.

- The planned fabric: where the state intervened by opting for two construction formulas, one at its own expense via collective and semi-collective housing as well as some public facilities, and the other at the expense of individuals (housing estates). The state's proactive move is part of the Urban Master Plan (PUD), which planned for these types of dwellings to fulfill the strong demand for housing.

We emphasize that, during this second phase, the rebalancing policy featured in the wilaya special plans primarily favored cities (particularly the principal towns of wilaya and dara) or concentrated big investments. This explains the urbanization carried out to the disadvantage of the partners, which has taken on an anarchic speed because to its enormity.

Until 2021: Given the town's agricultural vocation, the city of Oued Zenati has faced spatial stagnation with a rate of 0.65% and an area of 03 km^2. We observe that the city has expanded in the west, north-west, and south-east directions in the shape of housing estates, public facilities, and collective housing, with the goal of reabsorbing the vulnerable environment and even improving the city's image in general. Until date, the city's urban fabric has been primarily created by various forms of collective and individual housing for which the master plan of development and urban planning (PDAU) has well established the rules and standards of construction. It is vital to note that this city, like many Algerian cities, has seen anarchic urbanization, a significant loss of land with very good agricultural yields (L. Boulahia,2017,A. Naidja and M.Benmechiche,2021).

Computation of Six-Macroform Indices to Assess Urban form Mutations

This analogical comparison of the three spatial configurations that the city of Oued Zenati has adopted over its urbanization has revealed that its current form (2021) differs significantly from its initial core, which corresponded to the French colonial fabric bequeathed in 1977. On the other hand, it does not alter significantly from its 1999 shape. Although this analogical method enables understanding of the spatiotemporal evolution of the urban sprawl, as well as its morphogenesis from a simple geometric form to a more comprehensive form (Guérois,2003), it is insufficient on its own. As a result, there is a desire to quantify this urban evolution using the six macroform indices, which are primarily based on the geometric relationships that can occur between the values of perimeter, area, and distance of the digitation axis, as shown in Figure 4 and Table 4.

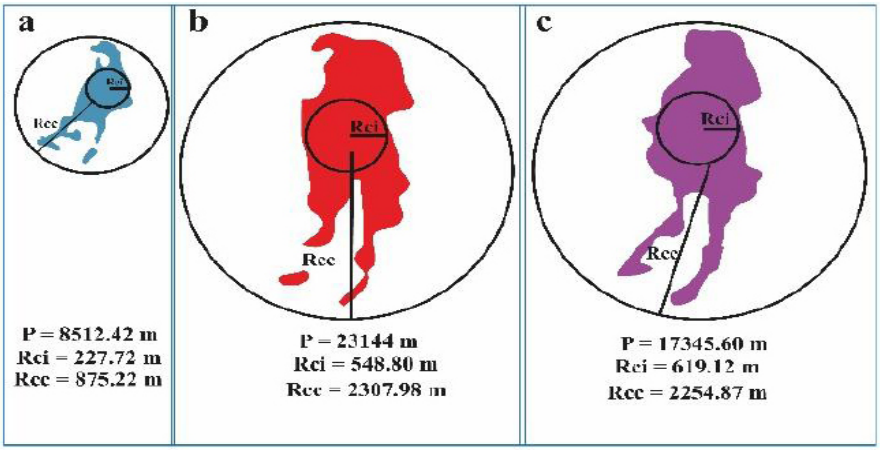


Figure 4. Calculation of perimeter, area, and distance of the digitation axis for the three urban forms of Oued Zenati.

Table 4. Values of the indices attributed to the adopted forms

Geometric shape	Description	Values obtained on each index					
		I_1	I_2	I_3	I_4	I_5	I_6
	Circle	1	1	1	1	1	1
	Very indented contour	0.54	0.79	0.78	0.79	0.8	1
	very digitized	0.09	1	-	1	0.45	1
	digitate shape	0.15	1.00	-	1	0.24	1
	Linear sinuous	0.10	0.15	0.21	0.15	1	1
	Straight linear	0	0	-	-	-	1
	Urban form of Oued Zenati town in 1977	0.03	0.26	0.75	0.25	0.08	0.53
	Urban form of Oued Zenati town in 1999	0.11	0.27	0.45	0.09	0.16	0.3
	Urban form of Oued Zenati town in 2021	0.06	0.23	0.31	0.02	0.001	0.3

Table 4 reveals that the value I1 of the city of Oued Zenati corresponds to the following values during the three study periods: I1 (1977) is equal to 0.03; I1 (1999) is equal to 0.11; I1 (2021) is equal to 0.06. These figures, which are near to zero, demonstrate that the urban patch of Oued Zenati city during these three eras is significantly stretched. Thus, the stretching index I2 calculation demonstrates the linearity of its shape during the three phases. The filling index I3, on the other hand, differs in that its one value corresponding to the ,year 1977 is equal to 0.75. This value is greater than 0.5, indicating the vast nature of the agglomeration during this time period. The I3 index values for 1999 and 2021, on the other hand, are lower than 0.5 and closer to the minimum value (0), showing the city's non-massive character during both times (Figure 5).

Concerning the filling index I4, the city records values less than 0.5 over all analyzed eras, giving birth to a digital or extended urban shape. The digital character of the city's shape during these three eras is confirmed by the computation of the filling index I5 (the values of the three dates are less than 0.5). However, the location (0.53) of the Oued Zenati agglomeration's I6 index in 1977, which is near to the values of the two major perpendicular axes (figure 5), shows a less digitized nature. This contradicts the macroforms for the years 1999 and 2021, in which the values of the I6 index exhibit digitation during these two eras. Based on these findings, we may conclude that the agglomeration of Oued Zenati experienced an elongated macroform (urban form) during these three stages of evolution.

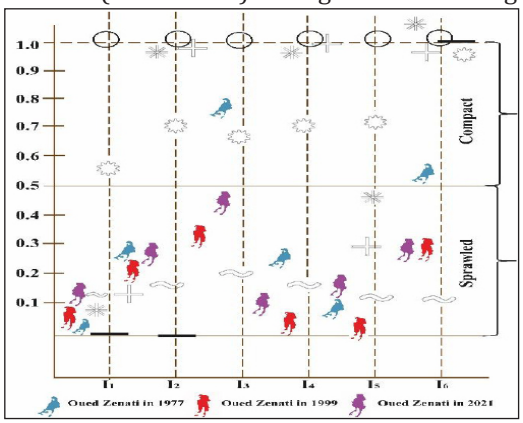


Figure 5. Position of the urban form figures of Oued Zenati during the three periods on each index compared to the elementary figures.

DIFFERENCIATION OF URBAN FORMS VIA PCA ANALYSIS

We used principal compenent analysis (PCA) to assure greater relevance to earlier analyses, which allows us to create matrices to project the variables into a new space that reveals the degree of similarity between the variables calculated. We recall that PCA is a factorial analysis in the sense that it generates factors (or principal axes) that are hierarchical and independent of the original variables (M. Béguin, D. Pumain,2000). In our scenario, principal component analysis (PCA) is an exceedingly strong method for condensing and synthesizing previously acquired findings. The correlation circle and the PCA observation graph are used in this analysis (See figures 6 and 7).

THE PCA CORRELATION CIRCLE

The correlation circle (or variable graph) depicts the relationships that exist between the components and the original variables. Vectors can also be used to display additional variables. Each point's correlation on an axis expresses how well the point is represented on the axis. It accepts values ranging from 0 (no correlation) to 1. (highly correlated). If this number is near to one, the point on the axis is well represented. Figure 6 clearly indicates that the points corresponding to the indices I2, I3, I4, and I5 are quite close to the correlation circle and thus very effectively represented on the factorial plane after completing this type of analysis. The relatively small angle formed by the dots corresponding to the indices I4 and I2 suggests that these two variables are negatively connected. The almost right angle produced by the indices I3 and I6, on the other hand, suggests that these two variables are independent of one another. Furthermore, the indices I2, I4, and I5 are near to the axis (F1), indicating that this axis adequately represents them. However, point I3 is close to the axis (F2), indicating that the index I3 is closely associated with the axis (F2). We can deduce from these results that the factorial axis (F1) corresponds to the combination of the stretching index I2 and the digitation indices I4 and I5. The axis (F2) represents the filling index I3.

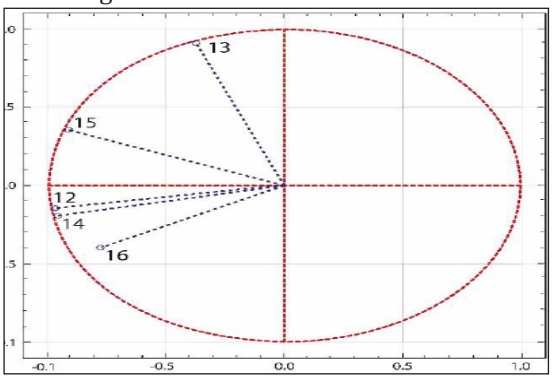


Figure 6. Projection of the variables (form indices) on the factorial plane (1x2).

The PCA OBSERVATION GRAPH

The observation graphs reflect the observations in the PCA space and allow the persons investigated to be represented on a two-dimensional map, allowing any trends to be identified (M. Béguin, D. Pumain,2000; M. Guerrien,2003). Figure 7 depicts the results of the PCA analysis for the city of Oued Zenati, which indicate a clear differentiation of the images investigated.

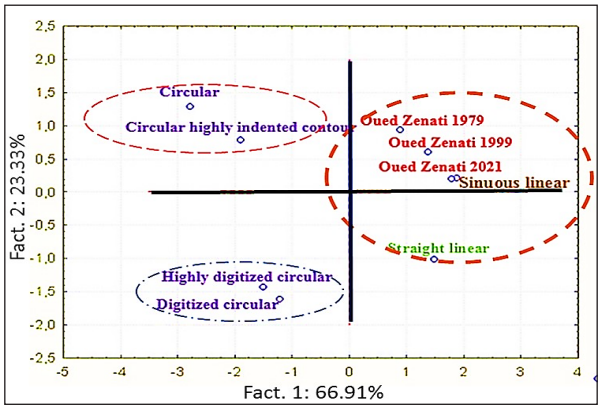


Figure 7. Projection of the indices on the factorial plane (1x2) (the sum of squared cosines ≥ 0.00 and Illustrative variable: I1)

As a result, we can distinguish three kinds of forms:

- The elongated form: includes the sinuous linear shape, the linear shape as well as the shape of the city of Oued Zenati in 1977, in 1999 and in 2021;
- The circular digitized form: includes the circular digitized shape and the highly digitized shape.
- The compact circular form: constituted by the two elementary figures circular and circular with very indented contour.

CONCLUSIONS

The study of urban sprawl of cities through the mutations of their urban forms is becoming increasingly significant in current days, particularly in the context of sustainability and climate change, both of which are becoming increasingly important. Through the case of Oued Zenati city in the north east of Algeria, this analytical study demonstrated how to combine remote sensing techniques with macroform indices, which are utilized by both urban planners and geographers. According to the findings of the analysis, the urban form of this city is positioned in the field of less compact sinuous linear forms as a result of its urbanization and development process.

This form is certainly influenced by geographical factors (location in relation to road infrastructures) and physical factors (presence of the Valley), but it also results from ill-considered urban policies of the day after the country's independence and the decade that followed, when the industrializing economy's policy largely encouraged rural exodus and the disproportionate growth of several formerly rural and agricultural villages. Although these findings are specific to the city of Oued Zenati, the methodology and methods employed in this study can be applied to other case studies throughout the world in order to generate tools for the management of urban sprawl and the preservation of natural and agricultural ecosystems.

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