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Application of the Distance to Natural (D2N) Index and Statistical Analysis of Different Anthropic Uses of the Río Grande De Comitán Watershed, Chiapas, México

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Abstract

The intensification of anthropic uses (i.e., increase of the hemerobic condition) threatens the remnants of native vegetation due to the reduction of its self-regulation capacity. In this research, the Distance to Nature (D2N) index for land use and land cover was applied in the Río Grande de Comitán watershed (Southern Mexico) to answer the following questions: 1) What were the land use dynamics observed in the Rio Grande de Comitán watershed in the trajectory through 1999, 2009 and 2019? 2) Does the subcategorization of the D2N allow one to identify which anthropic uses influence more the territorial expression of the watershed? To answer these questions, we performed a supervised classification of land use and land cover was performed in this watershed, and for the D2N index, the classification was simplified to three-category scale for the subcategorization of the anthropic component. Through Principal Component Analysis (PCA), we identified that agricultural anthropogenic use had the greatest influence on territorial expression. The reported scenario indicates a trend of gradual and continuous reduction of naturalness over the last 20 years. Additionally, the D2N index proved to be a useful tool to demonstrate both the anthropic impact, with the simplified scale, and the

component that most influences the territory, by subcategorizing the anthropic scale.

Keywords

Anthropic Land-Use Pressures, Spatio-Temporal, Principal Component Analysis (PCA), Environmental Planning, Nature Conservation

1. Introduction

Anthropogenic activities are a dominant factor for environmental degradation, e.g., industrial pollution, alteration of regional climate, the introduction of invasive species, and loss of biodiversity (Mancinelli & Vizzini, 2015; Zhao et al., 2006). In addition, agriculture increases at the cost of lost forest cover, affecting important ecosystem functions (Emery et al., 2021; Roux et al., 2021; Solly, 2021). This process highlights the challenges for the environmental planning of land use, including technological innovations and changing political and economic pressures. Understanding the range and degree of impact of anthropogenic forces is essential for nature conservation, environmental planning, and management information on the landscape. Currently, pressure on territory is measured by land use and cover areas using indicators. They assist in decision-making, monitor, and evaluate the efficiency of political and administrative measures (Steinhardt et al., 1999; Walz & Stein, 2014).

Anthropic uses intensification can be represented by an increase of the hemerobic condition of an area, which generates a higher vulnerability to the remnants of native vegetation due to the reduction of self-regulation capacity of the natural system (Borda-Niño et al., 2017; López et al., 2020). Indicators based on Spatio-temporal variation are important for characterizing changing events, monitoring environmental changes, and preserving the ecological integrity of these systems. Overall, indicators are important practices for the formulation of landscape ecological protection strategy when considering the spatial neighborhood and relations between spatial patterns (Meng et al., 2019; Liu et al., 2021).

Some authors emphasize that watersheds, being a natural drainage boundary in a common body of water, are more efficient for governance or management, as they can improve impacts in specific zones as priority areas (Cohen & Davidson, 2011; Oliveira Andreoli et al., 2019). In addition, watersheds can be used as functional areas to understand the dynamics of land use, i.e., headwater, floodplain, and streambank. In Mexico, watershed management is regulated in *"Ley de Aguas Nacionales"* actions for the management of water resources (CONAGUA, 2009). However, the environmental planning of land use in the watersheds is still incipient.

The index *Distance to Nature* (D2N) can be applied to such planning. D2N is composed by the indicators *degree of naturalness* (N_d) and *distance to natural*

habitat (D_n), and was developed by Rüdisser et al. (2012) and applied for the first time in Austria. An important subsequent development of D2N was performed in two different areas: in Lubumbashi, Democrat Republic of Congo (André et al., 2018), and in a Brazilian Natural Protected Area, the Irati National Forest surroundings in southern Brazil (Almeida et al., 2018). The time evolution of the index was the subject of both applications, showing gradients in the index that can be useful for natural regions accessment by highlighting threatened buffers surrounding core natural areas.

Therefore, the objective of this study was to apply and evaluate the Spatio-temporal change of the D2N for land use and land cover applied in the Río Grande de Comitán basin (Southern Mexico) between 1999, 2009, and 2019. This study addressed the following questions: 1) Which land-use dynamics were observed in the trajectory 1999, 2009, and 2019 in the Río Grande de Comitán watershed? We also improved the standard 3-classes categorization of the D2N results into five classes, so 2) Does the subcategorization of the D2N allow one to identify which anthropic use influences more the territorial expression of the watershed?

2. Material and Methods

2.1. Study Area

The study area was consisted of the Río Grande de Comitán watershed within an area of 80,993 hectares located in Chiapas State, Mexico (**Figure 1**). The watershed belongs to four municipalities: Comitán de Domínguez, La Independencia, Las Margaritas and La Trinitaria. Land use types in the watersheds are agricultural livestock, grassland, flood areas, urban zones, and rural settlements, such as private, public, and social properties legally constituted as Núcleos agrários (based in the land tenure system, classified in Ejidos and Comunidades Agrarias) (Ventura Patiño, 2008). The region's climate is temperate, sub-humid with a maxim temperature of 24˚C - 27˚C from May to October with mean annual precipitation of 1372.8 mm (CONAGUA, 2009).

The Lagunas de Montebello National Park is an important lake system and it is inside in this lower part of the watershed. It covers because it was declared a protected natural area in 1959, in 2003 it was integrated into the RAMSAR Convention, and in 2009 it was declared how the international network of biosphere reserves (Ponce Calderón et al., 2020). This area is localized in southern Mexico of the state of Chiapas (**Figure 1**).

2.2. Land Use and Land Cover

The land-use classification was carried out in Arc Map 10.5 software by the Segment Mean Shift algorithm and scale level of 50 (Ming et al., 2015). Landsat-5 and Landsat-8 imagery were obtained for 1999, 2009, and 2019 and georeferenced to the Universal Transversal Mercator (UTM) projection, World Geodetic System 1984 datum 15 N. These images have a spatial resolution of 30 m

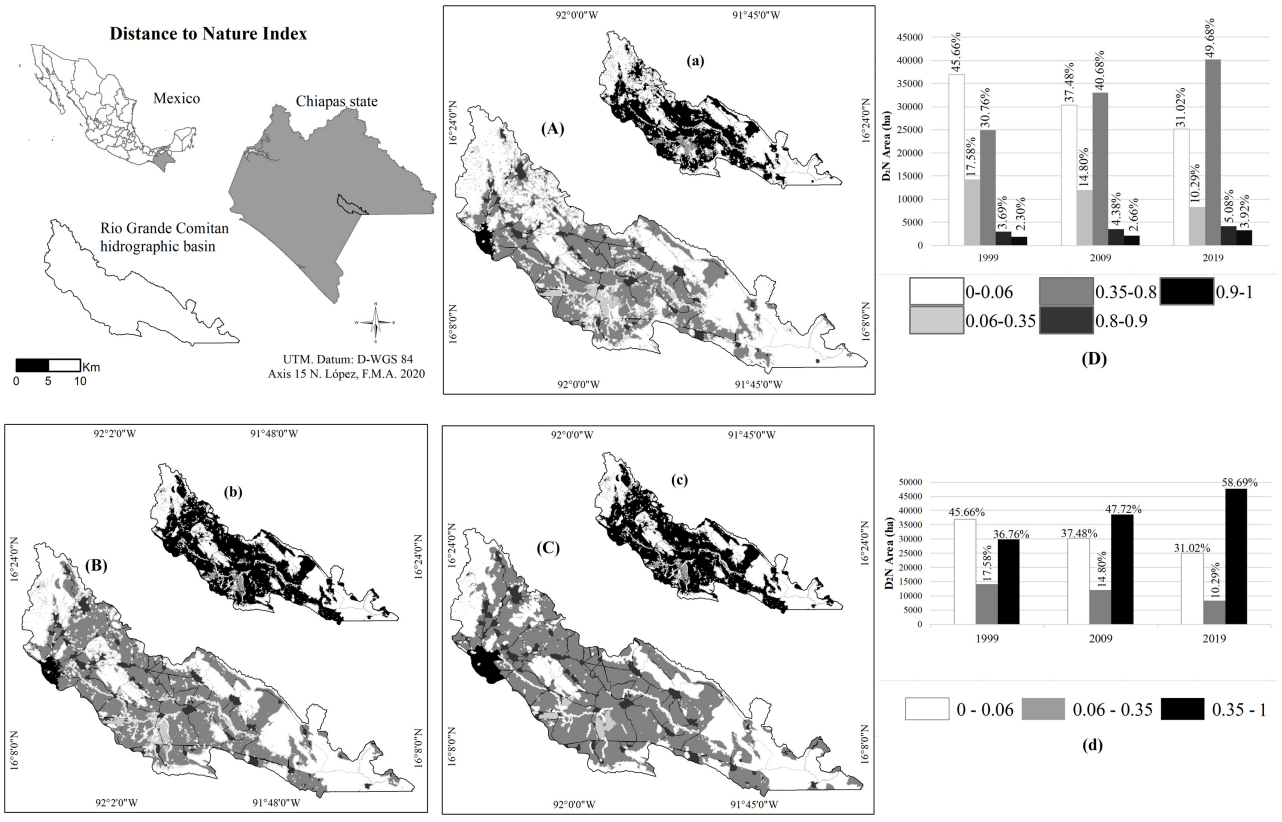


Figure 1. Distance to Nature (D2N) index values classified into the three categories (a) 1999, (b) 2009 and (c) 2019 and five categories (A) 1999, (B) 2009 and (C) 2019 for the Río Grande Comitán watershed (Mexico). There are summaries of the D2N values classified into the (D) five categories and (d) three categories. The study area localization is showed at the legend.

and a spectral composition of three bands RGB (Red, Green and Blue). The categories don't identify by the algorithm were corroborated by field visits in different years.

2.3. Hemeroby Reclassification and D2N Dynamics

We performed modifications in the hemeroby scale by studies of (Rüdisser et al., 2012) and (Almeida et al., 2018), to introduce socio-historic characteristics of the study area (**Table 1**). Land uses and land covers are associated with level 2 (Near-natural) because the natural system of the area study area is in *Núcleos Agrarios.* According to Article 27 of the Agrarian Law (Congreso de la Unión, 1917), rural social property constitutes the *ejidos* and *comunidades agrarias* (i.e., land, forests, and water), which the government grants to farmers and indigenous people for their use. Since the *Núcleos Agrarios*, in its territorial structure, they are composed of one or several *ejidos* or communal areas. This is a land property type unique in the world. Level 4 (Altered) is the pasture, level 5 (Cultural) regarding the local agricultural system that is integrated into zone parceled in *Núcleos Agrarios*, level 6 (Artificial with elements natural) known as *ejidos* these properties are the rural assessment and level 7 (artificial). All descriptions, categories and division criteria are summarized in **Table 1**.

Table 1. Hemeroby scale, description of threshold regarding its influence on biodiversity and comparative land-use types in Austria (Rüdisser et al., 2012) and in the Río Grande Comitán hydrographical basin, with three and five categories in relation with hemeroby high.

Level of Hemeroby	Description of Hemeroby degree (Rüdisser et al., 2012)	Three categories	Land use types in this study	Five categories
1. Natural	Natural system no or only minimal anthropogenic influence (e.g., global pollution)		-	-
2. Near-natural	The structure and type of the ecosystem is the same a naturally expected at the side but some characteristics (e.g., plant species composition) are altered through anthropogenic influences	**0 - 0.06**	Herbaceous vegetation and water bodies	**0 - 0.06**
3. Semi-natural	The naturally occurring ecosystem is no longer present but has been transformed into a new ecosystem type because of anthropogenic activities		-	-
4. Altered	Besides the changed ecosystem type, the edaphon is regularly disturbed by anthropogenic activities	**0.06 - 0.35**	Grasslands	**0.06 - 0.35**
5. Cultural	Intense and regular impacts lead to the destruction of the natural occurring edaphon. Natural occurring floristic elements are reduced to a minimum		Agricultural activities	**0.35 - 0.8**
6. Artificial with natural elements	Artificial system with natural elements; intensive and irreversible changes of terrain and landscape structure; soil sealing up to 30% natural elements only in the form of secondary biotopes	**0.35 - 1**	Rural settlements (ejidos), mineral extractions sites, airports	**0.8 - 0.9**
7. Artificial	Artificial system of structures, soil sealing over 30%		Urban areas and road networks	**0.9 - 1**

2.4. Statistical Analysis

A principal component analysis was performed: PCA to three (0 - 0.06/0.06 - 0.35/0.35 - 1), and five categories (0 - 0.06/0.06 - 0.35/0.35 - 0.8/0.8 - 0.9/0.9 - 1) D2N to determine if it is possible to identify the subcategory of anthropic use that most influences the territorial expression of the watershed. The analysis was made with PAST 4.03 (Abdi & Williams, 2010).

3. Results and Discussion

3.1. Land Use Dynamics

In this study, we demonstrated the increase of agricultural land during the last 20 years, and consequently, the greatest loss of native vegetation. Land classification and the use of land were classified by the degree of hemeroby showing variation during the years: 1999 (45.43%), 2009 (37.32%), 2019 (31.00%). These spatial patterns have natural conditions by the agriculture expansion. The most frequent anthropogenic influences on naturalness were the altered (level 4) and the cultural degree (level 5) of hemeroby, with 46.41% (1999), 53.84% (2009), and 58.58% (2019), which include grassland and agricultural areas. The artificial with natural elements and artificial level (6 - 7) of hemeroby, represented by ru-

ral areas and road networks, increased in the period considered: 8.16% (1999), 8.84% (2009), and 10.42% (2019).

3.2. D2N Application and Transition Values

The application of the D2N methodology resulted in a map for each one of the studied years. We classified the continuous original scale (from 0 to 1) with a three-category proposed by Rüdisser (0 - 0.06/0.06 - 0.35/0.35 - 1). We identified a continuous rise of anthropogenic effects over the entire period. The category 0 - 0.06 is related to the lower values of D2N, in which 15% reduction seen in native vegetation. The remaining area remained restricted to fragments of native vegetation as well as The National Park Montebello Lakes stands out located in the extreme southeastern and another preserved area extreme northeast in the highest part of the watershed.

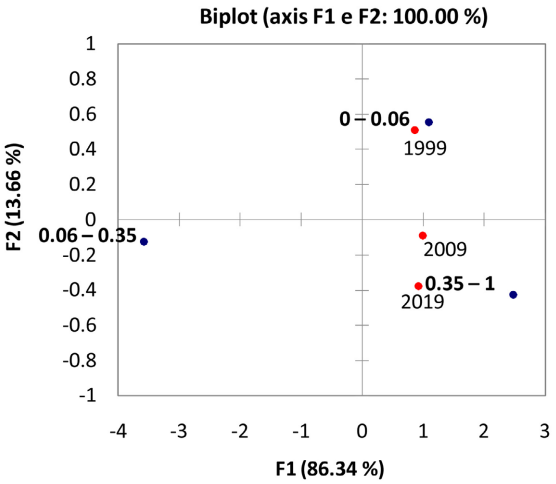
Intermediate values of D2N related to the category 0.06 - 0.35 showed a reduction in the middle region of the watershed. Category 0.35 - 1 showed the highest change due to the replacement of scheduled areas in the degree of hemeroby. Furthermore, there is a contrast between Near Natural and Alteral hemeroby categories, which means an increase of anthropization in the watershed. This showed two trending scenarios: 1) the lack of the original natural condition of the watershed and 2) the expansion of anthropic activities resulting from the agricultural activities and urbanization increase. Thus, the modification of the original landscape and ecosystem is observed, as well as the replacement of a natural component of the watershed. It is a progressive transformation into a cultural landscape, with a predominantly anthropic matrix.

Reclassification of the simplified scheme to a five-category scheme (0 - 0.06/0.06 - 0.35/0.35 - 0.8/0.8 - 0.9/0.9 - 1) allowed greater clarity in the interpretation of changes in the values of D2N of watershed, particularly, to the range 0.35 - 1. This reclassification enables a greater visibility as for the area of extension and location in the watershed, of the different types of influences of anthropic activities associated with agriculture and urbanization. The social land property (mainly called ejidos) has a long and interesting historic socio-economic background in Mexico. The way that they operate and manage the space has an impact in the decisions and managements of ecosystems. Therefore, it is a very important consideration in the whole analysis.

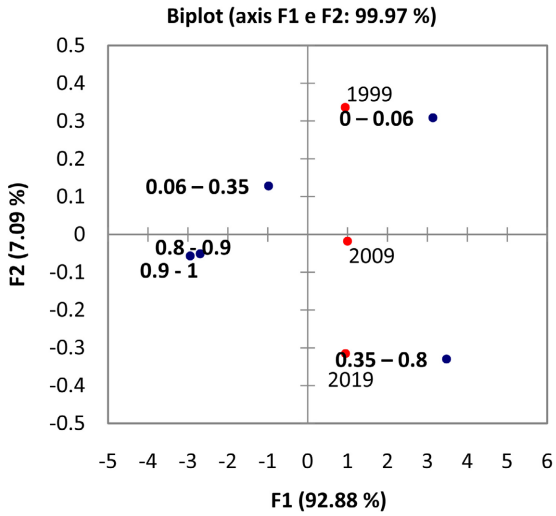
Furthermore, in this classification, we observe that component *Ejidos* can be considered as "anthropization nuclei in the watershed".

3.3. Statistical Analysis

The components of the PCA (**Figure 2**) based on anthropic impacts, explained 100% of the total variance to three categories (**Figure 2(A)**) and 99.97% of the total variance to five categories (**Figure 2(B)**). The first component F1, 86.34% of the three categories (**Figure 2(A)**) showed a positive correlation with the years 1999, 2009, and 2019. However, it does not show which component has the greatest anthropogenic impact over time. In both cases (**Figure 2**), the year 1999



(A)



(B)

Figure 2. Perceptual map two-dimensional shows the component values to F1 and F2 appropriated to evaluated the relation into values classified into three categories (A) and five categories (B).

is closer to the 0 - 0.06 variable, which shows a higher naturalness condition compared to the other years.

With the subcategorization of the anthropic component (0.35 - 0.1), according to hemeroby levels, it was possible to identify the variable that most influenced the territorial expression (**Figure 2(B)**). In this case, the direction of the variable 0.35 - 0.8 (agricultural anthropic) manages to characterize the nature of the anthropic spatial configurations in 2019, about the non-agricultural anthropic use variables (0.35 - 0.9; 0.9 - 1), which do not explain the total variation of components evaluate classified into categories.

The increased anthropic pressures can be explained by historic process, for example, the Agrarian Reform (1910-1920), their inclusion at the institutional level how Land Reform Law (Diario Oficial de la Federación (DOF) de 16/04/1971,

Article 27), and the amendment to Article 27 (1992). These actions constitute some of the determinants factors of spatial organization in Mexico. Despite the Agrarian Reform, in the '70 s, resulted in an increase in the deforested areas in Chiapas for the production of pasture in the ejidal territories for private sector cattle, due to the extreme poverty of the farmers (García & Bórquez, 2006).

Agriculture is the main source of income in the region with the production of tomatoes grown in greenhouses and, in rainfed agriculture, corn and beans rainfed agriculture. Studies in the area have shown the influence of deforestation of native vegetation, replacing it with intensive agriculture using synthetic fertilizers. For example: the presence of high concentrations of nitrates (Olea-Olea & Escolero, 2018); anthropogenic development and the impact on the water quality of the Parque Nacional Lagunas de Montebello (Alcocer et al., 2018); eutrophication (Alcocer et al., 2021), and the increase of near-cyclic sediments, such as the case of Lake Balamtetik (Caballero et al., 2020). Additionally, starting in 2003, there was a modification in some lakes from crystalline to yellowish water, foul odors and fish mortality (Fernández et al., 2021; Alcocer et al., 2016).

On the other hand, rural and urban population growth from 1990 to 2020 was 50.28% (90,156 inhabitants - 179,304 inhabitants). The growth of rural areas was 63.58% (41,857 inhabitants - 65,825 inhabitants) (INEGI, 2020). This suggests that the increase in rural human settlements in the *Núcleos Agrarios* is correlated with the increase in the anthropogenic agricultural component in the region (**Figure 3**).

The differentiated representation of the three categories of D2N for the range 0.35 - 1 stressed the contribution and clarity that can be delegated in environmental monitoring and planning, enabling the identification of priority areas and conservation actions as well as those most committed by the expansion of anthropic activities, effectively, adding to the social inclusion of local communities.

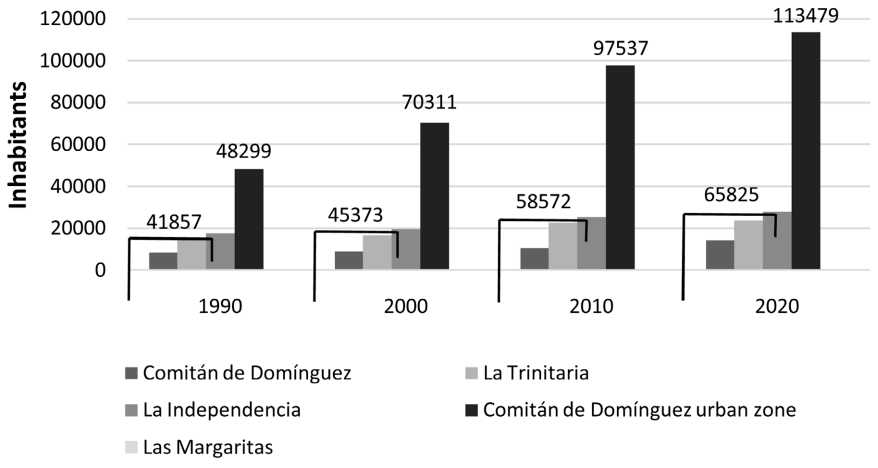


Figure 3. Graph of the population census of the rural zones of Comitán de Domínguez, La Independencia, La Trinitaria, and Las Margaritas municipalities and urban zones of the Río Grande Comitán watershed in 30 years.

4. Conclusion

The D2N demonstrated the potential to support the decision-making process regarding the environmental planning and monitoring of the watershed, contributing to the development of a sustainable land use policy. The D2N index proved to be a useful tool to demonstrate both the anthropic impact, with the simplified scale, and the component that most influences the territory, by subcategorizing the anthropic scale. The quantitative Spatio-temporal analysis of the dynamics of D2N values, grouped into three and five categories, showed the main changes in the trajectory of anthropic activities that occurred in the Río Grande de Comitán watershed, in the last 20 years, in which the reported scenario indicates a trend of gradual and continuous reduction of naturalness.

The fraction of urbanization related to the performance of rural settlements (*Ejidos*) in the form of spaces legally instituted for the effective insertion of campesino and indigenous communities can be regarded as part of the history of the issue of land tenure. The dynamics of the watershed anthropogenic pattern proves to be extremely dependent on agricultural development policies, as well as, on the historical and social context of land tenure in the Río Grande de Comitán watershed region.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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