A proposal for defining land use planning spatial units based on hydrological processes

Une proposition pour définir des unités spatiales de planification de l'utilisation des terres basée sur des processus hydrologiques

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ABSTRACT: In Mexico, land-use policy is determined at the municipal level, where decisions regarding land use and purpose are made. These localized practices fundamentally shape territorial organization, though often without coherence, harmony, or sustainability. Consequently, higher-level perspectives become crucial when resource scarcity and degradation, particularly of water, become apparent, necessitating a broader rethinking of resource access, utilization, and management. This localized approach underscores a critical issue: lived realities often transcend municipal boundaries. A shift toward a cohabitation-focused vision, one that surpasses political and administrative borders, is urgently needed. This necessitates a new model of territorial occupation and management, one that prioritizes integrated and collaborative approaches and serves as the foundation for territorial planning. Within this framework, the technical definition of management units becomes essential, enabling the design of strategies that link actions aimed at creating healthy, sustainable habitats while fostering a strong sense of co-responsibility in territorial management.

KEY WORDS: land use planning, watershed managment, GIS mapping, co-habitability.

RÉSUMÉ : Au Mexique, la politique d'utilisation des terres est définie au niveau municipal, où les décisions concernant l'utilisation et la destination des terres sont prises. Ces pratiques localisées façonnent fondamentalement l'organisation du territoire, bien que souvent sans cohérence, harmonie ou durabilité. Par conséquent, des perspectives de niveau supérieur deviennent cruciales lorsque la rareté et la dégradation des ressources, en particulier de l'eau, deviennent apparentes, nécessitant une refonte plus large de l'accès, de l'utilisation et de la gestion des ressources. Cette approche localisée souligne un problème critique : les réalités vécues transcendent souvent les limites municipales. Un passage à une vision axée sur la cohabitation, qui dépasse les frontières politiques et administratives, est urgent. Cela nécessite un nouveau modèle d'occupation et de gestion du territoire, un modèle qui donne la priorité aux approches intégrées et collaboratives et qui sert de base à la planification territoriale. Dans ce cadre, la définition technique des unités de gestion devient essentielle, permettant de concevoir des stratégies qui relient les actions visant à créer des habitats sains et durables tout en favorisant un fort sentiment de coresponsabilité dans la gestion du territoire.

MOTS CLÉS : aménagement du territoire, gestion des bassins versants, Système d'Information Géographique, co-habitation.

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1. Introduction

This work builds upon existing research regarding the importance of territorial organization using a watershed approach. Within the Latin American context, where territorial and environmental policy are crucial for sustainable development, the need for integrated watershed management involving diverse actors and scales is well-established (Bocco et al., 2005; Garrido et al., 2007; Chamochumbi, 2010; Pérez, 2010; López, 2013; Challenger et al., 2014; Bunge et al., 2014; Martínez, 2015; Cruz Romero et al., 2015; Osorio Vásquez, 2017; Caire, 2008; Jiménez-Otárola & Benegas-Negri, 2019; Moreira Braz et al., 2020; Báez & Cortizas, 2021).

While acknowledging the recognized advantages of integrating these analytical categories for environmental and territorial policy formulation, this work focuses specifically on the challenges of spatially delimiting management units and defining hierarchically structured policies across progressively smaller geographic areas. The concept of the hydrologic unit (HU) is central to this approach, defined as "An area of land, above or upstream from a specific point on a stream, which is defined by a hydrologic boundary that includes all the source areas that could contribute surface water runoff, directly or indirectly to the designated outlet point" [Natural Resource Conservation Service (NRCS), 1995].

Inspired by the aforementioned studies, this article proposes a simple, concrete, and replicable methodological approach to territorial planning. Crucially, it offers a straightforward framework for understanding the territory, facilitating both the conceptualization of territorial problems and the development of linked actions from regional to local scales. This framework emphasizes territorial organization beyond political divisions, promoting a new approach to territorial action based on co-responsibility and a strong sense of co-habitability, recognizing the interconnectedness of local actions and regional impacts.

This methodology was subsequently implemented in the State Program for Territorial Planning and Urban Development of the State of Michoacán 2022-2040 (currently under publication in the Official Gazette of the State of Michoacán). This document's territorial public policies serve to illustrate the potential of comprehensive territory management using this planning perspective. This manuscript details the technical foundation of the methodological process and outlines the expected outcomes of this territorial planning model.

2. Study area

This article examines the state of Michoacán, Mexico, as a case study. The state's complex geological formation is largely a product of tectonic activity resulting from the subduction of the Cocos Plate beneath the North American Plate. This dynamic has driven intense volcanism and other geological processes, shaping the region's diverse landscapes over millions of years. These landscapes range from the high peaks of the Trans-Mexican Volcanic Belt and the Sierra Madre del Sur, bisected by a network of active faults, to expansive, fertile valleys and rugged coastal zones. The region's lithology includes metamorphic basement rocks, sedimentary formations, and intrusive and extrusive igneous rocks of Cenozoic origin. These geological characteristics significantly influence Michoacán's hydrology, biodiversity, and natural resources.

Following millennia of human habitation, Michoacán's current population of 4.7 million results in a density of 81 inhabitants per square kilometer, surpassing the national average. Approximately 70% of the population resides in urban centers with populations exceeding 50,000. The capital city, Morelia, is home to 850,000 residents, while other major cities are distributed across the state. Michoacán contributes 2.5% to Mexico's national GDP. Despite its significant agricultural output, including nearly 80% of the nation's avocado production, this economic specialization poses considerable challenges for territorial planning and sustainable development (Figure 1).

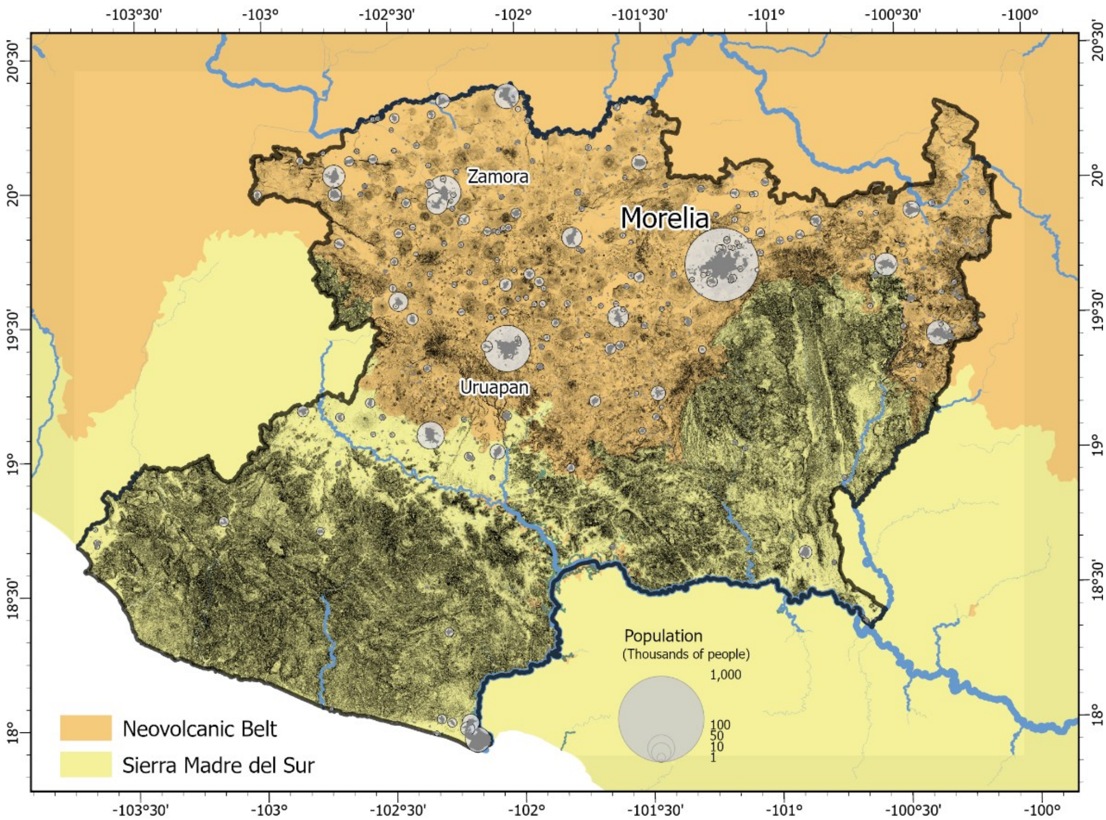

Figure 1 Case study are. Michoacán, Mexico.

3. Methods

The process of delimiting hydrographic basins was carried out based on the International classification and codification of watersheds and river basins, defining Hydrological Units following the scheme of Khan et al. (2001), see Table 1.

Table 1 Taxonomi and coding.

Area (km^2)	Adapted Hydrologic Unit	Code
=> 5000	Region	I, II, III, IV…..n
1000 - 4999	Basin	A, B, C, D, E…n
500-999	Catchmen	1, 2, 3, 4 ,5,…n
100-499	Functional zone	H (high), M (medium), L (low), L (Lake)
<=99	Territorial targering (TT)	Urban (U), S(Special), T(Territoria)

Source: Modified from Khan et al., 2001.

Regional scales were delineated using the watershed crests of rivers with a Strahler order of 6 or higher (Strahler, 1957). Basins were defined by streams of order 4 and 5, and catchments by branches of order 3 and 4. This delineation was performed using a 100-meter resolution digital elevation model.

Functional zones were delineated using a simplified segmentation model of high, medium, and low basins, based on morphometric criteria, specifically topographic slope (Black, 1997; McMillan, 2022; Wainwright et al., 2022). High zones are characterized by a predominance of 1st order channels and slopes greater than 10°; medium zones contain 2nd and 3rd order channels with slopes between 5 and 10°; and low zones are dominated by channels of order greater than 3 (including main channels) with slopes less than 5°. Reservoir zones, encompassing lakes, lagoons, estuaries, and artificial reservoirs, were also delineated.

The final territorial targeting process involved defining three land cover categories: urban areas, protected areas, and productive and environmental service areas (all remaining land not classified as urban or protected). Protected areas were delineated using officially decreed legal boundaries. Urban areas were mapped through manual photointerpretation of 10-meter resolution Sentinel-2 Level 2A surface reflectance satellite imagery, accessed via the Copernicus Browser. This manual interpretation method was preferred over automated classification due to its higher accuracy in capturing the complex and often fragmented nature of urban boundaries. Specifically, manual interpretation prevented the misclassification of peri-urban settlements, which, despite their functional connection to the urban core, can appear as isolated patches in automated classifications. Urban area delineation focused on identifying contiguous areas with established functional connectivity to the main urban center and the potential for future territorial coalescence.

4. Results and discussion

The state of Michoacán falls within four hydrographic regions that extend beyond its political boundaries. This first hierarchical level necessitates interstate collaboration to establish agendas that influence local decision-making (Black, 1997; McMillan, 2022). The intent is that policies and actions developed at this regional level should address the diverse problems that may arise. Analysis of the functional basin structure reveals a predominance of high and medium zones, suggesting that primary agendas should focus on these types of environments, particularly concerning water capture and transport (Figures 2 and 3).

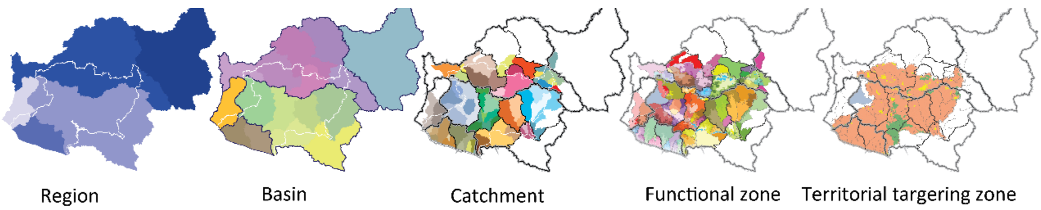

Figure 2 Spatial representation of the sequential subzoning of land use planing units of the state of Michoacan.

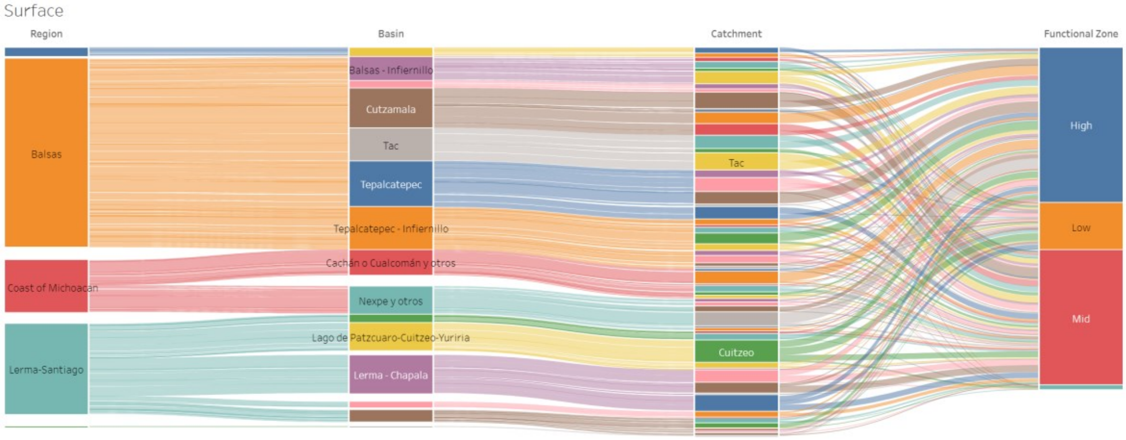

Figure 3 Hierarchy of Territorial Units in Michoacán. The width of the Sankey diagram bands represents the area of each unit.

Population patterns, used as a proxy for flow magnitude across different geographical and functional categories, reveal a concentration of population within the Balsas region. This is evidenced by the wider bands originating in this region, which indicate a larger population share compared to the Lerma-Santiago region. Within Balsas, the Tepalcatepec-Infiernillo basin exhibits the highest population concentration. In Lerma-Santiago, the Lago de Patzcuaro-Cuitzeo-Yuriria basin slightly outnumbers the Lerma-Chapala basin in population size. The distribution of population across different catchments within each basin also reveals variations in concentration. Finally, categorization of the population by functional zone (High, Low, and Medium) demonstrates that the majority of the population in both regions resides in Medium-level zones (Figure 4).

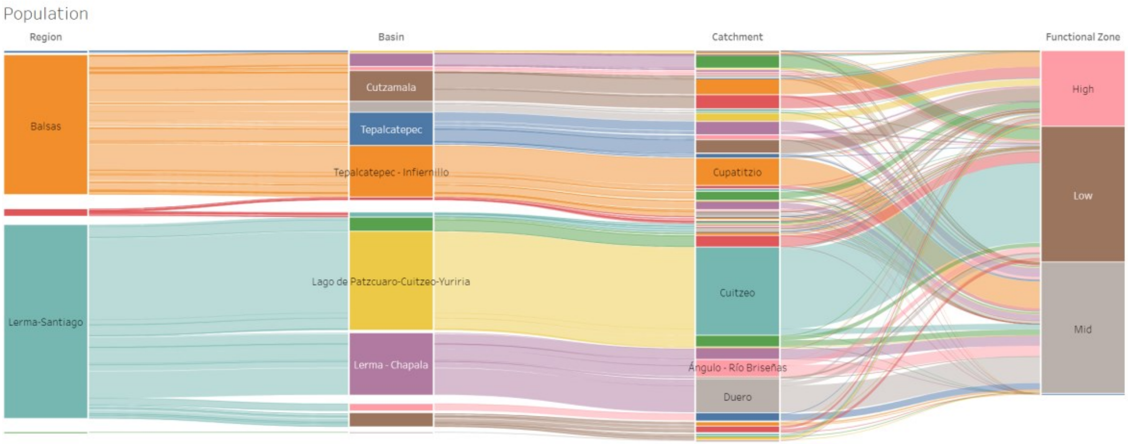

Figure 4 This shows the hierarchical organization of Michoacán's territorial units. The size of the Sankey diagram's flows corresponds to the surface area of each unit.

4.1. Example of transcalar policy implications

This Sankey diagram visualizes the distribution of territorial policies across the study area's diverse geographical units. Three primary policies—Conservation, Exploitation, and Protection—are allocated across three distinct regions: Armeria-Coahuayana, Balsas, and Lerma-Santiago. The diagram reveals a clear hierarchical structure, cascading from broad policy categories down to specific functional zones. Armeria-Coahuayana is exclusively dedicated to Conservation, flowing through the Coahuayana catchment and ultimately impacting the High functional zone. The Balsas region, while encompassing all three policies, predominantly channels Exploitation through catchments such as El Infiernillo and Tac, primarily influencing the Mid functional zone, and also includes the Salamanca-Rio Angulo catchment. Lerma-Santiago is primarily associated with Protection, flowing through the Lerma-Salamanca catchment and impacting the Low functional zone.

This visualization effectively demonstrates how overarching policies are implemented at progressively finer scales, from regional designations down to specific functional zones within catchments and basins. Consequently, the diagram illuminates potential focal points for integrated management strategies, considering the distribution and impact of these policies across varying geographical and functional contexts (Figure 5).

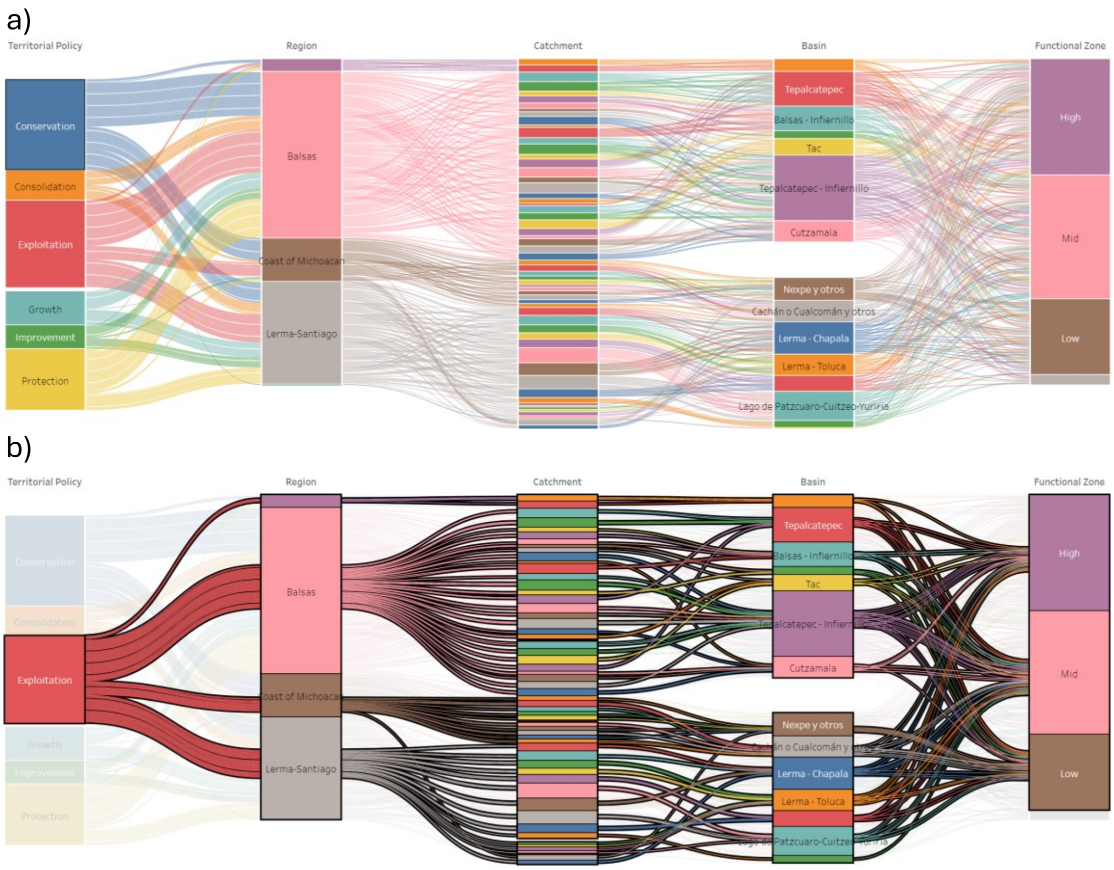

Figure 5 This illustrates how territorial policies are transferred hierarchically to smaller territorial units. It highlights the inherent co-responsibility we aim to foster at each level of governance. Figue a) shows the main territorial policies throughout the state, figure b) shows the dimension of the exploitation policy, which mostly corresponds to the large cultivation areas of the state.

As shown in Figure 6, the cartographic extent of the "Exploitation" territorial policy is predominantly found within the Balsas and Lerma-Santiago regions. This concentration strongly suggests these areas are the epicenters of agricultural activity in the state. Consequently, it's probable that targeted policies have been implemented here to govern land use and agricultural output. Furthermore, the distinct boundaries of the basins and catchment areas underscore the critical role of water resource management in Michoacán's territorial planning, particularly in its most agriculturally productive regions.

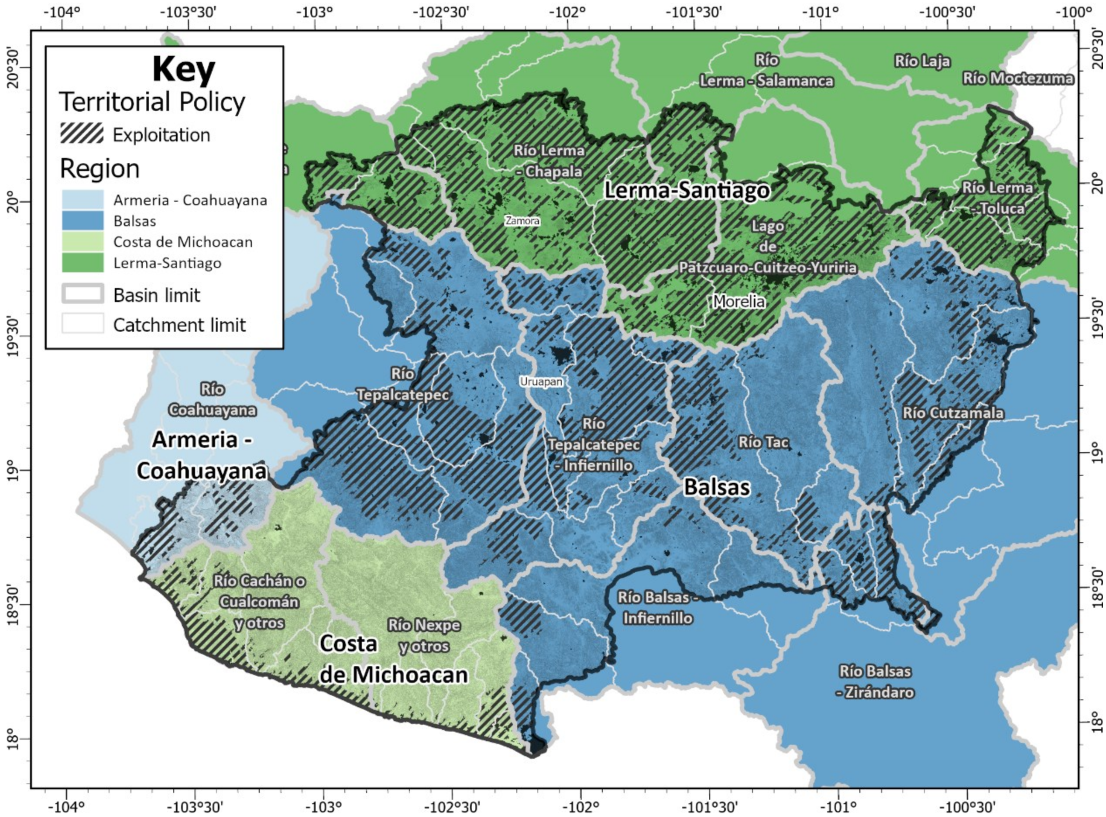

Figure 6 Cartographical dimension and location of the exploitation policy.

In Mexico, territorial planning is typically disconnected from hydrological dynamics. Conventional territorial policy often prioritizes sectoral market analyses, land-use vocations, and other technical assessments aimed at sustainable development. However, these approaches seldom foster coordinated actions at the territorial level. Many current contradictions in land-use models stem from this spatial decontextualization of public policy.

This exercise aims to propose an alternative model for territorial organization that breaks with current inertia in land management decision-making. By exclusively integrating a hydrographic perspective, it becomes evident that we inhabit intimately interconnected territories. From the standpoint of surface hydrological processes, it's graphically clear that actions at any level of the territorial hierarchy can inevitably affect both regional and local units.

The primary challenge of this approach lies in the necessity of establishing a legal framework that incentivizes interstate, inter-municipal, and inter-sectoral cooperation. This work proposes an organizational model and a potential public policy management system, systematized within a Geographic Information Systems (GIS)-based architecture. This, at a minimum, could significantly contribute to the monitoring of future territorial actions by integrating relevant tracking indicators.

5. Conclusions

This work focuses on defining territorial management units based on hydrographic processes at a regional scale. The model, in essence, is simple: at regional, basin, and sub-basin scales, units are delimited following the water divides of lower-hierarchy channels. At an intermediate scale, functional units are prioritized, dividing the territory into functional zones. At the local level, the criterion is based on the general functions of the land, classifying it into urban, protected, and the rest of the territory.

Methodologically, this approach is extremely simple. Under this organizational model of the territory, the essence is to concatenate policies that are territorially transversal. Under this assumption, the notion of cohabitability arises, where each section of land maintains deep functional ties with the rest of the units, at least up to the regional scale directly.

This approach facilitates the identification of the actors responsible for monitoring each policy and action. Being a territorial management unit based on hydrological processes, it is relatively easy to identify the potential water demand requirements for urban, productive, public uses, among others; and this is directly linked to the possibilities of each catchment area to seek more balanced exploitation models.

Regarding use and management priorities, it also allows easy identification of the potential vocation of the areas to promote the health of the water system, which allows us to imagine combinations of actions that favor it.

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