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Characterization of Green Infrastructure at the Local Level with Geographical Information System, Tunja (Colombia)

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Abstract

This article presents a characterization of the areas likely to integrate a Green Infrastructure (GI) for the Tunja city at local scale and spatial analysis is mainly applied to the land cover and land use of the study area. To identify the areas that could be integrated into the GI, four thematic dimensions were first zoned (ecological connectivity, multifunctionality, ecological status and accessibility to the population); they were later normalized on a scale of 1 to 10 to make them comparable; the dimensions were combined by an Analytic Hierarchy Process (AHP) and finally those areas whose pixel values were above the third quartile were selected in the integration of the dimensions. The zoned dimensions the following weights were obtained: *ecological connectivity* (48%), *multifunctionality* (30%), *ecological status* (13%) and *accessibility to the population* (9%). It was found that the main areas likely to integrate into the GI are concentrated in the western fringe of the city; however, the northwestern area has a greater fragmentation and lower ecological status than the southwestern zone (which refers mainly to the Protective Forest Reserve El Malmo). Likewise, several areas or patches were identified to the south of the city (referring mainly to wooded areas and presence of wetlands) as well as small

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wooded areas in the urban perimeter, but with greater isolation among the other areas of GI. Within the urban perimeter the zoning of areas that could be integrated into a GI was practically null.

Keywords: accessibility; connectivity; ecological status; green infrastructure; multifunctionality; spatial analysis.

Caracterización de la Infraestructura Verde a nivel local con Sistemas de Información Geográfica, Tunja (Colombia)

Resumen

Se presenta una caracterización de las áreas susceptibles de integrarse a la Infraestructura Verde (IV) del municipio de Tunja a una escala local y aplicando principalmente análisis espacial sobre las coberturas y usos del suelo de la zona de estudio. Para identificar las áreas susceptibles de integrarse a la IV se zonificó en primer lugar cuatro dimensiones temáticas (conectividad ecológica, multifuncionalidad, estado ecológico y accesibilidad a la población); posteriormente se normalizaron en una escala de 1 a 10 para hacerlas comparables; enseguida se combinaron las dimensiones mediante un Proceso de Análisis Jerárquico (AHP, siglas en inglés) y finalmente se seleccionaron aquellas zonas cuyos valores de pixel estaban por encima del tercer cuartil de datos en la integración de las dimensiones. En las dimensiones zonificadas se obtuvieron los siguientes pesos: conectividad ecológica (48%), multifuncionalidad (30%), estado ecológico (13%) y accesibilidad a la población (9%). Se encontró que las principales áreas susceptibles de integrarse a la IV se concentran en la franja occidental del municipio; sin embargo, la zona noroccidental presenta una mayor fragmentación y menor estado ecológico que la zona suroccidental (la cual hace referencia principalmente a la Reserva Forestal Protectora El Malmo). Igualmente se identificaron varias áreas o parches al sur del municipio (haciendo referencia principalmente a zonas arboladas y presencia de humedales) así como pequeñas áreas arboladas en el perímetro urbano, pero con un mayor aislamiento entre las demás áreas de IV.

Dentro del perímetro urbano la zonificación de áreas susceptibles de integrarse a una IV fue prácticamente nula.

Palabras clave: accesibilidad; análisis espacial; conectividad; estado ecológico; infraestructura verde; multifuncionalidad.

Caracterização da Infraestrutura Verde a nível local com Sistemas de Informação Geográfica, Tunja (Colômbia)

Resumo

Apresenta-se uma caracterização das áreas susceptíveis de integrar-se à Infraestrutura Verde (IV) do município de Tunja a uma escala local e aplicando principalmente análise espacial sobre as coberturas e usos do solo da zona de estudo. Para identificar as áreas susceptíveis de integrar-se à IV zoneou-se em primeiro lugar quatro dimensões temáticas (conectividade ecológica, multifuncionalidade, estado ecológico e acessibilidade à população); posteriormente normalizaram-se em uma escala de 1 a 10 para fazê-las comparáveis; em seguida combinaram-se as dimensões mediante um Processo de Análise Hierárquica (AHP, sigla em inglês) e finalmente selecionaram-se aquelas zonas cujos valores de pixel estavam acima do terceiro quartil de dados na integração das dimensões. Nas dimensões zoneadas obtiveram-se os seguintes pesos: conectividade ecológica (48%), multifuncionalidade (30%), estado ecológico (13%) e acessibilidade à população (9%). Encontrou-se que as principais áreas susceptíveis de se integrar à IV concentram-se na franja ocidental do município; porém, a zona noroeste apresenta uma maior fragmentação e menor estado ecológico que a zona sudeste (a qual faz referência principalmente à Reserva Florestal Protetora El Malmo). Igualmente identificaram-se várias áreas ou parches ao sul do município (fazendo referência principalmente a zonas arborizadas e presença de pântanos) assim como pequenas áreas arborizadas no perímetro urbano, mas com um maior isolamento entre as demais áreas de IV. Dentro do perímetro urbano o zoneamento de áreas susceptíveis de integrar-se a uma IV foi praticamente nula.

Palavras chave: acessibilidade; análise espacial; conectividade; estado ecológico; infraestrutura verde; multifuncionalidade.

I. INTRODUCTION

According to the European Commission [1] the Green Infrastructure (GI) is a strategically planned network of high quality natural and semi-natural zones with other environmental elements designed and managed to provide a wide number of ecosystem services and protect the biodiversity of both rural and urban settlements. Therefore, the identification, connection and preservation of the aforementioned networks is essential in the sustainable ordering of the territory. That is how Canto [2] acknowledges it, who points that at a European level, the implementation of GI projects has become a normalized element in the territorial ordination and development. The application of GI projects contributes ecological, economic, and social benefits, which grant a tenable development, as long as the conservation and management of the green zone is integrated with the territory progress and the planning of the already constituted infrastructure [3]. Vasquez [4] considers GI as a pivotal component in the planning of urban-ecological systems that are resilient to the climate change, through the provision of ecosystem services of mitigation of adaptation, for instance, in the storage and seizure of carbon dioxide; temperature regulation; or the possibility of the use of tenable transportation (and the correspondent reduction of greenhouse effect gases generation). Likewise, Jones and Samper [5] acknowledge the role of GI as an answer to face the climate change in London. In [3, 6] are summarized the main benefits which the GI projects implementation could give to, for example, the improvement of ecological and landscape quality, habitat management, local climate regulation, improvement of quality of life, among others.

In order to create GI zones, the Green Infrastructure Center [7] offers a six-step process oriented to create and apply GI plans: *i)* community goals setting, *ii)* local data review, *iii)* ecological mapping and assets generation, *iv)* assets liability evaluation, *v)* opportunities of the risks and set goals, and *vi)* implementation of opportunities. In addition, Esri [3] proposes three fundamental steps to generate GI zones where areas with ecological, culture, and scenic value are identified to create core areas and, therefore generate corridors and links among them. On the other hand, Aguilera, Rodriguez and Gomez [8] present a methodology, from a completely spatial point of view, about the coverage and uses of the soil for the selection of areas susceptible to integrate to GI from the dimensions of *multifunctionality, ecological connectivity, permeability or accessibility to the population* and *ecological value*. Also, Liquete et al [9] propose a methodology based on the notions of *ecological connectivity*, *ecosystems multifunctionality*, lending of ecosystem benefits for the nature conservation. In the United States, Esri [3] has compiled an online resource for the GI planning in the national framework, providing information about "intact cores" as a starting input for the green infrastructure definition with further detail. In Colombia there has not been advance in research about the generation of areas to integrate to a GI from a spatial scope. However, Remolina [10] found, through the review of thirty-two Territory Ordering Plans (TOP) of towns from Cundinamarca, that sixteen reviewed towns could have a GI according to the designations and classifications of the conservation elements that take part in each TOP.

The City of Tunja, capital of the Department of Boyacá, is located on the East Mountain Range. It has an extension of 121.4 Km^2 and a population of, according to the DANE in 2018, 167,991 inhabitants. Among the main economic activities, agriculture and the trading of goods and services are the most important ones. In accordance with the Alcaldía municipal de Tunja [11], the anthropic effect of a dynamic of quick and disordered growth of the urban net show multiple risks related to the lack of green coverage that protects the soil, disappearance of wetlands, floodings and sedimentation of channels, among others. Moreover, Rincon [12] states that Tunja received the 21st century as a complex city due to the production of historic transformation of its spatial models: a *compact, linear, dispersed*, and finally, *fragmented* city. This last model creates huge challenges in the adequate ordination of the territory, and, thereupon, the sustainability of it, since in a fragmented space the delimitation and connectivity of landscapes with ecological values and ecosystem services for the population are completely lost.

Besides, Tunja, in the TOP adopted by the Act 0241 of 2014, has delimited zones or areas with ecosystem importance where soils that take part of a *Main Ecological Structure* are included, but it does not have as such an explicit delimitation of such

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structure, and much less it has a zoning of networks or areas that achieve a definition or characteristics of a GI, which can be used as a supply for an appropriate ordination of the territory according to the sustainability criteria and the input in the quality of life of the population. Therefore, the goal of this investigation was to characterize the areas susceptible to integrate to the GI of the city of Tunja in a local scale through a Geographic Information System analysis.

II. METHODOLOGY

In the identification of the areas that are susceptible to integrate to a GI the zoning was performed into a combination of four dimensions: *multifunctionality, accessibility, connectivity* and *ecological status*; according to the methodology proposed by Aguilera, Rodriguez and Gomez [8]. In this methodology, the base inputs are *i)* the coverage and uses of the soil (1:25000 scale, correspondent to the updates of river basin management and development plan of the Chicamocha High River and the Garagoa River) and *ii)* the base cartography (1:25000 scale, correspondent to the plates of Instituto Geográfico Agustín Codazzi - IGAC).

A. *Multifunctionality*

The potential input that each cover and soil use has was determined regarding the arrangement of ecosystem services of provision (sweet water), regulation (air quality, carbon storage, extreme events moderation, erosion prevention), culture (recreation, tourism) and support (habitat). This input was evaluated through a qualitative grade (1-null to 4-high) by an application of eight surveys to professionals immersed in territory planning topics of different professional fields and experts of the environment in Tunja, taking as a final multifunctionality value the average of the grades of all the ecosystem services and the ones who were surveyed.

B. Ecological Connectivity

This was based on the work of Marull and Mallarach [13, 14, 15] in which, from the coverage and the soil uses, and through the use of the implement CostDistance (Arcmap), the Barrier Affectation Index (BAI) and the Ecological Connectivity Index

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(ECI) were identified by means of an affectation matrix, and the BAI with a matrix of the affinity of areas to connect (functional ecological areas).

For the calculation of the BAI it was necessary the use of the classification of the coverage and soil uses according to the affectation typology in the environment of the Table 1. The cost surface was determined through the sum of raster surface for each typology with the affection distance and coefficient registered in the Table 1.

Table 1. Soil coverage potential affectation matrix. Adapted from [13].

Description	Affectation coefficient (a_s)*	Affectation Value (Λ_s)
Neutral (N)	1000	0.10
Agricultural (Ag)	750	0.13
Forest (F)	500	0.20
Barriers (b_s)	250	0.40
Connectors (C)	1	100.00
(*) maximum distance (m) affected by the typology *b_5 = 100, Class 5 barrier weight. (Table 2)*		$\Lambda_s = b_5 / a_s$

Through the implement *CostDistance*, beginning with the generated cost surface and the origin of each subclassified barrier type (Table 2) a cost distance *(d_s)* for each origin (or each barrier type b_s) was generated.

Table 2. Coverage and soil uses that act as barriers. Adapted from [13].

Barrier class	B_s (*)	K_{s1} (**)	K_{s2} (**)
Landscaped spaces *(b_1)*	20	11.10	0.253
Secondary lanes *(b_2)*	40	22.21	0.123
Main lanes *(b_4)*	80	44.42	0.063
Urban spaces *(b_5)*	100	55.52	0.051
(*) Barrier affectation base weight *(**) Constants for logarithmic decrease of the 30%*			

To calculate the effect that each barrier class has over the surrounding space *(Y_s)* and the BAI the equations (1) and (2) were used [13].

$$Y_S = B_S - k_{s1} \ln(k_{s2}(B_s - d'_s) + 1) \quad , \quad Y = \sum Y_s \qquad (1)$$

$$BAI = 10 \left({}^{Y_i}/_{Y_{max}} \right) \qquad (2)$$

Where, the values of B_s, k_{s1} y k_{s2}, are registered in the Table 2, ($d'_s = B_s - d_s$, where $B_s - d_s > 0$), Y_i is the value that each pixel of Y takes, Y_{max} is the maximum value of Y.

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Regarding the calculation of the ECI, the Functional Ecological Areas (FEA) were selected in terms of the classification of the environmental conservation and protection areas of the TOP and the area delimited as Paramo Altiplano Cundiboyacense of the city. The cost surface was determined based on the effect that the BAI provokes and the affinity matrix between the coverage and the soil uses with each FEA (the affinity matrix was graded from 0 to 1, "related" to "non-related," respectively). With the cost surface adapted to each FEA and through the function *CostDistance*, a cost distance (X_i) was found for each FEA. In this way, the equation (3) was used [13, p. 12] to determine the relative Ecological Connectivity Index (ECI_r).

$$ECI_r = 10 - 9\left[\frac{\ln\left(1 + (X_i - X_{min})\right)}{\ln\left(1 + (X_{max} - X_{min})\right)}\right]^3 \qquad (3)$$

Where, X_i is the value of each cost distance i pixel, X_{max} and X_{min} are the máximum and minimum values, respectively, of the cost distance i.

Finally, with the equation (4) the absolute Ecological Connectivity Index (ECI_a), which takes into account all the FEA analyzed in the study zone, is derived.

$$ECI_a = \frac{\sum ECI_r}{number\ of\ ECIr} \qquad (4)$$

C. Accessibility to the Population

To determine the degree of accessibility that the population has to each point of the surface of study, the implement CostDistance was once again used and a subsequent linear reclassification for the outcomes interpretation. The cost surface was generated through the classification of the soil pending and the grade of displacement "difficulty" in each pending rank. Regarding the origin of the implement CostDistance, the trail and path ways were selected in order to prioritize in some way the movement on foot. The score of displacement cost was assigned in a way that the zones with less inclination were prioritized, as shown in the Table 3.

Table 3. Pending Classification. Pending ranks from [16].

Pending (%)	Classification	Cost
0 – 3	Slightly flat	1
3 – 7	Slightly inclined	2

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Pending (%)	Classification	Cost
7 – 12	Moderately inclined	3
12 – 25	Highly inclined	5
25 – 50	Slightly steep	8
50 – 75	Moderately steep	9
> 75	Highly steep	10

D. Ecological Status

This dimension was evaluated as an approximation of the ecological status related to the composition and configuration of the coverage and soil uses class [8]. This approximation was made through the zoning of the naturalness and the contrast among the present coverage and soil uses. According to Garcia [17], it implies the recognition of the environment conditions, which is very tough to measure on practice. This concept is normally more related to the seminatural systems, quasi-natural, or artificial, that is to say, to systems with some anthropic influence degree. The contrast meaning the affinity or difference magnitude between ecological characteristics of adjacent coverage and soils uses.

Aguilera [8] determined naturalness in relation to the data of Sistema de Información sobre Ocupación del Suelo de España (SIOSE), which allows to obtain several factors (For each type of soil use/coverage and naturalness level) for each tessellation of the territory. As the starting data of this study was CORINE LAND COVER, it was necessary to modify the obtaining process. Therefore, for the naturalness zoning, a net (square net of 100x100 parts, 5195 tessellations. The net size was chosen arbitrarily so that it allowed a great intersection of adjacent polygons) that covered the zone of study was created, and next an intersection between the aforementioned net with the coverage and the soil uses was generated. In this way, the area of each net tessellation and the area of each tessellation intersected to the coverage. Then, according to the Table 4, the coverage and soil uses were reclassified, and the naturalness degrees were determined taking into account to area percentage of each intersected tessellation according to the area of each respective net tessellation, which was used to generate a raster surface.

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Table 4. Naturalness degrees in each coverage and soil use. Adapted from [8].

Coverage and soil use	Naturalness degree			
	1	2	3	4
Wooden – scrubland, water sheets	< 20 %	20-50 %	50-70 %	> 70 %
Plains, grassland	> 50 %	20-50 %	10-20 %	< 10 %
Farmland	> 50 %	20-50 %	10-20 %	< 10 %
Artificial soils	> 25 %	10-25 %	5-10 %	< 5 %

In relation to the contrast, the software Fragstats was used, through the use of the metrics *Mean Edge Contrast Index* (ECON_MN) and the landscape level mobile window, to obtain a contrast value for each pixel of the zone of study surface. Likewise, it was necessary to get into a contrast matrix between the coverage and the adjacent soil uses, whose grading is obtained in a scale from 0 to 1 (null to high contrast, respectively) [18].

Both the naturalness surface and the zone of study contrast were normalized to an equal value scale in order to subtract the contrast zones from the naturalness zones, and obtain an approximation to the ecological status of the zone of study.

E. Dimension Integrity

With the four dimensions already zoned, their correlation degree was verified since correlated variables may slant the outcomes; in case of integrating them by means of a criteria evaluation, it would be necessary to distribute the weighing values [8]. Therefore, through the determination coefficient r^2, it was found that there is not a significant linear correlation between any of the four dimensions (the highest correlation value was 0.13 between multifunctionality and ecological connectivity, between the others it was lower than 0.04). In order to integrate the four dimensions, they were analyzed in a scale from 1 to 10 to compare them, and then, by the means of a Hierarchical Analysis Process-HAP prepared in HAP Excel template *(http://bpmsg.com)*, the weight of each dimension for their integration was determined. Ecological connectivity (48%), multifunctionality (30%), ecological status (13%), and accessibility to the population (9%) were the final outcomes.

The weight distribution is performed through a qualification of the importance of each dimension over the others, in a scale from 1 to 9 (same importance to higher importance). Such qualification was done taking into account their method and a

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higher number of calculation parameters in the dimensions. In other words, the dimension that had a higher number of parameters for its zoning is more relevant than the others.

F. Green Infrastructure

Bearing in mind the integration of the four dimensions, the GI index was found, so the pixels that had a value higher than the third quartile were chosen (value that gets the highest 25% of frequencies and observations in a data group) as the areas susceptible to integrate to a GI being.

III. Discussion

A. Multifunctionality

In the Figure 1(a), it is displayed the multifunctionality of Tunja, and in Table 5 there are the average value of the surveyed grading and the ecosystem services evaluated for each coverage and soil use. It was found that the coverage of dense, open, and riparian forests, and wetlands showed a higher average in the grading (>3), followed by the coverage of scrublands, grasslands, wooden plains and the tree plantations (2.5 to 3). The coverage of mosaics with nature landscapes, green zones, and urban recreational areas presented a lower value (2 to 2.5). Finally, the coverage of clean plains, crop mosaics, urban, industrial, and degraded zones had the lowest average of the grading (<2).

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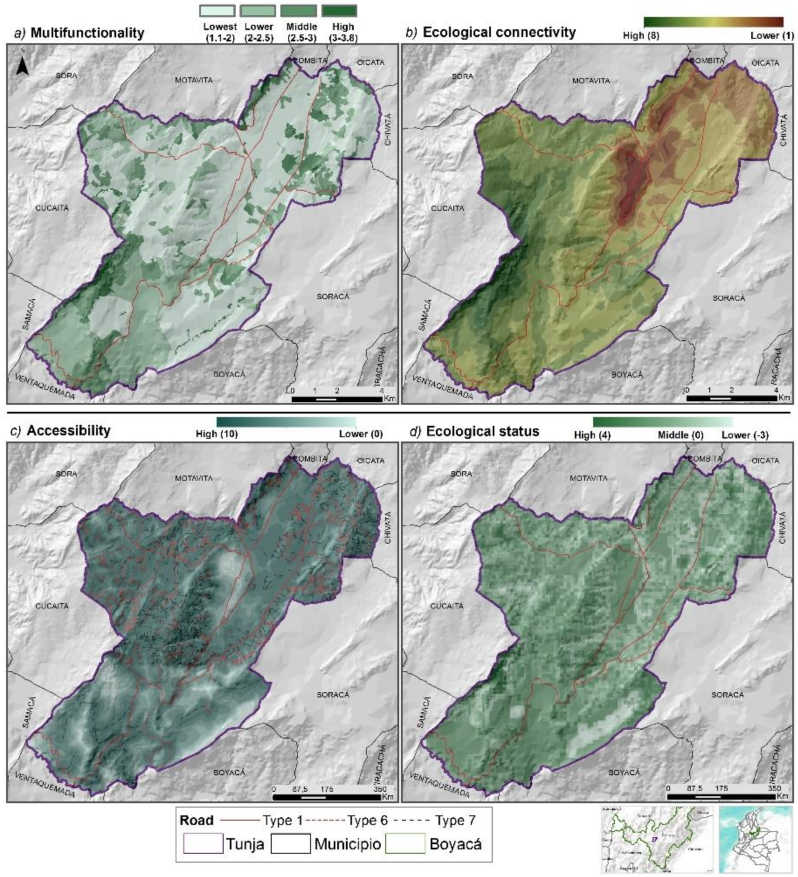

Fig. 1. GI dimensions of Tunja. a) Multifunctionality b) Ecological connectivity, c) Accessibility to the population, d) Ecological status. Own elaboration.

Table 5. Multifunctionality average evaluation. Survey-based elaboration.

Coverage and Soil use	Value	Coverage and soil use	Value
Degraded lands	1.16	Tree plantation	2.63
Industrial zones	1.19	Dense grassland	2.69
Resources exploitation	1.22	Wooden plains	2.69
Urban area	1.78	Dense scrubland	2.81
Crop mosaic	1.8	Wetland	3.42
Clean grassland	1.92	Low open forest	3.47
Recreational facilities	2.09	High open forest	3.52
Crop and grass mosaics, nature zones	2.34	Riparian forest	3.59
Urban Green zones	2.44	Low dense forest	3.64
Grass mosaics with natural spaces	2.44	High dense forest	3.8
Open scrubland	2.61		

The values above are product of the grading of eight professionals in the territory planning field, who with several different approaches, give a systemic view of the input that several coverage and soil uses in the lending of varied ecosystem services can provide. Nevertheless, it is necessary to involve more people in the grading who can contribute, apart from theoretical knowledge, experiences about the particular dynamics of the coverage and soil uses of Tunja.

B. Ecological Connectivity

Through the calculation of the BAI it was found that the urban zone, the main road and railroad net are the most important ones for the spatial ecological connectivity of Tunja. Therefore, these zones represent the lowest values obtained in the Ecological Connectivity Index. In this index (Figure 1(b)), the highest value was 8, being there the zones with the highest connectivity in the west of the town, bordering on the towns of Cucaita and Samaca (referring to the area of the Protective Forest Reserve El Malmo and the Paramo Altiplano Cundiboyacense). Moreover, zones with high value in this connectivity in surrounding areas of the wetland located to the southwest of the town are presented along with the forest coverage of it as well.

C. Accessibility

It was found a predominantly permeable or approachable surface in relation to the trail and path ways, especially from downtown to the north of Tunja, as shown in the Figure 1(c). However, this is a simplification as it was not taken into account the population concentration or thickness as a displacement object.

D. Ecological Status

It is shown in Figure 1(d) the presence of negative values that represent low-medium naturalness zones and high contrast. Nevertheless, the proportion of these negative values, which represent the worst ecological status, is relatively low, and are concentrated mainly on the wetlands and the tree vegetation. *a) Naturalness:* the coverage with some sort of anthropic intervention (For instance, crop mosaics, clean grasslands, urban zones, among others.), obtained the lowest naturalness value (0 to 2); nature-type coverage, where the arboreal coverage proportion is higher, like forests and wetlands, received the highest values (3 to 4). The medium average (2 to 3) are normally in relation to the adjacencies of the tessellation with different

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coverage and soil uses types. *b) Contrast:* An important highlight in the wetland zone located to the southeast of the town (Paso Amarillo Wetland) was found along with the arboreal vegetation predominance zones; moreover, while analyzing the contrast as a relationship among the coverage adjacencies, zones with a high quantity of different types of coverage stand out, showing an ecological fragmentation in the territory.

E. Green Infrastructure

In Figure 2 it is shown the areas whose pixel values are over the Q3 in the GI index through the four dimensions' integration, so they are susceptible to integrate to a GI. Nevertheless, these areas are just an approximation, since the lower values as the ones on the Q2 may be relevant as transition spaces or potential to strengthen the environmental functionality. The areas susceptible to integrate to a GI are concentrated mainly in the west of Tunja, bordering on Cucaita and Samaca. The zone referring to the Protective Forest Reserve El Malmo shows the best homogeneity, and from this, branches detach to the south of the town, which are also susceptible.

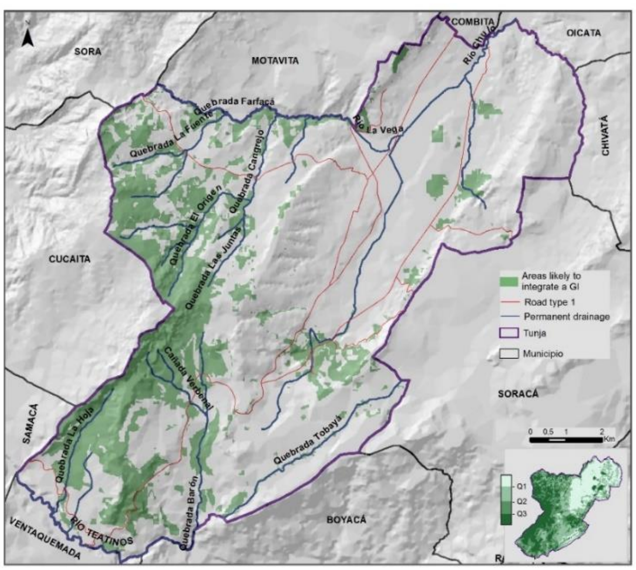

Fig. 2. Susceptible area to integrate to a GI in Tunja.

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Specifically, in the urban area it was found that the zoning of areas susceptible to a GI is practically null. This does not mean that there are not zones whose intrinsic and contextual characteristics do not allow the grading under this concept, but that it is necessary the adaptation of the starting data to a greater scale, and the use of another methodology according to such scale as, if the purpose were to calculate the ecological connectivity (by the use of the BAI) for an urban scale, the analysis would be virtually based almost entirely on barrier typology. Likewise, the prioritization of ecosystem services must be focused on the urban area.

It is important to remark that in the integration of the dimensions; it would have been possible to work with equal weights (25% each) by the means of a conservative approach. Nevertheless, the weight distribution according to the calculation types and characteristics of each dimension, allowed to somehow prioritize those areas which possess a potential connectivity and multifunctionality in the territory facing the possibility of accessibility to the population and the ecological status in accordance with interaction of coverage typology adjacencies.

From the areas determined as susceptible to integrate to the GI, it is possible to take as reference four zones (Z1a, Z1b, Z2, Z3 and Z4) given their characteristics such as closeness, fragmentation, micro basin, and present coverage, as seen in Figures 3 and 4.

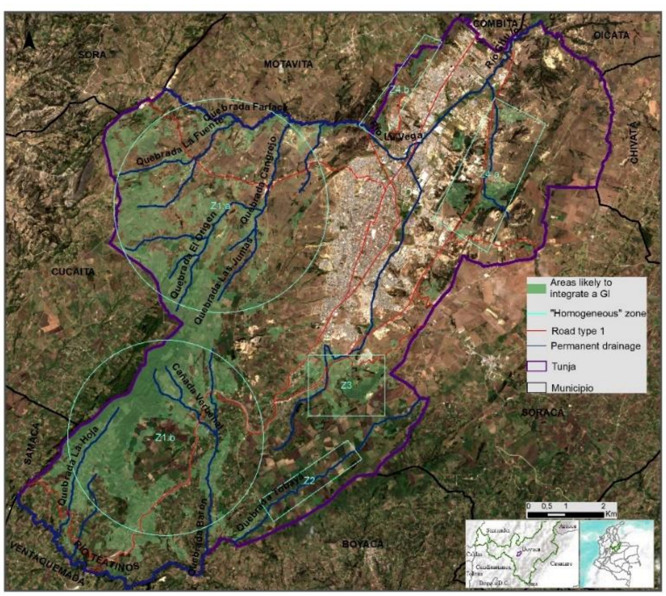

Fig. 3. Homogeneous zones in the GI of Tunja by satellite image. Satellite image of Sentinel 2 (February, 2019).

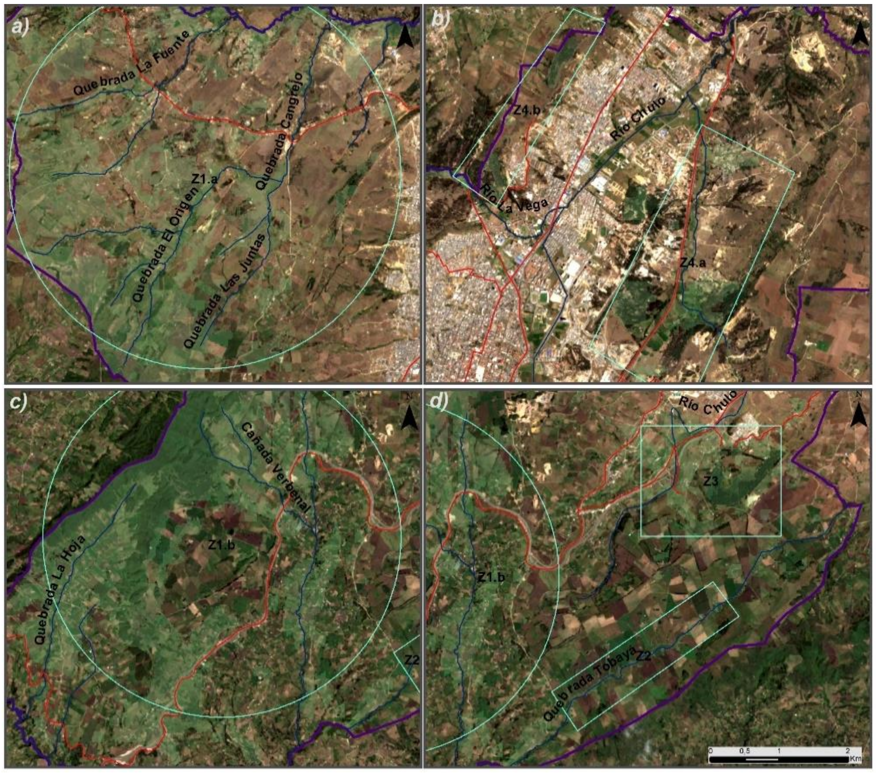

Figure 4. Detail of homogeneous zones in the GI of Tunja by satellite image. a) Zone Z1a, b) Zone Z4, c) Zone Z1b, d) Zone Z2 and Z3. Satellite image of Sentinel 2 (February, 2019).

1) Zone Z1a. Western strip (Centre to north). This zone is composed mainly of clean grasslands and farmlands coverage, as well as little forest areas, wooded grasslands and natural spaces. The Wetland "El Cardon" in El Porvenir County does not show any isolation, so surrounding agricultural activities affect the native vegetation and the emergence of surfactants (substance that decreases the surface tension) in the water due to the use of detergents [19], altering in this way the ecological quality of such system. In the area determined as "Paramo Altiplano Cundiboyacense" is located the source of creeks (or minor drainage) such as La Fuente, El Origen, El Cangrejo, and Las Juntas (microbasins being Farfaca, El Floral, and El Cangrejo), which are affluent from the Farfaca creek and the La Vega River, and therefore the subbasin La Vega. According to Acero and Cortes [20] this subbasin has deteriorated its soil and fauna and flora species due to the local activities, so it is necessary to implement ecological restoration strategies.

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2) Zone Z1b. Western strip (Centre to south). This zone is composed mainly of the forest and the dense scrubland (Protective Forest Reserve area El Malmo), gallery forest in the strip of the different drainages, wooden grasslands and farmlands located on the reserve area perimeter. Likewise, there are the wetlands "Aposentos", "Fuente Negra", and "Yerbabuena" in La Hoya, Barón Germania and La Fajita Counties. In the area surrounding the reserve, there are source of creeks like La Hoja, Las Perdices, Barón, Verbenal ravine, (microbasins being Barón Gallero, Teatinos-Verde, and Yerbabuena), which are affluent from the Teatinos river and therefore the Teations subbasin as well. The forest of this subbasin is characterized by generating the processes of water catchment, storage, and regulation to the Tunja aquifer and many aqueducts [21]. In [19] there is further information about the existent species in the Protective Forest Reserve El Malmo.

3) Zone Z2. In this zone the agricultural and rancher activities domain the area, which surround the wetland "Paso Amarillo" in the Chorro Blanco County, one of the most extensive in town. Due to the agricultural activities present in the wetland, there is agricultural waste [19] that affects the ecological status of this system. Moreover, there is the Tobaya Creek (Tobaya microbasin), which is affluent from the subbasin Teatinos.

4) Zones Z3 and Z4. These are focused mainly on forest areas and their closest surroundings, with the particularity of being located on the Tunja urban area perimeter, and having an evident fragmentation as well. To the south of the city is located the forest area between the Jordan River (Chulo River) and Tobaya Creek, which is what would be the urban area boundaries with the Runta County. In addition, Zone 4 is focused on arboreal coverage patches. To the east are located forest zones near La Colorada creek in Pirgua County, close to the Bogota-Tunja-Sogamoso (BTS) freeway, and the freeway which points to Soraca. To the west are located forest patches bordering on Motavita, along with the forest zone close to the La Vega River and Universidad Pedagógica y Tecnológica de Colombia.

IV. CONCLUSIONS

The input in the ecosystem services of coverage and soil uses of Tunja, or of the multifunctionality, is tightly connected to the presence of forests and wetlands coverage.

The urban area of Tunja and the main communication roads are the hugest obstacle for the ecological connectivity of the city. In relation to the areas with the highest ecological connectivity index, the western strip of Tunja presents more homogeneity, mainly because of the presence of the Protective Forest Reserve El Malmo and the Paramo Altiplano Cundiboyacense area. On the contrary, the middle zone in the northeast of the city is the strip with the lowest ecological connectivity due to the acting of the barriers.

The accessibility to the population of Tunja is very high from practically any point on the surface. However, in this calculation, it was not taken into account factors like population density, culture interest places, transport means, among others.

The ecological state, as a calculation approximation between coverage and soil uses naturalness and contrast show the coverage fragmentation present especially from the middle part to the northwest strip, referring to Paramo Altiplano Cundiboyacense. In addition, it is observable the vulnerability that valuable ecosystems have due to the soil uses on their perimeters.

The areas susceptible to integrate to a GI are concentrated mainly on the western strip of the city, with more fragmentation on the northwest area tan on the southwest area (which is related to the Protective Forest Reserve El Malmo). These zones must be object of a more detailed evaluation that permits the prioritization of actions aimed to the territory or GI planning. It is necessary to include areas with less integration value, as well as transition spaces that ease the ecological connectivity.

The methodology used in this study has multiple benefits in the approximation of areas susceptible to integrate to a GI in local and regional scales, and as a support asset in the territory ordering. Nevertheless, in an urban level, the applicability of the aforementioned methodology should be modified as the ecological connectivity and status approach may alter the outcomes; that is why it would be necessary to focus more on the barrier analysis. Likewise, the identification of the ecosystem services and the accessibility areas for the exploitation of these must be centered on the urban aspect.

AUTHOR'S CONTRIBUTION

The methodology development was conducted by Cristian Hernandez Rojas under the coordination of Rigaud Sanabria Marin. The data collection, data analysis and writing of this paper was carried out by the two authors.

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