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INTEGRATION OF GIS TECHNOLOGY IN THE URBAN PLANNING TO EXTEND THE CITY OF ZAMORA, SPAIN

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Abstract

The present study has established a methodology to determine the most environmentally sustainable area for the expansion of a city center using Geographic Information System (GIS) technology. This technology permits the graphical information associated with a municipality to be manipulated, integrated, analyzed and represented in a simple way that is cost effective during the early decision making steps, which analyze the various options regarding the urbanistic planning prior to taking final decisions.

In order to delimit the growth zones, three types of factors were established: restrictive (those whose presence made urbanization impossible: close proximity to a treatment system, risk of flooding, steep slopes, protected land, high quality agricultural land and geotechnical problems); determinant (those who determined which sectors would require additional costs upon urbanization: distance to the preexisting infrastructures, heavy traffic and close proximity to an administrative center) that determined which periphery areas were suitable for the construction of new buildings; and finally establishing which areas were to be built up through a decision factor that satisfied a particular municipal need.

Moreover, to facilitate the urbanistic process, the selected areas were divided into cadastral parcels that were analyzed, and their dimensions and existing visual impact were determined. In addition, the type of dwelling to be utilized was recommended once an urbanistic analysis was carried out on the adjacent areas and the urban transport system was designed, connecting the new growth area to the city center.

Key words: Geographic Information System, geo-environmental cartography, sustainable growth, urban planning

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1. Introduction

The Population settlements bring forth groups of buildings in determined places and of specific qualities. In the last century, the process of urbanization has considerably grown globally due to the fact that currently half of the world's population resides in urban areas (Seto and Fragkias, 2005). As a result, urbanization is the main cause for the irreversible loss of land (Luck and Wu, 2002; Martínez-Graña et al., 2013; Martínez-Graña et al., 2014a; Westervelt et al., 2011). In this context, some cities have grown without a clearly defined ordinance, and over time, this type of growth should be regulated through official building regulations with the aim to achieve sustainable medium and long term growth, according to new trends and population demands. In such cases, and especially in those areas where no type of regulated planning exists, i.e. countries with large populations and few resources, serious environmental and social problems appear. Their rectification is the main challenge to planners of the 21st Century (Bendor et al., 2013; Irwin and Bockstael, 2002; Klauco et al., 2017; Martínez-Graña et al., 2014b; Poelmans and Van Rompaey, 2009). In Spain during the last few decades, there has also been an intense period of

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urbanization, especially between 1995 and 2007, incited by a time of high economic activity in which large metropolitan areas in both big and medium-sized cities were expanded and consolidated.

Equally, the different urbanistic activities that are carried out within a given population settlement should be correctly planned in order to achieve a territorial model that guarantees environmental protection, and at the same time provides an adequate quality of life to the populace. In the present work an expansion area in the city center of Zamora (Fig. 1) was determined using pre-established factors that ensured the compliance of technical requisites and the environmental sustainability of the project. For this reason, the objective of this work was to develop a methodology using Geographic Information Systems, via the analysis of geographical data and established factors, which permitted the spatial determination of peripheral areas of the city of Zamora that accommodated, in a sustainable way, the development of new buildings and urban services.

This methodology can be applied to any environment in an easy and efficient manner, and without the need for large economic costs due its characteristics. GIS technology has gained a great deal of importance since traditional (paper) cartography has been replaced by geographically referenced data (Burrough and McDonnel, 1998). To date, GIS is an essential tool used by municipal managers and planners in the management and planning of different resources owing to its easy handling of the geo-spatial data throughout the various stages of planning (Arentze et al., 1996; Haidu et al., 2017; Lee, 1994; Martinez-Graña et al., 2014c; Ribeiro et al., 2013). Hence, in the last 25 years, due to the boom of GIS and the gradual integration of environmental criteria in the urbanization and decision making process, a multitude of works related to territorial planning, sustainable development and the use of GIS have been carried out. (Aguilera et al., 2011; Bostrom, 2012; He et al., 2011; Li, 2011; Oh, 2001; Ryan, 2011; Sterk et al., 2009; Sung et al., 2001; Van Der Perk et al., 2007; Wu et al., 2000; Xie et al., 2012; Yeh and Chow, 1996). There are also several planning studies that are based on a multi-criteria evaluation where different environmental factors, such as geology, hydrology, vegetation, topography and etcetera, are analyzed and considered in the planning process (Carver, 1991; Grabaum and Meyer, 1998; Joerin et al., 2001; Martinez-Graña et al., 2014d; Otero et al., 2013; Pueyo et al., 2011; Robu and Macoveanu, 2009).

Urban planning is responsible for the urbanization of land at a local scale, where its main aim is to foresee the correct development of territory in relation to the process of urbanization (transformation of rural land into building land), which requires specific components that guide this process.

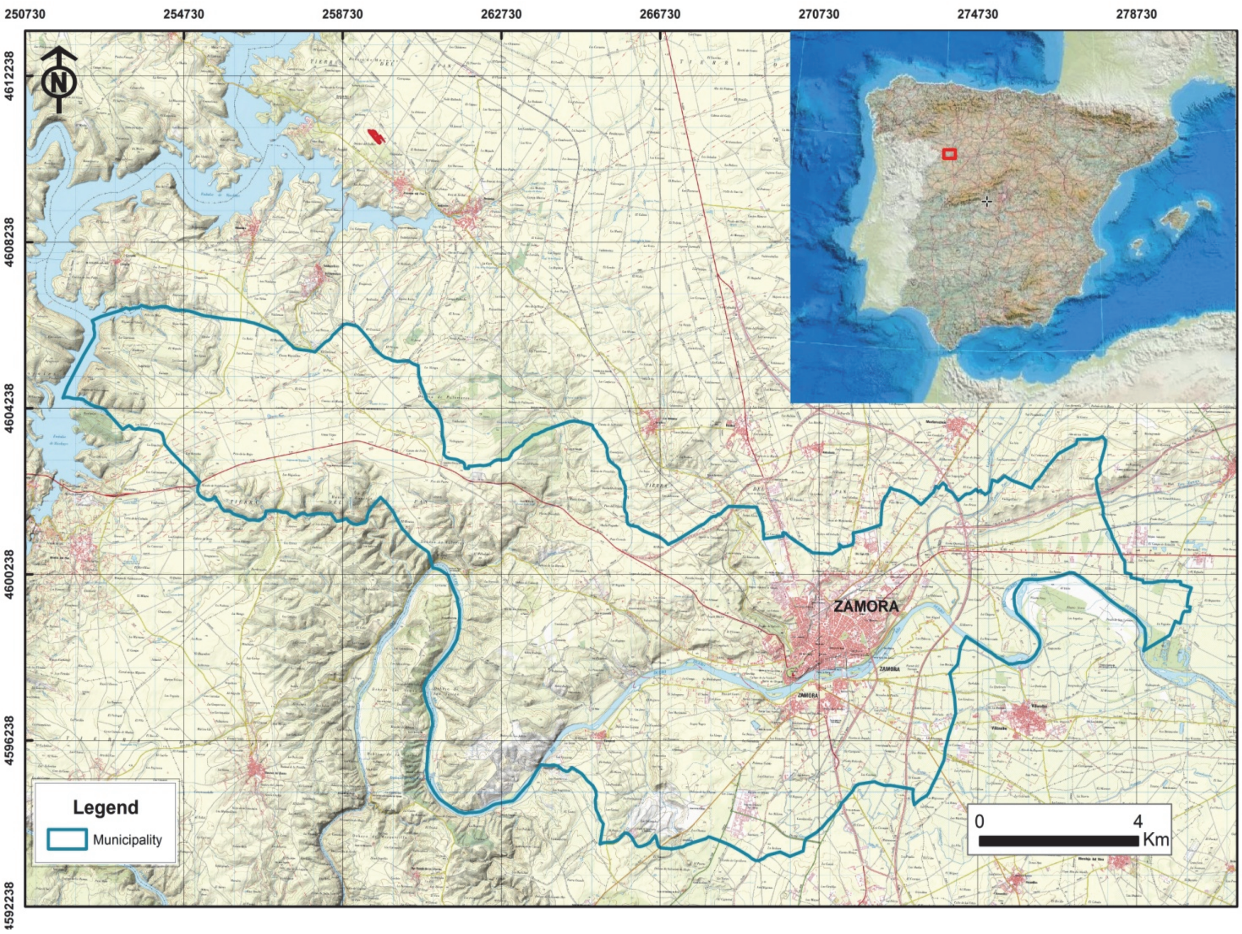


Fig. 1. Localization map of the municipality of Zamora

In Zamora, as in other large urban populations, the General Urban Development Plan -*GUDP*- is the base ordinance for developing municipal land, which can utilize all the ordinance and urban management tools within the legislature, in contrast to other instruments. The *GUDP* establishes a territorial model that is completed within a given time and outlines the general and specific objectives for each type of the territorial parcels according to land use.

2. Material and methods

The The identification of the most favorable area for amplifying Zamora's city center was carried out based on the combination of restrictive (elements that impede the construction of housing in certain areas) and determinant (elements that determine which areas, suitable for building, are the most economically profitable) urbanistic criteria, in which the periphery areas most adequate for accommodating new buildings were localized. The selection of the final sectors was done in agreement with the decision criteria, defined by the objectives or the actions outlined by the Government. Finally, a cadastral analysis was conducted on the selected areas, the appropriate type of housing was chosen, the value of the resulting parcels was analyzed, and a public transport network was designed to connect the new built up areas with the city center.

Before carrying out a detailed study regarding the various factors, Zamora's physical environment was characterized (in terms of land use and geological, edaphological and hydrological characteristics) in order to provide a basis for the analysis of restrictive factors. In relation to this, the Land Use Map (Fig. 2A) highlighted the agricultural areas containing irrigation crops in the eastern sector of the city that were replaced by non-irrigated crops, grasslands, and forest and scrub formations in the most western areas. On the other hand, the Geological Map (Fig. 2B) showed that the city was seated mainly over Quaternary materials made up of pebbles, gravel and sands deposited by the Duero River. It was over these materials that the deepest layers of land within the area (fluvisols) developed and were comprised of soil typical of the valley of the Duero River, while the other sectors were situated more to the east of the city and appeared to be mainly seated over a sandstone lithology. Over this material the luvisols formed, and in the far north and south limonites and loams appeared; luvisols developed in the southern part of the city, and cambisols appeared in the far north, as shown in Edaphological Map (Fig. 2C). The Hydrological Map (Fig. 2D) exhibited the rivers and streams of the town, and the areas protected by the Hydraulic Public Domain -*HPD*- (Sheelanere et al., 2013; Stellmes et al., 2013; Vidal et al., 2016).

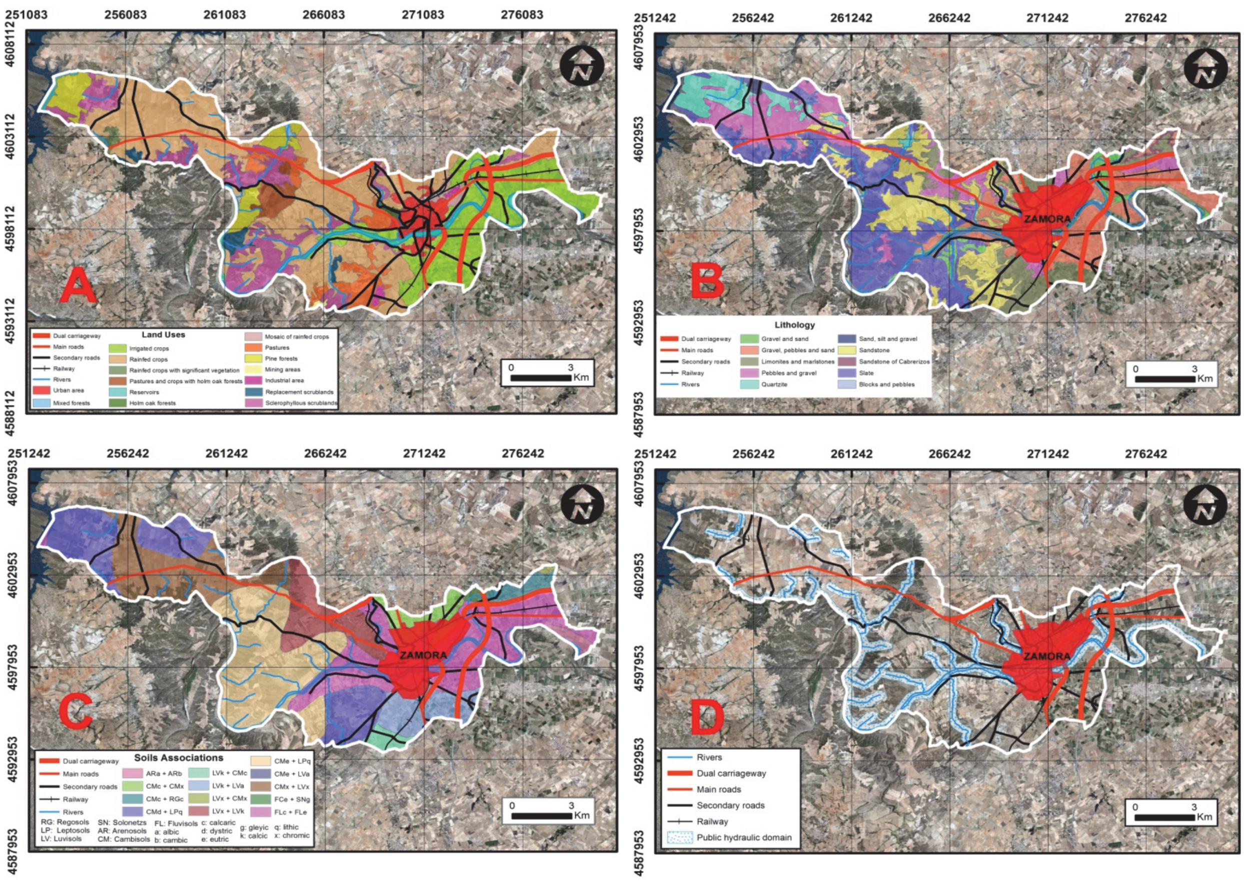


Fig. 2. (A) Land Use Map; (B) Geological Map; (C) Edaphological Map; (D) Hydrological Map

Lastly, the sites of interest to be utilized in subsequent analyses, such as schools, administrative building etc. were identified and localized spatially by elaborating a geo-database, as an *Excel* file, that could be imported into the GIS software, which contained the locations of the sites of interest. These areas were geolocalized in the map using a geocoding service. In addition, the town was divided into 300-meter grids using Hawth's Tools. Those areas that fell within the outskirts of Zamora were selected based on their location, and were the areas that would finally be put forward for construction.

2.1. Study of restrictive factors

Each factor was analyzed individually and then later analyzed in combination with the periphery areas capable of accommodating new buildings and those which could not, in order to avoid urbanizing areas with natural risks, excessive additional costs, and areas protected due to high environmental value (Martinez-Graña et al., 2016).

2.1.1. Steep slopes

To avoid extra construction costs, the areas with slopes greater that 30% were not built up. Starting from 1:25000 Digital Elevation Model (DEM25), these areas were determined by obtaining the curve levels, creating a DEM in the format TIN, which was subjected to a slope analysis; a raster slope map was generated that reclassified and differentiated the areas with a slope less than or greater than 30%. In the Slope map of Zamora (Fig. 3A) it was appreciated that there were no slopes in the peripheral area of Zamora that were greater than 30%. Thus, this factor did not present any restriction on the process of urbanization.

2.1.2. Use of protected land

The areas that were declared, according to their natural characteristics- ecological or structural - as "Protected Land" should not be built up. This included any of the following three types of protected land: Areas of Ecological Value (includes the most valuable ecosystems); Areas of Agro-environmental Value, (contains areas with high productive value and the areas associated with rivers and streams that harbor important fauna and flora in their banks; and Environmentally Fragile Areas (areas with different peculiarities, such as complex relief, steep slopes, soil erosion, Mediterranean relict shrub areas or highly visible landscape. In the Protected Land Map (Fig. 3B) different protected areas could be observed together with unprotected areas, highlighting spaces that could be used for livestock farming (combining a large portion of non-irrigated crops, grassland areas and areas for raising livestock) and industrial areas that contained sand and gravel quarries, tree plantation and etcetera. The undeveloped protected areas within the urban part of the city included: the southwest part of the city where highly productive irrigated crops were grown within the Duero Valley (Area of Agro-environmental Value), and the ecosystems connected to the Duero and Valderaduey rivers, which presented an interesting riverbank flora and associated diverse fauna (Environmentally Fragile Areas).

2.1.3. Land capability for agriculture

In order to produce a Thematic Land Capability Map that permitted us to know how valuable the lands were in a particular region according to their productivity, information was taken from a Basic Land Map, which in turn was elaborated using information coming from a Land Map of Castile and Leon. Afterwards, the land was evaluated to define the Land Classes, according to the universally recognized Land-Capability Classification system (Klingebiel and Montgomery, 1961), using a broad database of environmental, morphological, physical and chemical soil data, and its capacity to be used for agriculture and forest use. Lastly, each soil was assigned its corresponding land class (10 profiles were chosen from the most representative soils in the area), leaving the richest and most productive soils protected (Classes I and II). In the Land Class Map of Zamora (Fig. 3C) the most productive and valuable soils were observed to be situated over flat soils and soils of the river valley (Fluvisols) capable of being irrigated (Class II). Also, deep soil with good characteristics (Cambisols and especially Luvisols), situated over flat soil or with a slight slope, were assigned to Class III. These soils corresponded to the areas designated to non-irrigated crops in the north and southeast parts of the city, and were also distributed throughout the western section of the town.

In rocky areas with a high slope, close to river escarpments, the soils were less developed, such as Regosols; however, this did not inflict any limitation on the cultivation of rainfed crops (Class IV). Finally, the rest of the soils were included within Class VI, being less developed and of a poorer quality. This soil was greatly limited and impeded agricultural exploitation, but was adequate enough for the cultivation of dry grasslands and dry pastures (oak trees) in flat areas, and shrubs in escarpment areas.

2.1.4. Geotechnics

A geotechnical characteristics analysis determined the unsuitable areas that were then excluded from the process of urbanization to avoid possible risks to the community and extra construction costs. A Geotechnical Map was created using the Geological Map of Zamora as a base, upon which the various existing risks were added (lithological, hydrological, geotechnical and geomorphological) in accordance with the Geotechnical Map of Spain. In the Geotechnical Map of Zamora (Fig. 3D) it was observed that the territory was divided into zones with favorable, acceptable or unfavorable conditions. The worst conditions were found in the western part of the town containing material that was easily capable of breaking into slabs, such as quartzite and slate, and attached to steep terrain, conditions that might have led to problems with landslides.

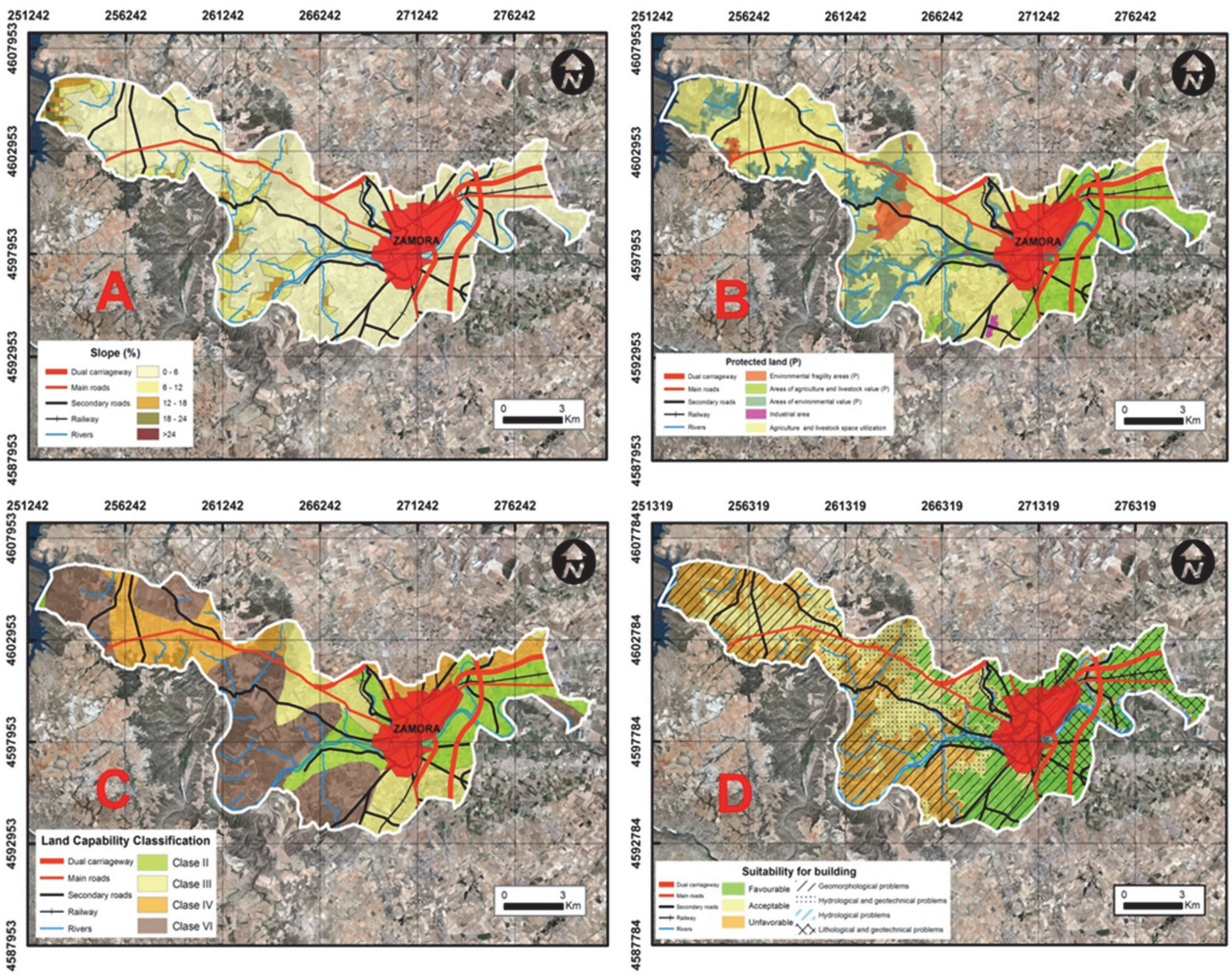


Fig. 3. A) Slope Map; B) Protected Land Map; C) Land Capability Classification Map; D) Geotechnical Map

In the east part of the town, and generally within the city center of Zamora, except for the areas linked to waterways, favorable building conditions were observed. This was due to the flat and stable morphology of the area and to the presence of stable and resistant materials (sand, gravel and alluvial clay deposits in the vicinity of the Duero River, and the sandstones and conglomerates in the north part of the city).

2.1.5. Areas of low quality of life

New buildings should be situated within clean areas with optimum environmental conditions. As regards, the influence of the city's treatment plant on the quality of life of the new residents' was taken into account. In order to guarantee the well-being of the community, an analysis of the influence of proximity was conducted within multiple rings (Fig. 4A). As a result of the analysis, two areas of restrictive influence were identified that would make urbanization of the area impossible: one included a 200-meter radius affected by noise and odors and the other a 400-meter radius affected by bad odors. After carrying out the analysis, it was observed that none of the peripheral areas suffered from these effects, and therefore, the factor of proximity to the purification system will not be considered as an issue from here on (Dewi et al., 2013).

2.1.6. Risk of flooding

The areas with a risk of flooding should not be urbanized so as to protect the community and to avoid economic losses. To determine these areas three factors were analyzed: slope (a slight slope, less than 3%, more difficult to evacuate water), close proximity to a waterway (area delimited by the Hydraulic Public Domain) and altitude (a height of 630 m. was established as having less chance of risk). Using the reclassified raster (Fig. 4B), there areas were assigned values close to 1 for those areas that presented risk, and values close to 0 for those areas without risk. Lastly, using the raster calculator, a summation was obtained that represented the risk of flooding for each area, discarding the areas that presented risk of flooding.

After the restrictions were analyzed individually, a global restrictive analysis was carried out generating a summation of the elements (restrictive areas had values close to 1 and the non-restrictive areas had values close to 0) using algebra for maps (Fig. 4C), and by calculating the mean restrictive values for each sector by zonal statistics.

The sectors that did not present any restriction on the process of urbanization, being those that had a value less than the fixed reference value (1.05), were established and selected based on attributes (Fig. 4D).

2.2. Study of the determinant factors

After the periphery sectors without restrictions were determined, they were differentiated based on their suitability to accommodate new buildings; the most adequate were those areas that required the lowest extra costs. These sectors were compared through a series of determinant factors.

2.2.1. Proximity to preexisting urban infrastructures

The future buildings needed to provide the basic supply of electricity, potable water and waste disposal, and the new infrastructures that covered these services should connect up with the already existing ones; the best areas to build were the nearest to already existing networks. Using the plan/blueprint of the preexisting networks, which are geo-referenced and digitalized, the GIS calculated the distance between the growth points and the infrastructures, chose the minimum distance, and elaborated a distance map using the interpolation method of Inverse Distance. Regarding the distance of the electrical supply (Fig. 5A), the north and south periphery areas of Zamora were found to be closer than those situated in the east. Also, in the distance map it was observed that all of the areas were quite close to the supply network, except for some areas in the far north and south. Furthermore, it was observed that the distances to the sewerage system (Fig. 5B) were generally greater with respect to the rest of the infrastructures, being less so in the northeast sector.

2.2.2. Road density

The presence of roads in growth sectors implied a significant economic benefit, as the cost involved in connecting roads to the already existing infrastructures was less. To determine the number of roads a density analysis of the framework of the city was carried out (Fig. 5C), which indicated that the greatest road density was located in the northeast and northwest; the rest of the areas had an intermediate road density.

2.2.3. Proximity to administrative zone

The new buildings needed to be located relatively close to the city center (administrative and commercial zone) in order to provide a high level of serviceability to the future population. Using an area of influence with multiple concentric rings of 500 meters and its reclassification, a descending valuation was established for the different areas as they moved farther away from the center. According to the distance map in relation to the administrative center (Fig. 5D) the areas of growth farthest away from the center were located in the north part, while the distance was less for the areas located in the west and southwest parts of the city.

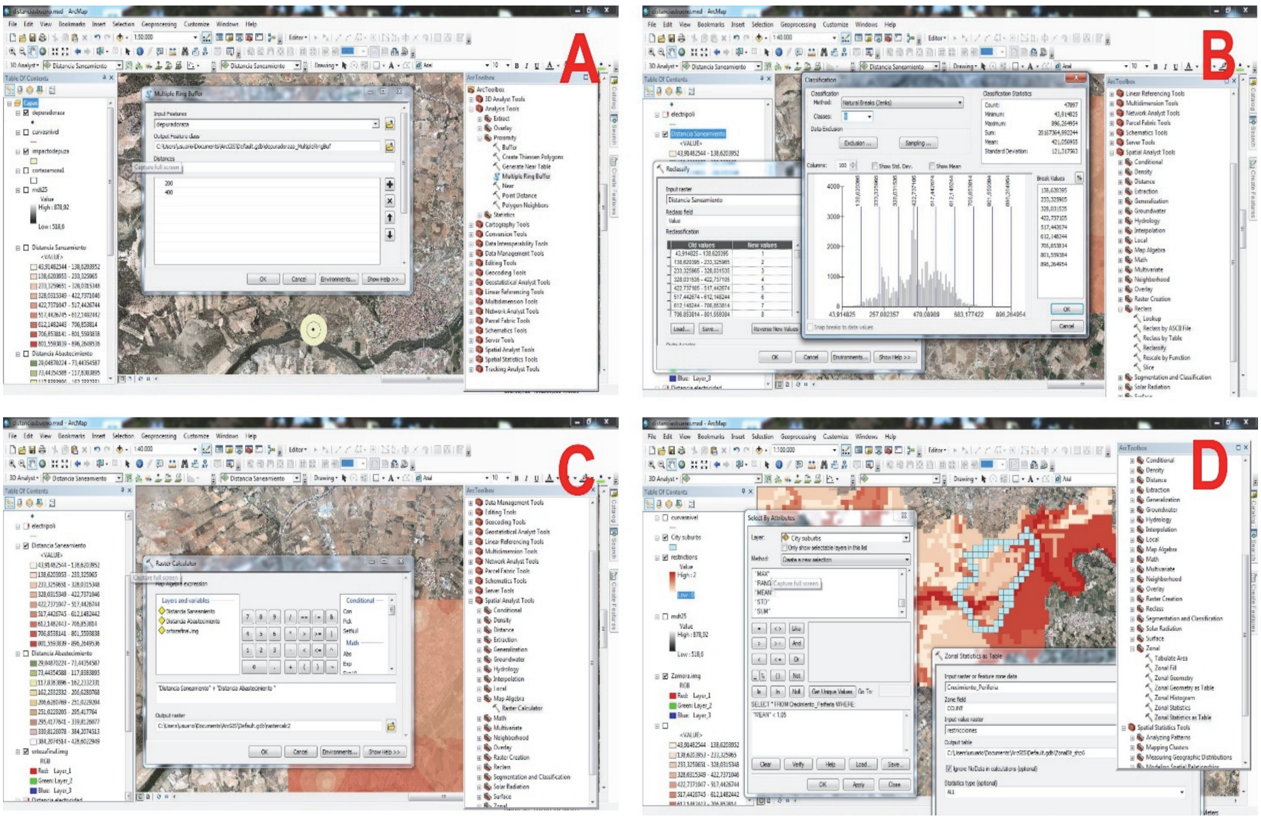


Fig. 4. (A)Proximity to the purification system analysis; (B) Raster reclassification tool; (C) Raster Calculator; (D) Zonal Statistics and Selection Based on Attributes to select the peripheral areas without restriction

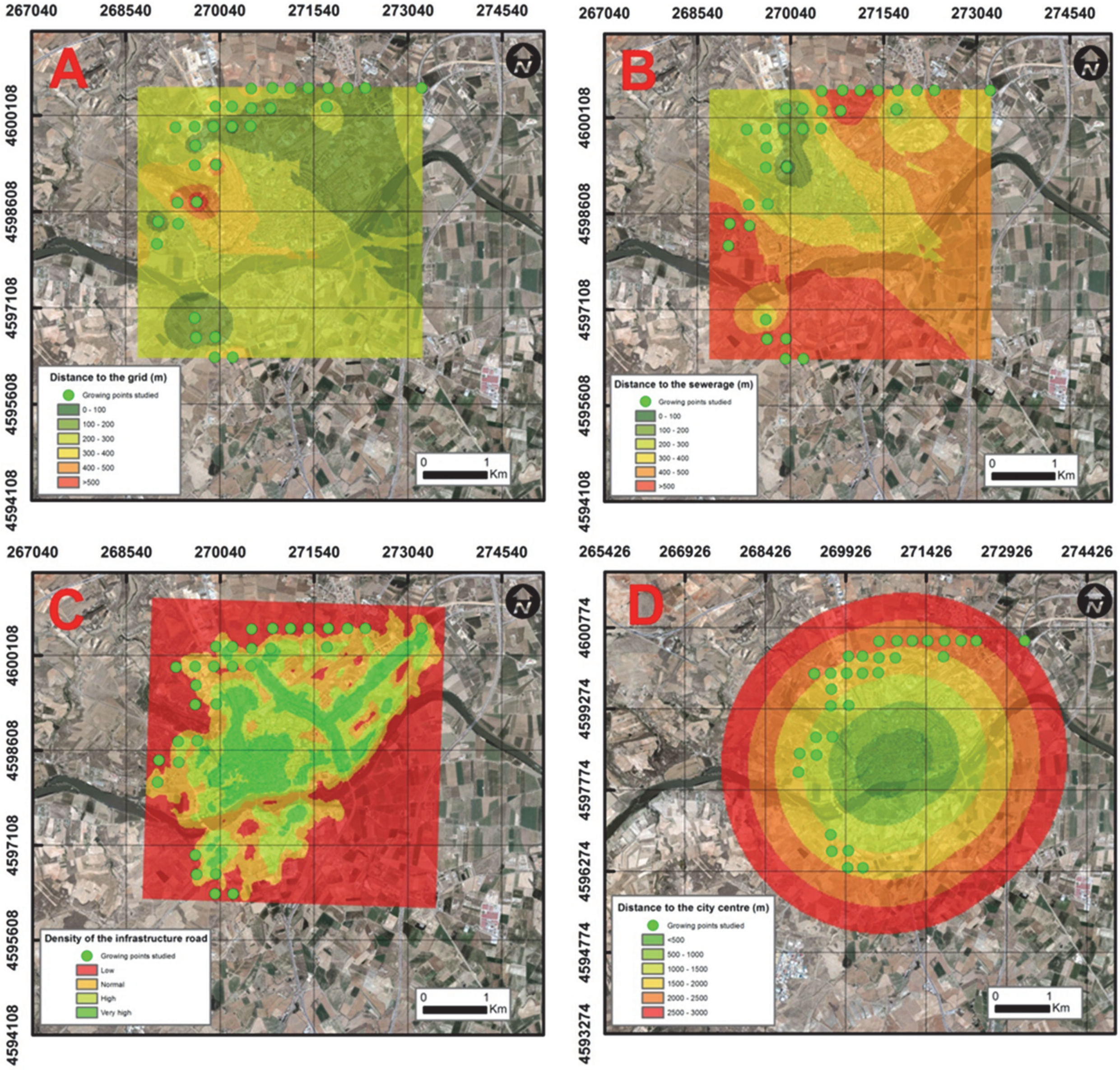


Fig. 5. (A) Distance Map to the electrical supply; (B) Distance Map to the sewerage system; (C) Road Density Map; (D) Distance Map to the city center

Similar to the study of the restrictive factors using the raster calculator, zonal statistics and selection based on attributes, a joint analysis was carried out on the determinant factors (assigning the same weight for all factors) and established the areas of growth that yielded the lowest expense.

2.3. Decision Criteria

According to the type of study and societal needs, the decision criteria might vary. In this case, only the close proximity of the different growth areas to schools with the largest number of vacant places were considered. The objective was that these schools would accept the new students originating from the built up area, avoiding the need to build new schools that would increase costs. Hence, after the public and private schools were identified using an address localizer, the city was divided in accordance with the area of influence of each school using the "Thiessen Polygon Method", which labelled each polygon with the number of vacant places of each school.

2.4. Analysis of the areas selected for urbanization

After the expansion areas of the city center were defined, the analysis of a series of factors that served to improve the execution of the process of urbanization was carried out.

2.4.1. Division of land into parcels

Once the areas to be urbanized were selected they were defined as execution units (cadastral parcels) that facilitated urbanization. To do this, an image of the existing plots was obtained from the Electronic Land Registration Office, which was geo-referenced and served as a base to digitalize the different parcels that made up the growth areas.

2.4.2. Housing typology analysis

The type of building that was recommended for the growth area was determined, and the maximum number of floors that was recommended to build, based on an analysis of the characteristics of the houses of the surrounding area using *Google Maps* y *Google Earth* viewers, was established. The objective was to integrate the new buildings in the best way possible into the already urbanized environment to achieve a certain level of homogeneity in the urban structural framework.

2.4.3. Parcel value analysis

There were multiple variables that influenced parcel price: extension, visibility, location, and etcetera. However, in the present study only the value of each parcel in relation to its view of the industrial areas was analyzed. Using the cartography of the industrial areas obtained at the SIOSE, the calculation of viewsheds was carried out and a visibility map of the industrial areas was obtained from each parcel. Lastly, the magnitude of visual impact (null, low, medium, high and very high) was determined using zonal statistics for each plot.

2.4.4. Establishment of the transport network

To guarantee a satisfactory connection between the city center and the new growth area, a transport route connecting both areas was designed. To do this, a Geodatabase was created, generating a dataset of elements that included the structural framework of the city of Zamora. Afterwards, using the Utility Network Analyst software, a new transport route was designed.

3. Results and discussion

Following the analysis of the different established factors, the most adequate areas for expansion within the city center of Zamora were determined. As already mentioned, the periphery areas of Zamora were first subjected to an analysis of a series of restrictive factors, which discarded the urbanization of areas that manifested some type of factor that was designated as being restrictive. The areas that did not present any type of restrictions (Fig. 6) were studied in accordance to the imposed determinate factors, and were selected to further identify those that yielded the least amount of extra economic cost (Fig. 7A), while the rest of the areas were eliminated. Once the periphery areas that satisfied the imposed restrictive and determinant factors were established, the decision criteria was used to determine which ones were to be put forward for construction. Since it was necessary to provide satisfactory educational centers to the future population within the urbanized area, it was proposed to build in areas close to schools that could accommodate the new influx of students. Then, after the areas were divided into zones and the number of vacant places was studied, it was observed that the schools located in the outskirts of the city were the ones that had the most available places, especially within the north and east part of the city. For this reason, it was decided that the areas that would be urbanized were the ones that were situated close to this area (Fig 7B), which had enough free land capable of being developed (north parts of the city).

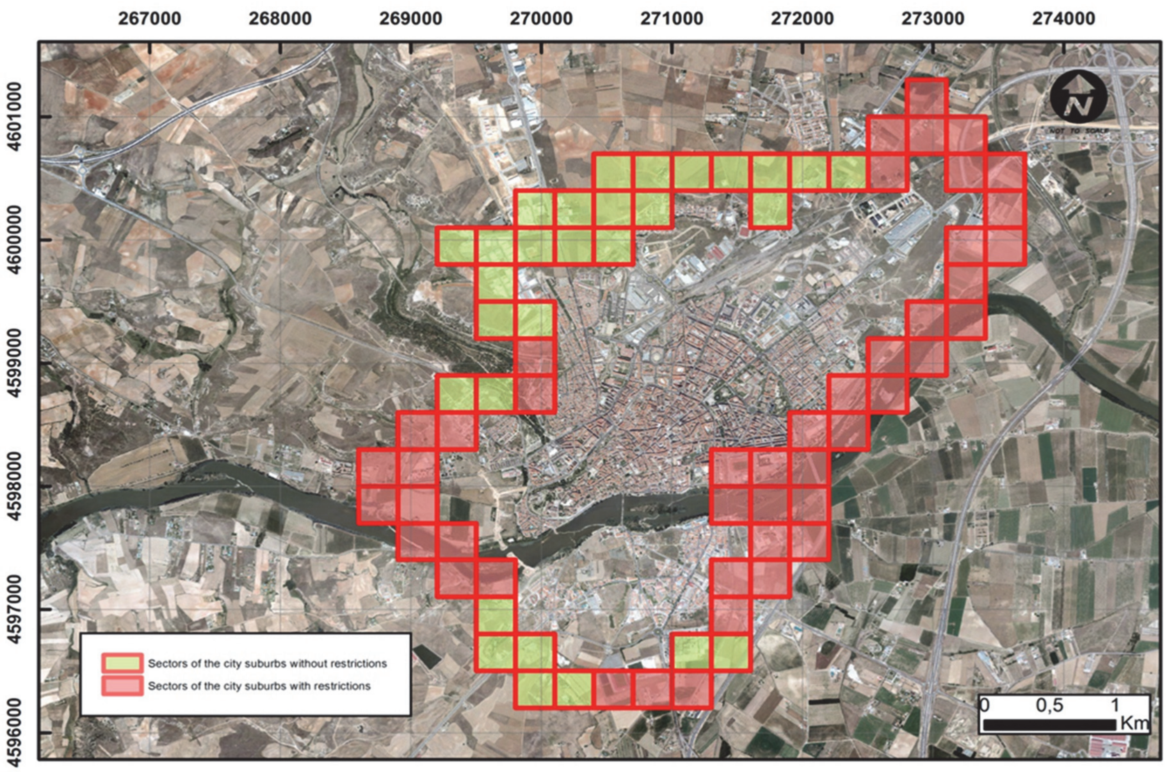


Fig. 6. Periphery areas of Zamora without urbanization restrictions

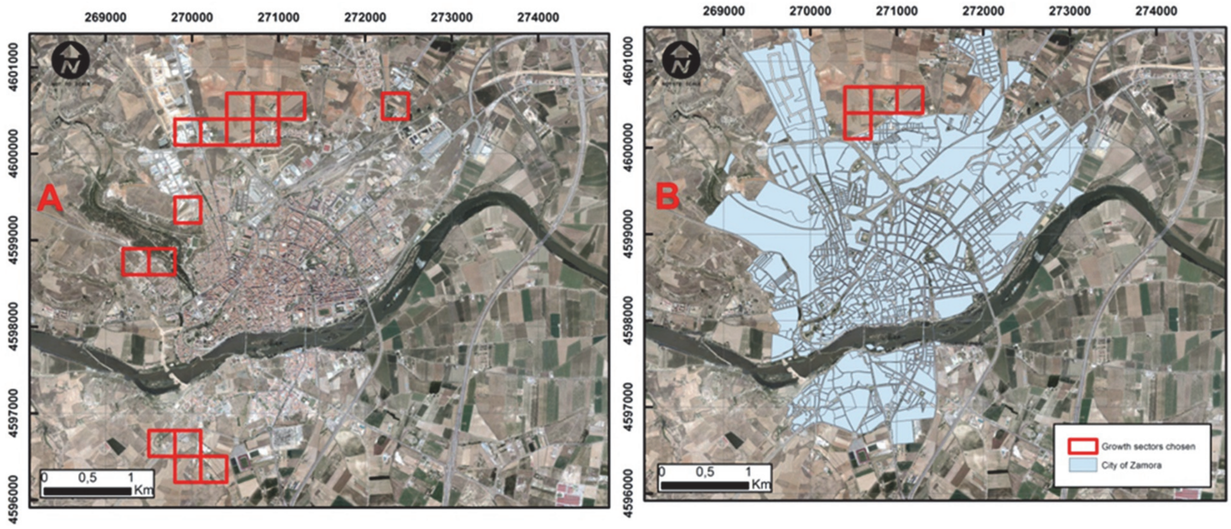
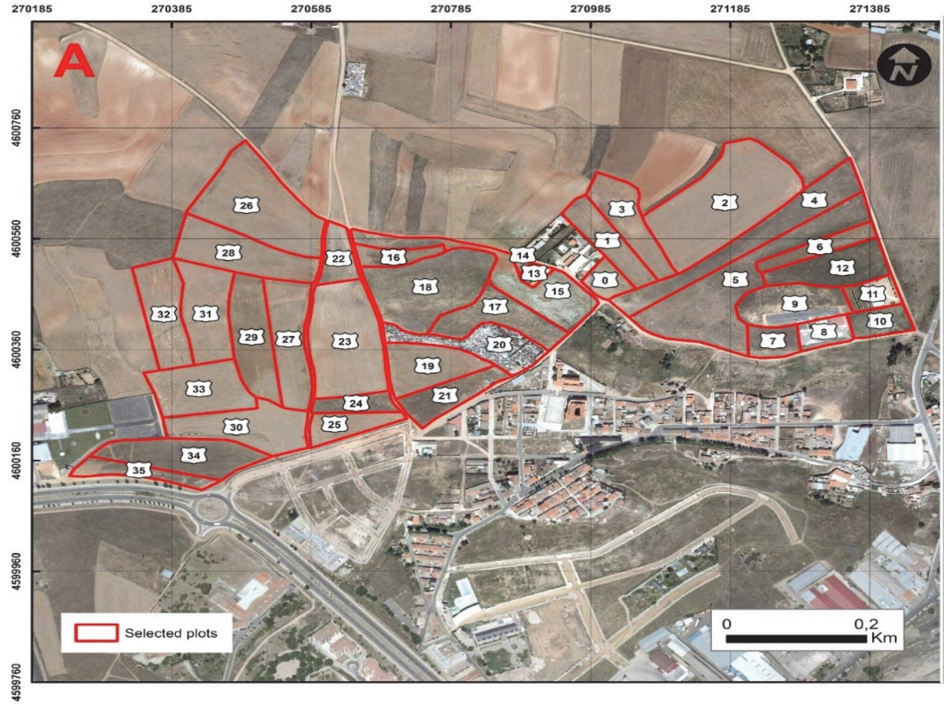


Fig. 7. (A) Periphery sectors without limitations on urbanization;
(B) Periphery sectors chosen for the expansion of the city center of Zamora



Parcel	Area (m^2)	Perimeter (m)
0	3209.1	229.7
1	7403.3	444.3
2	28118.8	696.9
3	9181.3	495.3
4	15844.7	944.5
5	24366.2	1032.4
6	4573.3	411.1
7	3993.3	256.49
8	3689.0	249.0
9	10081.9	413.1
10	4125.5	265.9
11	3760.1	254.0
12	9548.6	456.3
13	1208.5	139.6
14	406.4	92.5
15	13796.2	969.8
16	3470.4	314.1
17	9728.3	544.3
18	18660.9	563.6
19	9488.6	427.4
20	9286.1	579.5
21	7008.0	413.2
22	4495.8	307.2
23	19961.3	586.8
24	3676.7	312.9
25	5122.9	351.9
26	21034.8	621.4
27	11949.1	577.8
28	13196	552.1
29	11983.8	555.7
30	12693.9	551.2
31	11741.8	505.8
32	10810.8	498.4
33	11736.4	452.1
34	12022.3	559.0
35	4664.4	466.5

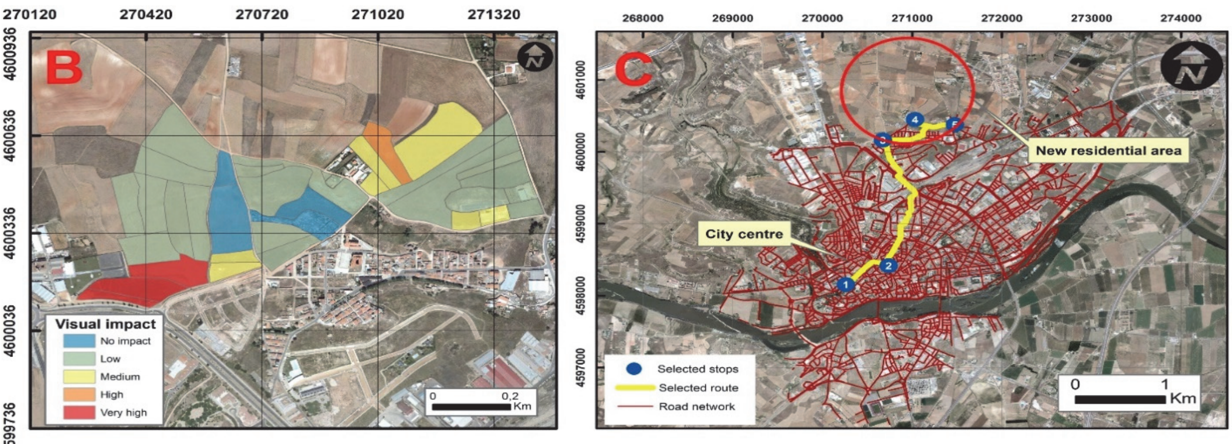


Fig. 8. (A) Cadastral Parcels proposed for urbanization; (B) Visual Impact Map of the selected parcels;
(C) Proposed transport network

The sectors proposed for urbanization were divided according to the cadastral parcels they comprised, and also the dimensions of each one were established (Fig. 8A). Afterwards, the factors that could cause price variation of the plots, consequently affecting future construction, were estimated. As previously mentioned, price variation could vary in relation to the visual impact of each parcel (Fig. 8B). The sectors chosen for expansion of the city center of Zamora were found within the neighborhood of Villalobos, an area where two main types of housing were distinguished: older one floor houses (some in a bad state of conservation) and newer houses with mainly two floors. Regarding this, it was advised that the new buildings should not contain more than two floors, so as not to alter the homogeneity of the city's structural framework.

The selected parcels, which included an extension of 356,039 $m^{2,}$ were mostly used for livestock farming, with mainly non-irrigated crops. The rest of the land was unused, with the exception of an area that was used to house old cars that caused a great visual impact. It was advised that this car scrap yard be removed to minimize the visual impact, and any other problems that it could possibly cause for the future residents, and to maintain urbanistic uniformity. If this would have been impossible it was suggested that the area be developed into a green area that would have lessened the impact. Additionally, it was recommended that green areas be included within the new growth sector in accordance with the already existing green areas in the city, acting as transition zones between green areas and the field crops attached to the proposed growth sector. Finally, a public transport network was designed (Fig. 8C) that could be added to the local road network, which created an adequate connection between the new growth sectors and the urban nucleus.

4. Conclusions

In a society that increasingly tends to aggregate into large urban centers, the expansion of cities, as a consequence of the housing demand created by the population that moves to these areas, can cause territorial imbalances if adequate measures are not taken. For this reason, urban growth should be regulated via a series of planning instruments that guarantee a balanced territory, and equal distribution of the different facilities and services.

Today, Geographic Information Systems are a convenient, quick and very economical tool for analyzing the different problems that may arise in territorial planning and management, as it allows for the capture, management, handling, analysis, modelling and representation of the geo-referenced data. This technology is particularly interesting when used in the initial stages of planning.

The present study is an example of the applicability of GIS in the analysis and characterization of the physical environment and for resolving planning and building ordinance problems, as implicated in the expansion of a city center. Using a simple methodology, and by addressing the established factors, the different sectors initially proposed for the urban expansion were selected for or discarded from the process in relation to their compatibility with the before mentioned factors.

Therefore, in a planning and building ordinance study it is essential to analyze the physical environment and its reception capacity, with the ultimate goal of selecting those sectors that provide adequate environmental protection. Also, it is necessary to include the geotechnical requirements needed to accommodate the new buildings in a satisfactory and safe manner, in order to ensure the proper protection against risks and the good quality of life of future communities.

Furthermore, to select the different growth sectors, the financial outlay should be taken into account and determined in order to supply the different infrastructures and basic services, with the ultimate goal of avoiding high extra costs that would otherwise make the project nonviable.

Acknowledgments

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