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Artificial wetlands as a key for the construction of new sustainable urban systems.

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Abstract

Along the water route, man and nature interact intimately. The flow and occupation of the water route led to a relationship that emerged naturally within its logic. However, based on a deep understanding of complex and dynamic ecological processes, the relationship between man and natural processes has changed. Control and centralization buried these processes through a system of invisible infrastructures, causing a disconnection between the water path and the landscape's ecological processes. Providing clean water and an adequate sanitation system does not represent great complexity. While essential technologies and engineering principles have been mastered, it is striking that more than one billion people in the world still lack access to clean water, and almost two billion struggle with inadequate wastewater treatment. Furthermore, water-related diseases are the leading cause of premature death in developing countries. In searching for a solution to water sources and soil pollution, we propose exploring Artificial Wetlands (AW) as Nature-Based Solutions (NBS). These solutions provide environmental, social, and economic benefits. The research focuses on a hydraulic sanitation system disconnected from the central network. This system includes designing a system of artificial wetlands to treat wastewater produced by direct discharges to streams and rivers and proposes an AW in Sinincay (peripheral parish), where 42% of their territory does not have a wastewater treatment system. The results show that this phytoremediation technique is a passive and aesthetically pleasing cleaning practice that utilizes plants and solar energy to treat polluted waters. Thus, it is imperative to rethink sanitation concepts in order to integrate constructing infrastructures, ecological functions, and accessible spaces for people as a new alternative to a sustainable urban system.

Keywords

Artificial Wetlands; Sustainable Development; Ecological Processes; Wasterwater Treatment

1. Introduction

The accelerated growth of urban agglomerations is a phenomenon that, although globally accepted, admits nuances and particular considerations depending on the local context. In the case of Latin America, specifically the city of Cuenca-Ecuador, we can foresee two characteristics for the coming years: 1) the consolidation of a majority of urban population and 2) a high rate of urban growth, which has overflowed the city itself and threatens the territory as a whole.

Thus, this projection anticipates an enormous challenge for city planning. It is imperative to rethink the methodology and instruments used to run the city because expansive growth threatens the whole of the territory (Corboz & Marot, 2001), fragmentation and loss of soils of ecological value, biodiversity, climatic and hydrological alterations, among others (Delgado, 2008). The objective of this study is to explore off-grid infrastructures through nature-based solutions (NBS) in the transition space between the city and the countryside known as peri-urban, an edge space that is characterized by its speed of transformation and which will presumably be where a large part of the sustainability and resilience of cities in Latin America is at stake (Arola, 2014). The proposed system, artificial wetlands using the phytoremediation technique, provide environmental, social, and economic benefits.

In this context, this paper takes a theoretical and methodological approach consisting of three sections. First, the *Theoretical foundation*, through the analysis of three categories, (2.1) Urban edge, argues the need to recognize urban edges as a new design category that allows us, on the one hand, to distance the negative connotation of the term peri-urban, and on the other, to go beyond the urban scale and overcome old binary oppositions such as center/periphery. (2.2) Social Metabolism and the City, explains the relationship between social systems and ecological systems as parts of the same metabolism. (2.3) Water and the City, recognizes water as a process of construction and hydrosocial transformation, which presents a manifest interrelation between nature, society, and technology (Boelens et al., 2016). Second, *Cuenca as a case study*, recognizes the edge of the city as a space of opportunity, and the problem which represents the lack of wastewater treatment as the main cause of premature deaths in developing countries (Swyngedouw, 2006b). Third, *Artificial wetland*, reviews decentralized and off-grid infrastructure in the Sinincay parish, where 16 of the 38 communities do not have a wastewater treatment. The results revolve around new sanitation concepts that interrelate infrastructure, ecological functions, and accessible public spaces for people.

2. Theorical foundation

As the city journey moves forward, two fundamental facts mark the history of the modern city: many people have been living in cities since the end of the last century, and more people will be living at the periphery in the next century. However, between the 1980s and 1990s, urban planning has been stubbornly focused on the urban center, insisting on a center-periphery dichotomy that has increased inequalities, especially in developing countries (Tzaninis et al., 2020).

Since most people live in cities, the periphery is the area that undergoes the most significant changes, where much of the sustainability and resilience of cities is at stake. However, when we define cities, we usually resort to opposing categories: city-countryside, urban-rural, interior-exterior, and so forth, separated by a clearly defined boundary. Yet, a third space occupies the gap between these two that deserves recognition as a new project category that allows overcoming the negative city-countryside dichotomy and understanding the third space as a space of opportunity (Galindo & Giocoli, 2012).

2.1 Urban edge

But, how can we conceptualize this edge space that neither fulfills the proper functions of an urban nor rural setting characterized by an ambiguity (Busquets & Sola Morales, 1999); linked to a form of expansive growth; and also can serve as a suitable sample for explaining transformations within social, cultural, and environmental relations? At first glance, periurbanism looks at the city from the center, highlighting that no periphery exists without a center (Tzaninis et al., 2020).

As defined in the European context, the peri-urban is considered to be the space surrounding urban areas and merging with rural areas (Piorr et al., 2011). It is therefore identified as a center of innovation, knowledge, and globalization. It is also the place where new types of housing, transportation infrastructure and multifunctional agriculture with a diversity of recreation sites and ecosystem services have been experimented. These new types of urbanization processes are occurring, but under particular pressure on land use, which puts urban sprawl at risk, as well as various social and environmental problems associated with this condition. Therefore, several authors have identified urban-rural linkages as emerging matters that require not only new approaches to politics and funding, but also new epistemologies (Allen, 2003).

In addition to being constantly transformed, the periurban space, like the territory, is also a space that is constantly being renovated. Unlike the slow construction of the territory, however, it is characterized by its speed of change: it extends, relocates, moves from place to place, and it's neither a field nor a city (Avila Sánchez, 2001).

The ecotone refers to habitats that are located between two interacting systems with high diversity differentials, such as meadows and forests and sea —which by interacting— develop a "third space" (Burbano et al., 2017). The third space is defined by the presence of agricultural and non-agricultural activities within the same geographical area (Tacoli, 1998) and is further defined by two groups of actors: rural and urban, with different ways of living, producing, thinking, and different interests. André Corboz (2001) provides the following example:

"In the image of the countryside as a happy Arcadia, the peasant had never recognized himself. Nevertheless, paradoxically, he had an almost identical representation of the urban, that is to say, as fictitious as the other, since he conceived the city as the place of permanent leisure, and since he had absolutely no voice, he did not get to make himself heard about his condition; meanwhile, the man of the city continued to perceive it as the green solitude to which he himself aspired" (Corboz & Marot, 2001) .

Therefore, this space in transition becomes a disputed territory, leading its actors and inhabitants to compete to subsist and control the territory and its resources; a conflict in which the dominant factor is the urban and the vulnerable one the rural (Ballén-Velásquez, 2014). Nevertheless, the loss of rural and environmental character is not the only factor defining this phenomenon; it is also the lack of urban attributes, such as low density, lack of accessibility, infrastructure, among others (Allen, 2003). Meeus & Gulinck (2008) describe urban transformation as a phenomenon with low density, dispersion, fragmentation, and consumption of a large amount of land and energy.

According to Delgado Viñas (2008), this expansion process is highly destructive of natural resources, as buildings located on land coincide with the land of ecological value (agricultural and environmental), causing the fragmentation of the territory and also alterations in climatic conditions, hydrology, and other factors (Delgado, 2008).

2.2 Social metabolism and the city

As a result of society's visions, expectations, anxieties, and problems, the city emerges from how it understands and perceives its changes over time and as a result of multiple transformations. Many authors, including Kennedy, Cuddihy, and Engel-yan (2007), and Timmeren (2014), suggest that cities' vitality depends on their spatial relationships with the surrounding environmentand global resource networks. The reason for this is that in the latter stages, resources traveled longer distances to reach cities, thereby depleting the closest and most accessible resources, and ultimately limiting the development of cities (Kennedy et al., 2007). The growth processes of cities initially included their immediate environment for their growth, but later, resources traveled longer distances to reach the cities, leading to resource depletion and consequent limitations for their development. Since the goods used in urban processes, especially food, have reached such a point, modern cities do not depend on their zones of influence, but rather feature in continental and global economic networks (Timmeren, 2014).

CAS (complex adaptive system) is the most accepted definition of a city today. It is adaptive because it changes and learns from experience and complex because different actors of different nature form it. These are formed by various elements of great interconnection between them (Acero Caballero et al., 2019).

The term metabolism comes from the Greek metabole, meaning change. This concept appeared in the 19th century to study the physical and chemical transformations within an organism, allowing it to maintain itself, grow, and reproduce (Clark & Foster, 2010). Subsequently, ecological metabolism appears to refer to the functioning of ecosystems.

The city can then be understood as a social-ecological system of cyclical behavior. Thus, a complex system that is subject to changes and called to be more resilient, can adapt to changes more efficiently. In this sense, they present an adaptive cycle that requires exploring new theories, methodologies, and planning tools that respond to the new demands-challenges present in the territory: territorial metabolism from a social metabolism and decentralization approach; thus, it seems to present a fruitful field.

Finally, social metabolism appears through the social sciences and is designed to explain the relationship between human beings and nature. Social metabolism relates to social and ecological systems (Foster, 2004). It refers to the set of processes through which human societies appropriate, circulate, transform, consume and excrete different products (matter, energy, and information) or processes of ecological metabolism (Foster, 2004). Human societies are also understood as complex, organic and dynamic systems (Gandy, 2004, Odum, 1971), which produce and reproduce the indispensable conditions for their existence, based on their metabolism with nature (Gandy, 2004).

From an organic vision, social metabolism can be understood as an interconnected space of flows and dependent on external inputs of energy, matter, and information. As a result, it cannot explain by itself how space is historically produced, requiring instead that we establish an ecological-historical basis as the basis of what is social, with the possibility of lasting in time (Swyngedouw, 2006a). This approach of metabolism allows the study of how rural and urban landscapes have been historically produced.

Similarly, to build the economy of the future focused on the urban based on the inclusion of social equity, environmental justice and urban ecosystem services, can be recognized as the normative objectives of the concept of Urban Metabolism proposed by Timmeren (2014). For this author, modern society is dissociated from nature and such transition from unsustainable societies/cities to more sustainable and resilient societies/cities will be gradual and evolutionary. Open and global energy and material systems are now supplemented by short-loop economies, whose primary characteristic is to be based on the local and regional. Consequently, short-loop economies have the potential to increase awareness and creativity at the local level, not only in terms of participatory governance and social integration, but also allow for a better balance between local, regional, national and international markets. In this way, large corporations/centralized governments must cede more power to communities, giving them more control over what is produced in the local setting, allowing for fair trade and benefit to both parties (Timmeren, 2014).

Within this conceptual framework related to social metabolism and the city, decentralized infrastructural systems stand out as an alternative to the conventional centralized and cumulative systems, typical of the industrial city and its contextualized reproductions.

The fair and efficient distribution of resources is one of the significant challenges of the current urbanization process at the global level. Under this premise, the world summit (UN-HABIT, 2015) establishes in its Issue Papers that:

"Given the global trend of growth of urban areas, they will tend to capitalize unequally on the majority of resources, and this may have adverse effects on universal access to resources (...). This trend requires urban planning strategies that promote decentralized resource management in areas such as renewable energy, drinking water supply, and wastewater treatment" (UN-HABIT, 2015). The latter, wastewater treatment, is of particularinterest to this study."

For Swyngedouw (2004), urban metabolism is a socio-ecological process of metabolizing the ecological system. Cities are the places where the environmental system and its social relations are intensely re-elaborated. Therefore, they can also be conceived as nature (Swyngedouw & Cook, 2010). Thus, when Harvey (1996) argued that "there is nothing unnatural about New York City", he meant that cities and social systems, in general, are transformed into socio-natural hybrids that reveal social and ecological processes; and are part of the same metabolism (Heyden, 2003).

Urban metabolism is crucial in understanding urban-rural relations since rural areas and natural areas co-depend directly on this (Ariza Montobio, 2013). Such interdependence between the ecological and the urban; and their constitutive processes allow the assumption that all types of nature are socially mobilized, economically incorporated (commodification), and physically metabolized. Swyngedouw & Kaika (2014), recognize that this race supports the urbanization process. On the other hand, rural metabolism refers to the metabolism of rural social-ecological systems, where its population to survive depends on agriculture, livestock, forestry, hunting, fishing, gathering, and extraction (Toledo, 2008).

In this way, the urban/rural dichotomy is maintained and accentuated in planning, with the ideological complexity of limits uses, among others, typical of a complex system. In this sense, Tzaninis et al. (2010) propose that there is the need to overcome the distinction between center and periphery, viewing them as parts of the same socio-environmental continuum, to overcome the inequal development that this produces.

2.3 Water and the city

Social systems are sustained through flows and trans-flows of matter and energy (Daly, 1974), one of which is water. The complex network of metabolisms is supported by the constant circulation of water in, through, and out of the city; without its uninterrupted flow, life and the web of practices that constitute the city's essence would be impossible (Swyngedouw, 2004).

The social system appropriates the water resulting from the ecological metabolism. Water is: captured, pumped, purified, chemically regulated, piped, transported, bought, and sold; used in homes, by living beings, in agriculture, in industry, in electricity generation, transformed into waste and returned to the ecological system; all this determined by complex political, economic, social, cultural and ecological processes (Kaika, 2003).

Traditionally, in the course of water, one can observe an intimate relationship between man and nature. Its flow, its occupation, generated a natural relationship respecting the logic of this course. Elisee Reclus (1850), in Historia de un arroyo, describes the importance of this metabolic process. As a human geographer, he thinks of the utility and the service that a stream provides: in fishing, irrigation for crops, gardens, in the mills and factories that he finds downstream, in the cities' water that forces the construction of dams.

It is necessary, he argues, to learn to use it in a complete way for the irrigation of our fields and the dynamization of our wealth, then we will be able to make it work for the shared service of humanity, instead of leaving it to the sun the crops and straying into pestilential swamps (Reclus & Guazzelli, 2001). And so it continues, [...] this water will undoubtedly become dirty later on; it will pass over fragmented rocks and rotting vegetables; it will dilute muddy lands and will be loaded with the impure remains poured out by animals and men; but here, in its pit of stone or its cradle of reeds, it is so pure, so luminous, that one would say that it is condensed air [...] (Reclus & Guazzelli, 2001).

The relationship between man and natural processes, according to Reclus, is based on a deep understanding of complex and dynamic ecological processes. Since the idea of control and centralization buried these processes through a system of invisible infrastructures, a disconnection has ocurred between the path of water and the ecological processes of the landscape (Stokman, 2008). Therefore, it is essential to introduce water management as an integral part of the rural/urban landscape, which, as it has been previously stated, is dominated by open spaces and has a clear agricultural vocation.

Hence, providing clean water and adequate sanitation is not exactly rocket science. Essential technologies and engineering principles are known and mastered, management systems, biological, physical and chemical processes are well understood. However, it is striking that more than one billion people still suffer from inadequate (both in quantity and quality) access to water, and almost two billion have unsatisfactory wastewater treatment. These are some reasons for water-related diseases that cause premature deaths in developing countries (Swyngedouw, 2006a).

This problem is aggravated in the so-called developing countries. In the case of Ecuador, wastewater discharge is the leading cause of contamination of water sources (Isch, 2011). For this reason, exploring innovative strategies that allow a paradigm shift in the management of water resources, particularly wastewater, will optimize this process and create greater access to this service.

3. Cuenca as a case study

The Ecuadorian city of Cuenca has the ideal characteristics for the proposed study. Cuenca is an intermediate city that exemplifies this scenario in which 65% of its population is already urban, also what will foreseeably be the type of environment for the majority of global urban growth (Ballet, C. Llop, 2004). Furthermore, projections for the next thirty years making Cuenca one of the cities with the fastest urban growth rate in Latin America (AA.VV, 2014).

Under these characteristics, the contemporary city is understood as a "city-territory" to identify the importance of its changes within the spatial, economic and social structure. The approach to the case study allowed the analysis, interpretation and prospective of remediation strategies that were addressed at three levels: city-territory, as a whole and in detail (Figure 1).

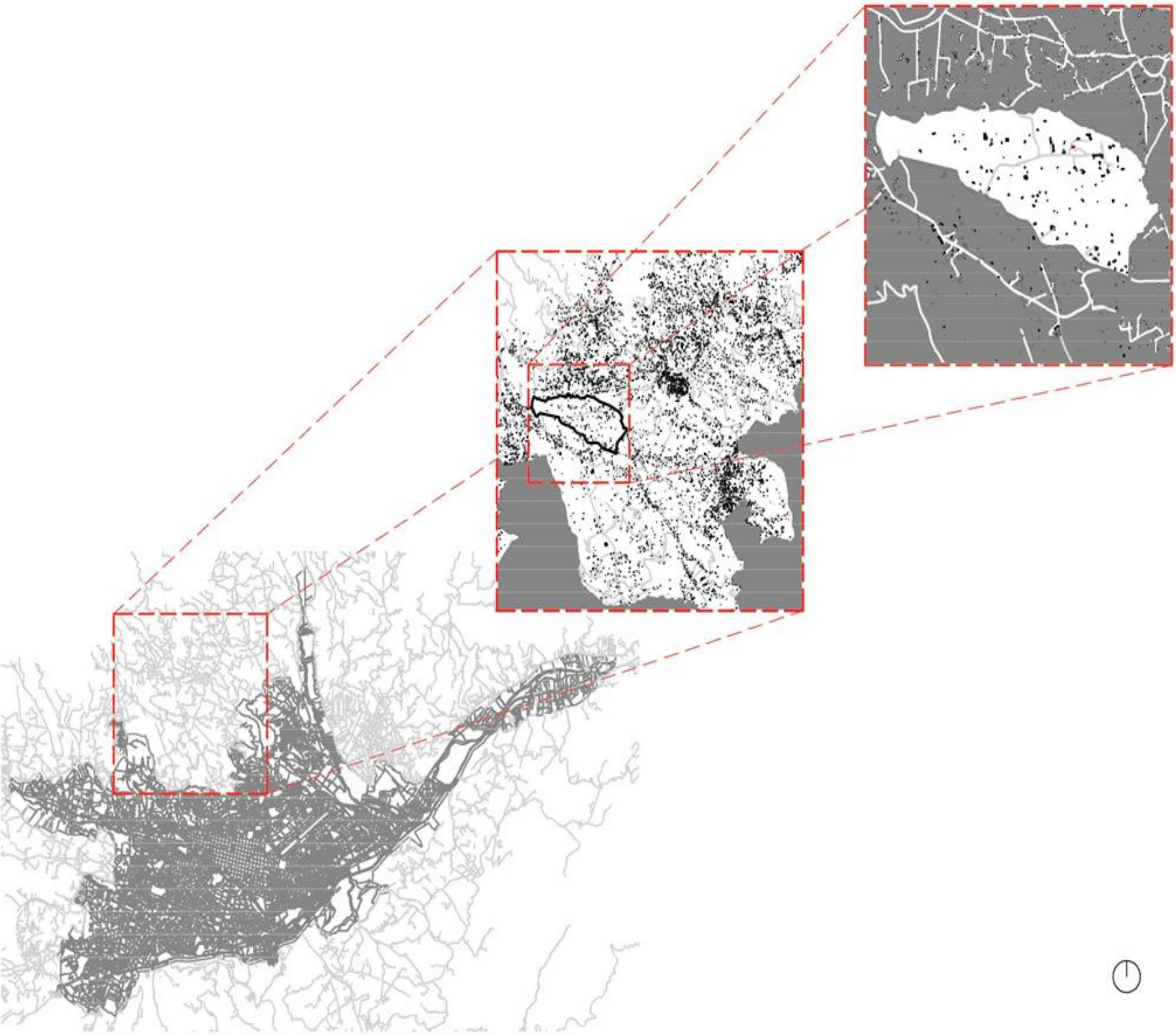

Figure 1 Work scales. Own elaboration.

Cuenca comprises 15 urban and 21 rural parishes, and it is expected to double its population in the coming years. This population will be located mainly on the city's edge, known today as peri-urban areas. This fast transformation process has occurred in the rural parishes of Sinicay, Ricaurte, El Valle, Baños (1 -6 -10 -12) (Figure 2). These parishes present the accurate scales and intensities to understand this phenomenon.

On the other hand, it is urgent to rethink the centralized wastewater treatment system that the city uses. Cuenca is the only city in Ecuador that treats its wastewater; 98% of its wastewater is treated, but only within the urban area (approx. 8000 Ha). However, the city is surrounded by a strip (approx. 24000 Ha) of foamy, diffuse quality land, colloquially referred to as peri-urban. It coincides with the transition zone between city and countryside, where, today a third of the population lives. Still, there are null or partial water treatment systems.

Sinincay (1) comprises 4648 ha, and it has a population of approximately 20,000 inhabitants distributed in 38 communities (Pakariñan, 2015). This territorial edge of the city is constituted by rural, urbanized, and natural fragments articulated by a complex capillary hydrographic network. This particular characteristic allows observing a process of hydro-social construction and transformation (Boelens et al., 2016) (Córdova et al., 2020) ,which represents a relationship between nature, society and technology (Boelens et al., 2016) .

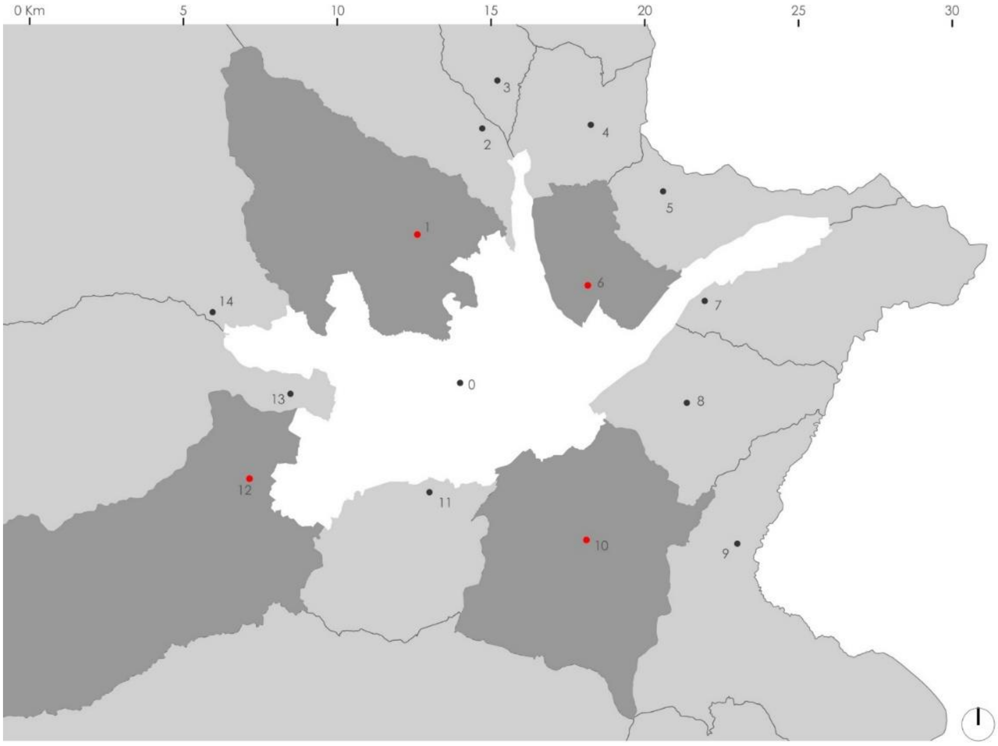

Figure 2 Object of study. Own Elaboration.

The rural parish of Sinincay is located only 7 km from the center of Cuenca. Its main characteristic is its high relief; (72%) corresponds to slopes higher than 12%, and its altitude ranges from 2567 to 3959 meters above sea level. A large part of the parish is highland wetlands, which stands out for their high ecological value.

Another outstanding feature is the empty land/space (not occupied by buildings), which is mostly used as agricultural land, and constitutes the territorial matrix (Forman, 1995) (Figure 3). This agricultural land has a smallholding structure, leading to low productivity levels due to monoculture, inadequate technology, and limited technical assistance. However, a hydro-social system is recognized. This has allowed complementing the economy of the territory. A clear example is the community Playas del Carmen.

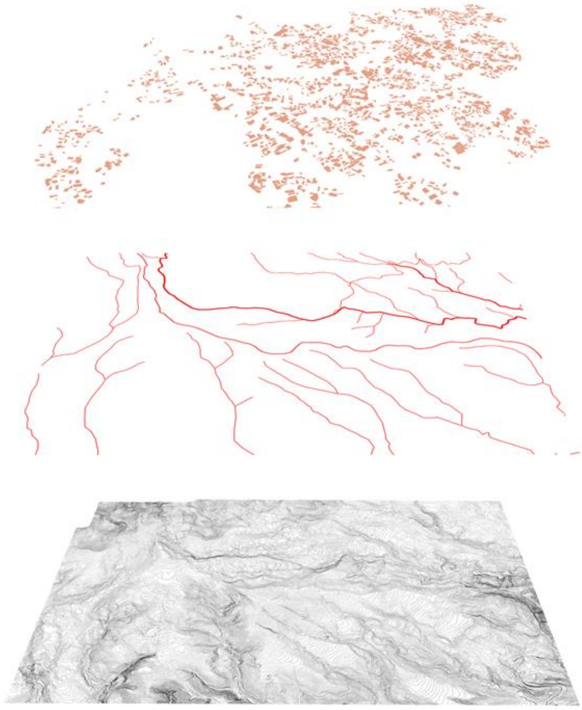

Figure 3 Territoral Matrix of the Sinincay Parish. Own Elaboration.

4. Artificial Wetlands

Playas del Carmen is a field of open spaces crossed by a winding road with houses on its edge. There are green areas all around as well. This community has 65 hectares and a density of 6 houses/ha. The Sinincay River, streams and green areas are natural factors. Like most of the analyzed rural parishes, there is a rain-fed agricultural tessera as the most representative due to the topographic conditions, the low budget that these territories capture, and the lack of wastewater treatment as an aggravating factor (Figure 4).

In these transition zones, wastewater treatment is partial or non-existent. Either because of the distance to the leading network, in which case the city's budget is insufficient, or because of technical factors due to the relief of these parishes. In the case of the Sinincay parish, 16 out of 38 communities do not have a wastewater treatment system. It seems like we are facing new opportunities to harmonize better urban growth, environmental values, and the provision of off-grid infrastructures.

A solution to the pollution of water and land sources by residential wastewater discharges is included in the Nature-Based Solutions (NBS), which are cost-effective solutions that provide environmental, social, and economic benefits. These are resilient and bring diversity and nature to the city; and, in specific cases, to rural communities.

The proposal focuses its attention on a hydraulic sanitation system disconnected from the central network located at the city’s edge. This system consists of designing a system of artificial wetlands (AW) to treat wastewater resulting from direct discharges into streams and rivers.

The process has to take advantage of the physical, chemical and biological processes that occur when water, filter media, plants, microorganisms, and the atmosphere interact with each other. This process is carried out through three general steps: first, removing suspended solids by sedimentation and filtration; second, because of biodegradation of organic matter by aerobic and anaerobic microorganisms; and third, by eliminating pathogenic microorganisms by sedimentation, filtration, and the predatory action of other organisms (Arias Martínez et al., 2010).

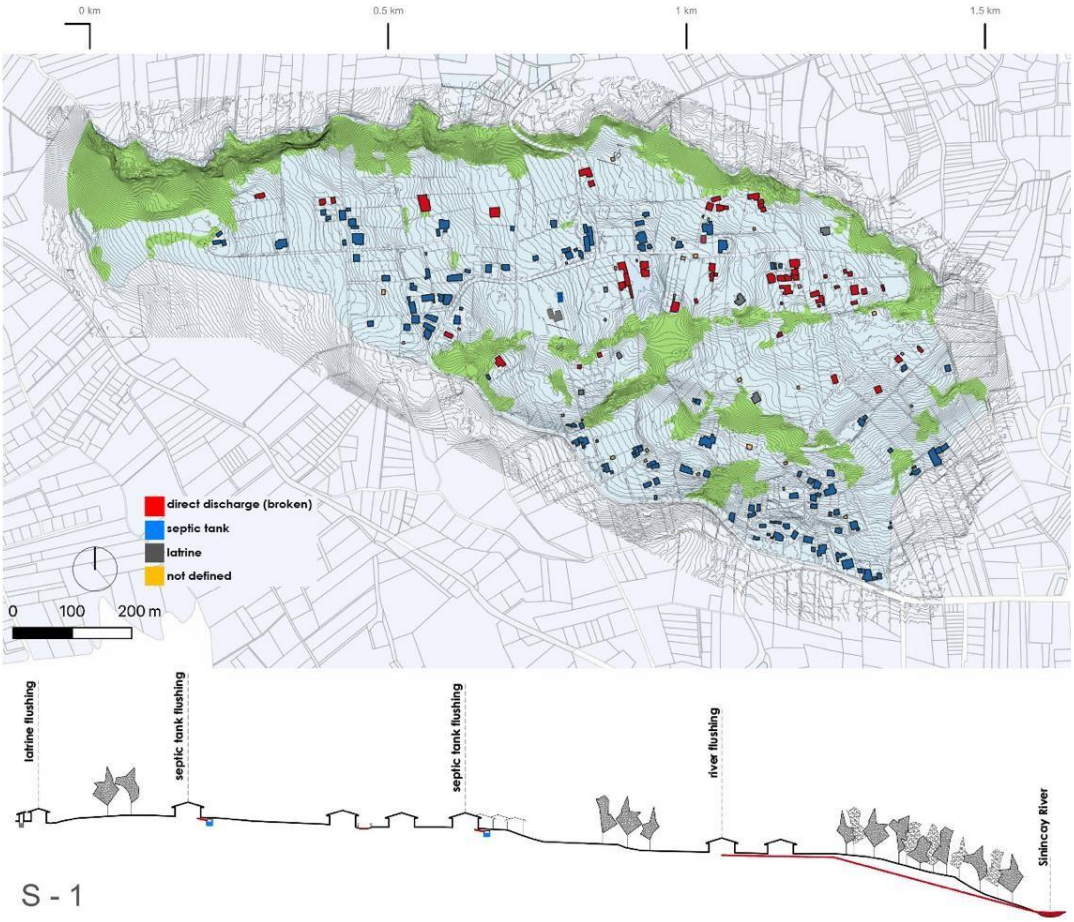

Figure 4 Detail scale, Playas del Carmen. Discharge of wastewater into the river. Own elaboration.

This phytoremediation technique is characterized as a passive and aesthetically pleasing cleanup practice that takes advantage of the capacity of plants and solar energy to treat contaminated water. On this technical arrangement, plants act as traps or biological filters that decompose contaminants and stabilize metallic substances present in soil and water by setting them in their roots and stems or metabolizing them as microorganisms do to convert them into less hazardous compounds.

The construction of AW is an attractive, cost-effective alternative in construction, operation, and maintenance; it is environmentally friendly and applicable in peri-urban areas if compared to conventional wastewater treatment particularly in developing countries (Gopal, 1999).

For the case study, the proposed technique is the design of a sub-surface flow AW (Figure 5). This system consists of a biological filter filled with a porous material (volcanic rock/gravel). Macrophyte plants are planted on the surface of the filter, and the pre-treated wastewater flows horizontally through the filter. With this system, the water level is maintained below the surface of the granular material; therefore, the presence of plagues and the absence of foul odors is minimal. Likewise, its modular condition allows the addition of new units according to its needs. It also constitutes an economically viable solution.

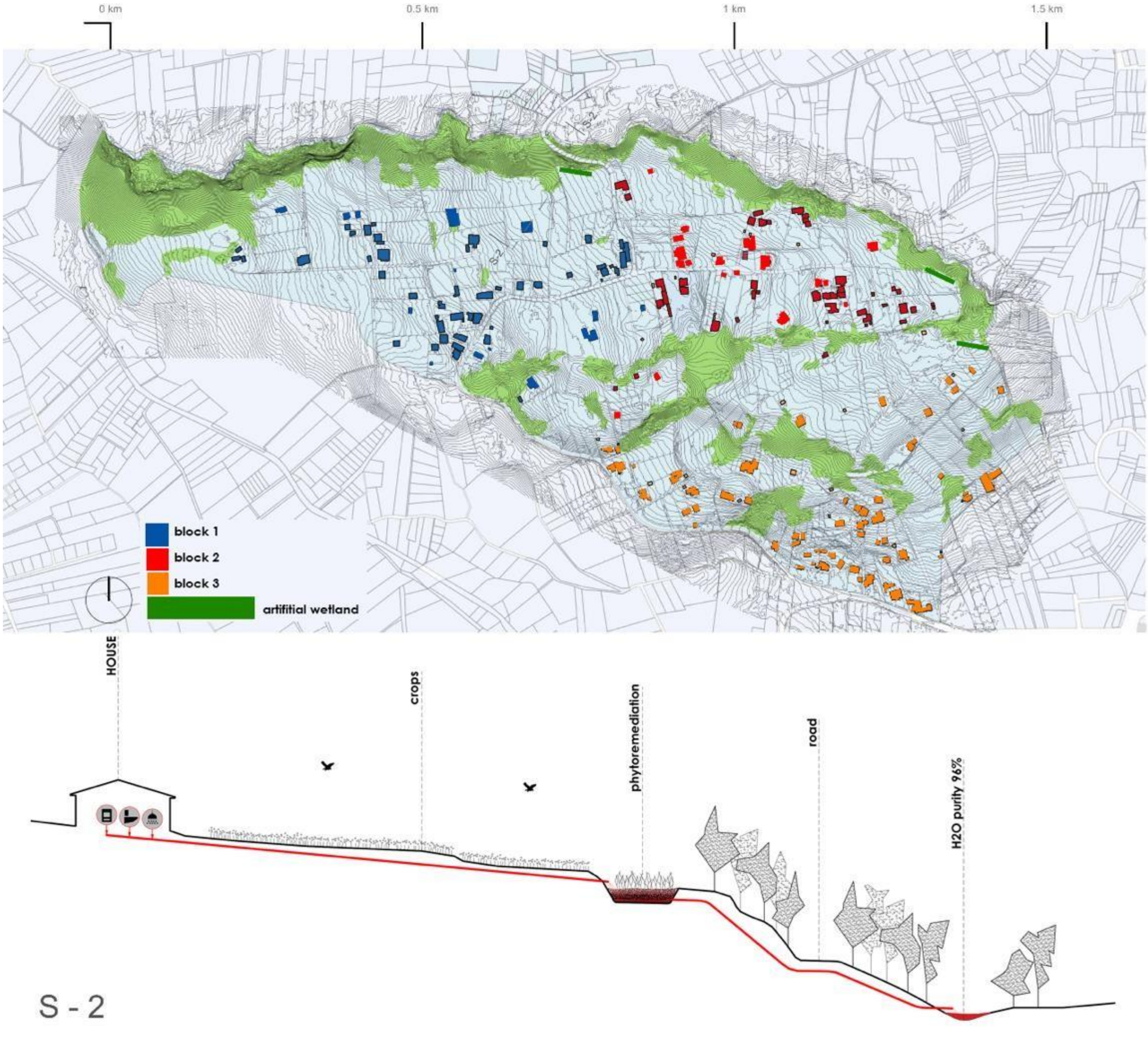

Figure 5 wastewater Hydraulic system outside the net. Playas del Carmen. Own Elaboration

5. Conclusions

Urban fringes are areas between the countryside and the city, and their proximity to the urban center precludes their use as agricultural or forestry land. Therefore, the main characteristic is the ambiguity of multiple services, actors, and interests.It is also important to note that this region is expected to be home to most of the population during the current century. Urban edges must be recognized as a new project category that allows us to move away from the connotation of peri-urbanism and transcend the city-country dichotomy.

Third spaces (neither urban nor rural) have their own characteristics and problems. It has a great ecological value constituted by agriculture, forestry, and the corridors created by rivers and streams that should be appreciated and recognized. This should also be a central component when designing and planning a new sustainable and resilient urban/rural dimension.

To preserve this area, we must eliminate urbanistic expectations, which should be understood as a space of opportunity that articulates crops, forests, communities, and cities in a complex and evolutionary manner beyond being considered an expansion zone.

For the specific case in the Sinincay parish, 5 of its 38 communities do not have running water, and 16 of these do not have a wastewater treatment system which is 42% of its territory. The same thing occurs in other rural parishes of Cuenca and the country in general, which is the leading cause of pollution of water sources.

However, this problem presents new opportunities for better harmonization between urban growth and environmental values. For this reason, exploring innovative strategies that allow for a paradigm shift in water resource management, particularly concerning wastewater, will allow optimization and greater access.

The construction and maintenance of a conventional wastewater system are very costly (Delgadillo-lópez & González-ramírez, 2011) and requires an extended amortization period of between 50 and 100 years. This transition area is not due to these territories' accelerated transformation and growth.

Consequently, it is necessary to urgently rethink these sanitation concepts with a new approach that interconnects the construction of infrastructures, ecological functions, and accessible public areas as a possible path to new sustainable territorial systems (Stokman, 2008).

Thus, the exploration of an off-grid water treatment system favors the protection of water sources and could strengthen the productive character of agricultural areas, promote food self-sufficiency, and increase the economy.

Also, it is crucial to promote the geographical convergence of production and consumption in contemporary cities, in which today's, open and global systems of energy and materials are complemented by short-loop economies; premise that at the end of the 19th century, anarchist geographers (Reclus and Kropotkin) saw as capital, and contemporary ecology sees as essential for energy savings and greenhouse gas reduction (Oyon, 2011) (Timmeren, 2014).

Furthermore, these studied territories with multifunctional characteristics can generate their own water, energy and assimilate their waste, and above all else, they are also suitable for living. In this way, it is ideal for shaping new sustainable centralities to reduce dependence on the center and create a multipolar urban/rural ecosystem, an isotropic body, and a system without a center or periphery (Viganò et al., 2016).

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