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A Simple Method for Identifying Appropriate Areas for Onsite Wastewater Treatment

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Abstract: Onsite Domestic Wastewater Treatment Systems (ODWTS) are increasingly important for treating domestic wastewater in metropolitan contexts, especially in suburban sectors isolated from sewer networks and centralized treatment plants. When ODWTS are not correctly planned and located in suitable places, or are not properly designed, they can cause groundwater contamination and generate risks for human health. This work presents a Spatial Decision Support System (SDSS) to zone specific areas based on a few simple parameters. The proposed tool can be easily adapted to different contexts, even where institutional capacities are low. Results obtained in the metropolitan area of the Lerma Valley (Salta, Argentina) show strong contradictions between our zoning and current urbanization features in the study area. As a result, environmental impacts and health hazards are likely to manifest in the short or medium term. The sectors with the best receptivity conditions were found in the southern sector of the study area. We argue that ODWTS can be safely implemented in many areas as long as this concept is embedded in urban planning initiatives, which usually also require the consolidation or development of appropriate institutions and control systems.

Keywords: spatial decision support system; domestic wastewater; onsite; Salta

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1. Introduction

The Sustainable Development Goals (SDGs), established by the United Nations General Assembly in 2015, are the most important international initiative to face climate change by promoting the protection of the environment at a global scale. Among its 17 objectives, the 6th one (SDG6) proposes to guarantee "clean water and sanitation for all" within the next 15 years [1]. However, some questions arise: are developing regions able to achieve full coverage of water and sanitation services by expanding their centralized infrastructure? Is the centralized conception of water and sanitation services the most convenient strategy for achieving SDG6? The economic and environmental opportunities (and challenges) involved in urban expansion can also facilitate the "unequal provision of public goods and services across sprawling metropolitan suburbs that give rise to residential segregation and pockets of poverty" [2] (p. 177). Global experience in metropolitan public services, especially in developing countries, shows that urban sprawl generally occurs faster than urban planning (if planning exists) or, in other words, public services always lag behind unplanned suburban expansion. This scenario requires urgent rethinking of the existing paradigms of how basic public services are provided in metropolitan and suburban areas [3]. The growth of metropolitan areas in Latin American countries has been significant in recent decades, and global urban expansion trends are showing a dispersed occupation of land [4]. By 2050, it is estimated that 90% of the population will be concentrated in the metropolitan areas of cities [1]. Much of what we call "metropolitan areas" in Latin America are actually an agglomerate of poorly urbanized sectors, lacking basic services and attributes that define the urban. While metropolitan areas grow, ever-increasing demands for public services have generated the need for an, at present, unrealistic speed of expansion of centralized water and sanitation networks and related infrastructure. Although the complete coverage of dispersed metropolitan and semirural areas appears as a utopic goal in the near term, in many countries governments and decision makers do not seem aware of the need to put forward alternative regulations and policies that promote safe, affordable and sustainable options for water and wastewater planning in metropolitan areas.

Centralized wastewater systems consist of a collection network serving large and densely urbanized areas, transporting effluents to one or more wastewater treatment plants. On the other hand, decentralized wastewater systems include a range of technological options for treating wastewater in the place of generation (onsite systems) or near it, including a limited collection network (cluster systems) [5]. Centralized wastewater infrastructure is costly to operate and expand, especially in areas with low population densities and dispersed households [6]. In most cases, metropolitan areas in developing countries include informal settlements, different kinds of public housing developments and consolidated urban sectors coexisting in a highly complex scenario. In suburban areas, the last sections of the centralized network usually coexist with decentralized and mainly informal and unregulated Onsite Domestic Wastewater Treatment Systems (ODWTS), especially onsite forms, where septic tanks are the most widely used devices [7–9]. In Argentina, for instance, there is no clear environmental legislation that includes ODWTS as a formal component of sanitation, nor is there a suitable institutional arrangement and legal framework for integrated urban management of water and sanitation. The diffuse pollution produced, exacerbated by housing density, is a serious health and environmental risk that is not adequately addressed by local institutions. Despite the long-term use of ODWTS in many places, there is still little information about the performance of non-regulated systems [10].

The use and management of ODWTS have become an important research focus worldwide [11–18]. Domestic wastewater is composed of a mixture of effluents from toilet and other domestic sources, such as showers, washing machines, and washrooms. ODWTS can provide adequate treatment of domestic wastewater without expensive transport infrastructure, besides generating greater opportunities for wastewater reuse near the place of generation, such as house gardening or cleaning. Despite these advantages, ODWTS are often considered a short-term and conjunctural solution for wastewater treatment, usually by both users and local management institutions [19]. In this regard, the United States Environmental Protection Agency (USEPA) recognizes that on-site treatment systems, if well-planned, constructed and controlled, should be considered permanent components of the wastewater treatment infrastructure [5]. Comprehensive guidelines with technical information about the selection, installation, monitoring and maintenance of ODWTS have already been established in many countries, compiling several studies and local experiences around the world [5,20]. The most important issue at present is the political inability of governments and water institutions to adapt and/or develop a comprehensive wastewater policy for metropolitan areas and merge it with urban planning.

Site suitability evaluation is a central component of decentralized treatment planning. This kind of study captures technical information in order to evaluate the capacity of a particular area to support the installation of ODWTS. The risks for human health and the environment are high when ODWTS are located in non-suitable areas for decentralized wastewater treatment. Good management of decentralized sanitation depends first on the selection of suitable places with adequate soil conditions as the final destination of treated wastewater [21]. The treatment systems must also be configured according to the required effluent quality, in addition to being correctly installed and maintained. In fact, in urban and suburban contexts, the most important sources of aquifer contamination with nitrates, bacteria and viruses are often the sewer system leaks and pollution produced by the ODWTS [22–25]. Site selection is a common field of application for Spatial Decision

Support Systems (SDSS). SDSS combine spatial and non-spatial data, the analysis and visualization functions of Geographic Information Systems (GIS) and decision models in specific domains to compute the characteristics of problem solutions and they facilitate the evaluation of solutions [26]. SDSS are specially designed to help decision-making processes mostly involving complex spatial problems, and one major component is the GIS [27]. These decision tools have the capacity to process a wide range of information, perform analysis of potential strategies, regulate the use of resources and evaluate the environmental implications. The contribution of GIS to environmental sciences is linked mainly to the type of information they manage and the perspective of the reality they provide. It is these two properties that have made it possible to make information of the most diverse nature comparable in the same (spatial) system. The aim of SDSS is to help policymakers access, interpret and understand information from data, analyses and models, and to guide them in identifying possible actions during a decision-making process [28]. SDSS applications include, in addition to site suitability, resource allocation and service coverage, among others

Numerous decision factors are commonly used worldwide to decide which system (centralized or decentralized) is the better option for sanitation planning. The distance between the urbanization project and the centralized sewerage system (connected to treatment plants) [29], the costs of new infrastructure expansion work [30], the possibilities of reusing treated wastewater [31], the vulnerability of the aquifer [23,32] and planned density for new developments [33] are some of the factors that could assist decision makers. Despite these methodological options and tools, poor institutional conditions and the lack of reliable data, including deficiencies in the basic studies required for new urban developments, could render site suitability studies impracticable for most regions, especially at the municipal or local scale when national guidelines do not exist.

This article has two main sections. First, we present a tool that we developed for site suitability assessment of ODWTS at a regional scale, using the metropolitan area of the city of Salta (in northern Argentina) as a case study. We selected the case study by searching for an area highly comparable with other metropolitan regions in Latin America and the developing world. Salta already has several sectors with high levels of nitrate in groundwater due to the lack of proper onsite wastewater planning [34,35]. The selection of this case study is also related to the high dependence of this city and metropolitan sectors on groundwater resources. The main goal was to test a simple, reliable and easy-to-replicate method for municipal use, without the need for a large pool of variables. Second, we discuss normative and policy challenges in terms of decentralized wastewater treatment viability in metropolitan areas and their relationship with the accomplishment of the SDG6, in the context of developing countries' cities.

2. Materials and Methods

2.1. Study Area

The metropolitan area of the city of Salta (MACS) covers the mid and northern portion of the Lerma Valley and concentrates more than 50% of the population of the province of Salta in an area of approximately 600 km^2 (Figure 1). The city of Salta has a population of 535,303 inhabitants, and if the metropolitan area is considered, the population exceeds 620,000 inhabitants. According to the National Institute of Statistics and Censuses (Argentina), over the last 10 years, the population in the metropolitan area has grown by 28.8%, while that in the city of Salta has increased by 13.2%. MACS is, in fact, one of the metropolitan areas with the highest population growth in the country. MACS includes the city of Salta and several towns with strong interactivity within the metropolitan area, such as La Caldera, Vaqueros, Campo Quijano, Rosario de Lerma, Cerrillos, La Merced and San Lorenzo, each one with its own local government. The most urbanized sectors are located about 1200 m above sea level, with sectors of higher altitude in the peripheral areas. With a subtropical climate, characterized by a dry period between the months of April and November, the region has experienced unplanned urban expansion on a matrix of rural features. The development of public and private urban development projects, together with informal settlements, demands ever greater volumes of water for domestic use, in the context of an uncertain situation regarding water availability [9,36].

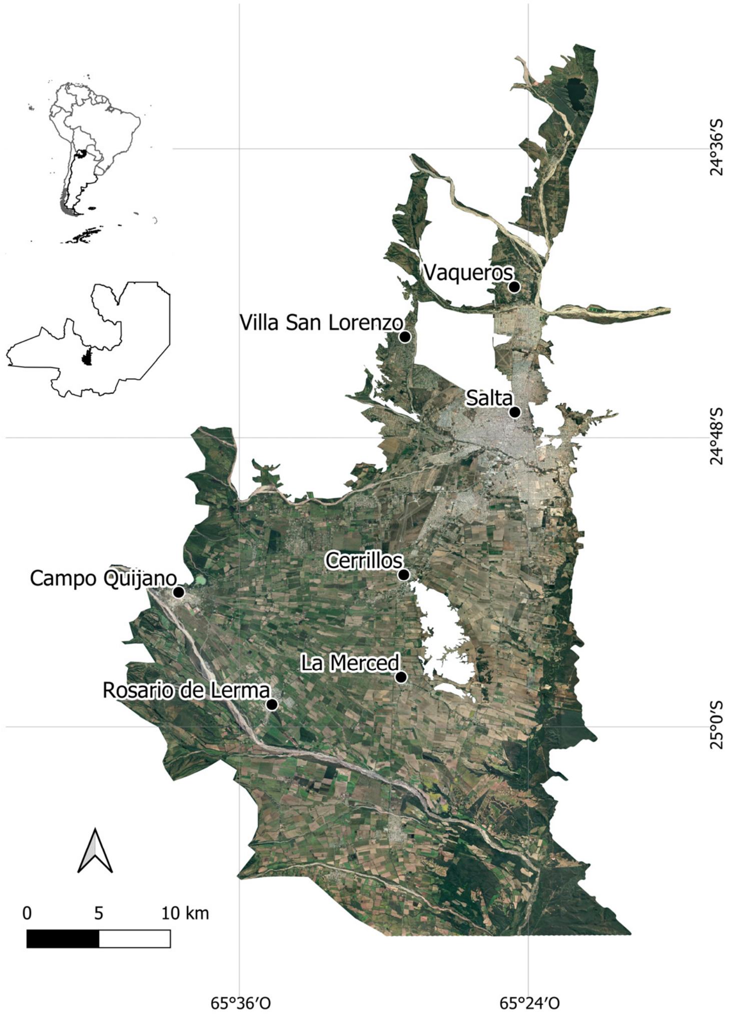

Figure 1. Metropolitan area of Lerma Valley with the detailed location of different towns (black points). On the top left is shown the specific location of the province of Salta and the study area.

Although centralized water and sanitation services have a well-established legal framework, decentralized onsite management has not been included in the legislation yet. The lack of norms and regulations has led to a situation of failure of a large (and unknown) number of systems currently in use [10]. It is well known that septic systems have an intrinsic accumulated environmental impact [37], but in Salta, septic tanks are acquired from the local market or constructed directly in place without the need for any institutional permit, legal control or monitoring process. More complex and efficient ODWTS are usually used in middle and high-income urbanized neighborhoods (e.g., gated urbanizations) due to internal requirements and greenwashing commercial strategies, but monitoring processes in this kind of urban project are still not very effective, and they suffer from unclear institutional roles. Improvements in ODWTS are mainly related to the complementation of the septic tank with anaerobic digestion and filtering steps, along with final disposal in infiltration fields instead of soakaway pits.

The expansion of urban centers and the progressive growth of urban sectors in interurban spaces have also led to significant shortcomings in basic sanitation infrastructure, especially wastewater treatment. Unplanned urbanization of dispersed urban areas has generated a grid of ODWTS without any type of location criteria, with little regulation and non-existent institutional monitoring [10]. As a consequence of this lack of wastewater treatment planning and infrastructure, long-term and severe groundwater contamination has been observed [29,30].

2.2. Spatial Decision Support System and Site Suitability Mapping

The main objective of the SDSS is the classification of the study area according to its aptitude for performing ODWTS. This process has a twofold purpose. Firstly, with the identification of "already at risk" areas, the local authority can actively develop appropriate management guidelines to manage human health and environmental risk, as well as apply urgent actions. Secondly, it identifies areas where either the density of ODWTS should not be increased or more appropriate assessment techniques need to be implemented to ascertain the most suitable ODWTS to be used [21].

Communication, collaboration and adoption for a real-world problem with prospective user groups such as municipal or local governments is a desirable target, but it can only be addressed if available tools and methodologies are accessible, understandable and viable for its adoption and integration by end users [28]. Simplicity and replicability appear to have hindered SDSS development and later adoption by intended users. There are numerous studies and vast international experience in the field [15–17,23,31,38–40], and well-known institutional and governmental guidelines from different countries, such as the Environmental Protection Agencies (EPA) from the U.S.A. and Ireland [5,20]. The number of factors suggested in most studies could be inaccessible or unmanageable for most governments in developing countries, especially at the municipal or local level. To address this problem, we attempted to obtain a balance between two main lineaments: robustness and replicability. This implies the challenge of considering as few factors as possible with the highest quality of analysis and potential replication elsewhere. In this line, we selected two types of factors, classified as Environmental and Planning ones. Figure 2 shows a flowchart with the factors used and the overall methodology stages to constructs the SDSS for urban sanitation planning. Environment-based factors constitute natural conditions in places that cannot be (or are difficult and expensive to be) modified for onsite sanitation development. Environmental factors such as soil condition or groundwater features (among others) constitute established natural conditions that urban planning needs to deal with, and although they can be modified to a certain extent, they should be taken as permanent conditioning features. On the other hand, Planning factors are mainly related to constructed or normalized things such as infrastructure design, limiting distances and constructed buildings that can be, to a certain extent, modified or redesigned over time. Planning factors analysis over environmental layer information allows one to visualize the most conflicting features of the "problem shed" or case study selected.

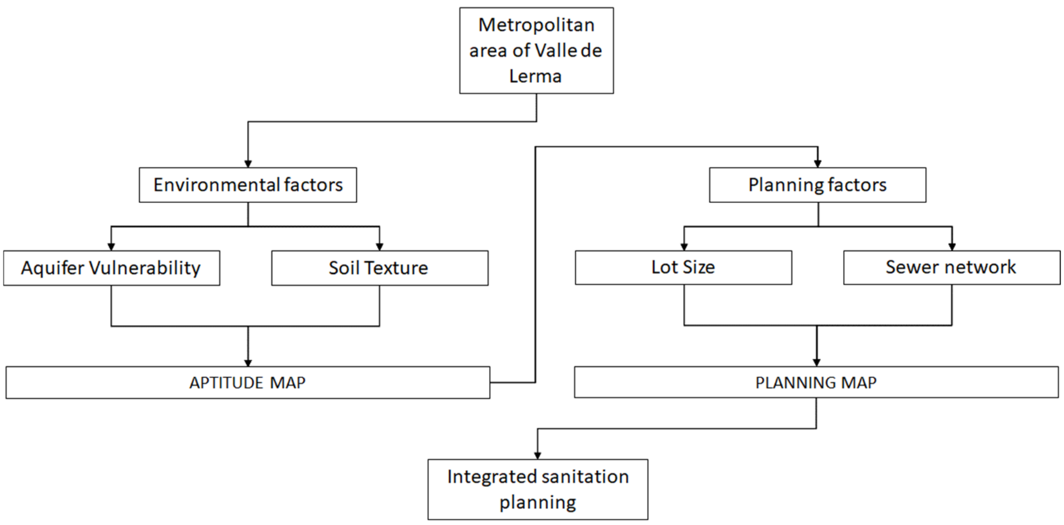

Figure 2. Methodological flow chart with factors and elements considered in the SDSS.

2.2.1. Environmental Factors

(a) Aquifer vulnerability: Aquifer vulnerability is determined by its predisposition to be affected by an external pollutant [20], and is based on the fact that some land areas are more vulnerable to groundwater contamination than others. The soil that receives the effluents from an ODWTS is the only protective barrier for groundwater resources. In areas where the water table is close to the surface, the risks of contamination with nitrates, bacteria, viruses and other contaminants is high. This multidimensional indicator was assessed earlier in the study area [41] through different physical parameters such as soil and aquifer characteristics, unsaturated zone thickness and permeability of the unsaturated zone. Aquifer vulnerability was used as one of the most important factors in site selection for ODWTS [15,21,23,31]. Aquifer vulnerability information is commonly accessible from scientific or governmental publications available for the general public. Water table distance is considered a central factor in the prevention of contamination in areas served by ODWTS [28,39,40]. This factor is mainly associated with the (environmental) water contamination risk.

(b) Soil texture: Soil type has a great impact on contaminant transportation, determining the amount of water that can infiltrate and the attenuation of contaminants stemming from an onsite system. The capacity of the soil to receive and disperse the effluent is crucial for the viability of the ODWTS [12]. The proportion of sand, silt and clay in the soil determines the drainage characteristics, the retention of nutrients, and the rate of removal of pathogenic organisms that can persist after treatment [42]. Pathogens are almost always eliminated after infiltrating in the most superficial layers of the soil. The most suitable soils will be those with intermediate textures, with good water storage capacity, nutrients and retention of microorganisms. Studies have shown that the processes of filtration and biological decomposition of the residual pollutant load present in the ODWTS effluent can be removed in the first layers of the soil [38]. Morphological features of the soil, particularly structure, texture, and consistence, are better predictors of the soil's hydraulic capacity than percolation tests [5]. This factor is mainly associated with (human) health risk. Suboptimal texture in soil could cause wastewater accumulation on surface and human contact with partially treated effluents. The texture layer used was obtained from Instituto Nacional de Tecnología Agropecuaria (Argentina's National Institute of Agricultural Technology).

The proposed environmental factors were interrelated to classify the study area in terms of environmental suitability for ODWTS use. Green, yellow and red colors represent the environmental aptitudes for planning ODWTS installation in a particular sector, based on the interaction between factors. Green shows areas with acceptable aptitude for ODWTS, yellow areas require further examination to consider their suitability and red areas do not have aptitude for installation of ODWTS and should be treated with a centralized sewerage system. The chart in Figure 3 shows all the possible combinations between soil texture categories (Loam, Silt Loam, Clay Loam, Sandy and Clayey) and aquifer vulnerability categories (Low, Medium and High). The interactions between categories define 15 potential environmental aptitude classifications for each area that were named by a Code. A brief technical description of all possible Codes and its general environmental limitations is included in Table 1.

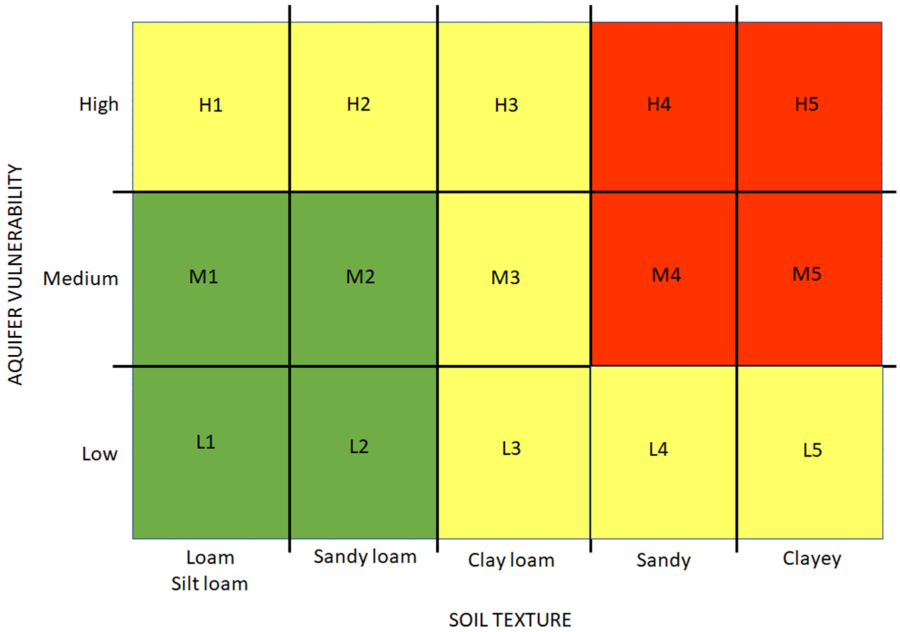

Figure 3. Possible combinations between soil texture and aquifer vulnerability categories. Green: acceptable aptitude for ODWST, Yellow: further examination is needed, Red: no suitable for ODWTS. The codification of Aptitude factors is described in detail in Table 1.

Table 1. Classification codes for onsite wastewater planning.

Code	Brief Description of the Aptitude and Limitations for Onsite Wastewater Treatment
L1	The soil and the vulnerability of the aquifer are optimal for decentralized treatment.
L2	Although the soil may show somewhat high infiltration rates, the aquifer's characteristics are optimal for decentralized treatment.
M1	The site shows good aptitude for decentralized treatment due to an optimal soil condition, although the aquifer has medium vulnerability.
M2	Although the soil texture and aquifer vulnerability are not optimal, general conditions still show a good aptitude for onsite wastewater treatment.
H1	Despite the good soil conditions, the high vulnerability of the aquifer requires additional studies to determine the capacity of the site for onsite wastewater treatment.
H2	Due to the high vulnerability and suboptimal soil conditions, additional studies are necessary before planning decentralized treatment.
H3	Need for additional studies due to high vulnerability and/or possible soil limitations for onsite wastewater treatment.
M3	Need for additional studies due to high vulnerability and/or possible soil limitations for effluent infiltration.
L3	Low aquifer vulnerability, but it is necessary to deepen the soil assessment in order to check for potential soil limitations for onsite wastewater treatment.
L4	Low aquifer vulnerability, but it is necessary to deepen the soil assessment in order to check for potential soil limitations for onsite wastewater treatment.
L5	Low aquifer vulnerability, but the soil infiltration capacity may be limited. More studies are needed to confirm onsite wastewater viability.
H4	The use of onsite wastewater treatment is not recommended due to the high risk of groundwater contamination.
M4	The use of onsite wastewater treatment is not recommended due to the high risk of groundwater contamination.
H5	The use of onsite wastewater treatment is not recommended due to the high risk of groundwater contamination and the strong limitations of the soil.
M5	The use of onsite wastewater treatment is not recommended due to the high risk of groundwater contamination and the strong limitations of the soil.

2.2.2. Planning Factors

(a) Lot size: Decentralized wastewater management systems are appropriate for low-density communities [5]. Like any planning factor, lot size depends on urban planning and can, therefore, be managed over time. However, inaccurate management could become problematic. Lot size has a direct influence on groundwater contamination risks in decentralized sanitation [37,40,43,44], and must be sufficient to allow proper treatment, natural attenuation and dispersal of discharged treated wastewater in soil. Smaller lot sizes may not provide enough space to establish a properly sized soil infiltration system. In some countries, lot sizes less than 0.4 hectares were considered to be inappropriate or to pose some risk of soil infiltration [21,31]. In the United States, for instance, a lot size smaller than 0.2 hectares is considered unsuitable for ODWTS use [23]. Studies show a strong correlation between nitrogen and pathogen concentrations in groundwater in high densities of decentralized treatment systems [45]. Nitrogen from ODWTS is not efficiently removed by the soil, so the only way to prevent aquifer contamination is by reducing housing density [5]. In sectors more densely populated or with poor environmental conditions for ODWTS, cluster systems (a limited sewer network with an exclusive wastewater treatment plant for a neighborhood) are more reliable options. In this work we proposed a lot size of 0.10 hectares to be considered a minimum acceptable size for ODWTS use [31]. A lot size of 0.10 hectares is usual in metropolitan sectors of the study area, and we think that it could be considered an achievable minimal target. Lot size layers were obtained from Dirección General de Inmuebles de la provincia de Salta (the official real estate agency of Salta Province, updated in 2020).

(b) Sewer network: This factor is considered one of the most important elements for urban sanitation planning. Visualization of sewer networks' coverage allows an overall estimation of most critical areas where wastewater collection is lacking and where secure decentralized wastewater treatment options are inescapable. The overlay of this factor with environmental conditions could also highlight strong failures, conflicts and inequities caused by the unplanned urban sprawl process. Previous works in this field used distances between urban developments and existing sewer networks as a key indicator for wastewater treatment planning [23,31]. The layer used in this work was provided by Salta's Water and Wastewater Company (CoSAySa), updated in 2020.

2.3. Critical Areas Identification

During the process of overlapping environmental and planning factors, critical areas were identified. These sectors were chosen in order to deeper the analysis of the outcomes of the model in particular places. The selection follows two main rules: (1) sectors where an incipient urbanization is combined with the absence of sewer networks and low aptitude areas for ODWTS installation, (2) availability of scientific background regarding linkages between groundwater contamination and incompatible urban planning. As a complement, field verification visits were carried out in different sectors of the study area, attempting to identify potential deviations of the model outcomes.

3. Results and Discussions

3.1. Aptitude for ODWTS

The Aptitude map resulting from the interaction of environmental factors (Figure 4) shows that there are important sectors with suitable conditions for ODWTS planning (see Figure 4c). These sectors present an acceptable combination of aquifer vulnerability with adequate soil textures for the final transmission of the effluents to the soil. The sectors with the highest potential for ODWTS use are large sectors in the south of the study area, currently not served by sewer networks (see Figure 4c). In these areas the environmental conditions allow the planning of ODWTS as a valid and potentially long-term solution for domestic wastewater treatment. Loamy soils in combination with an adequate depth of the aquifer reduce the risks of contamination of groundwater and, at the same time, configure a good soil capacity to receive and treat residual contaminants that can resist ODWTS overall treatment, especially nutrients and pathogens [5]. The worst areas for ODWTS (in red) were located in the southwestern and northern sectors of the metropolitan area, both coincident with well-known aquifer recharge areas and thick soil textures. Currently, in the urban area of Salta, the dynamic piezometric levels are, on average, between 10 and 50 m lower than those registered 50 years ago, increasing the risk of a downward flow, which would produce the entry of pollutants into deep reservoirs. Yellow areas (medium aptitude) represent sectors where environmental conditions are not ideal for onsite wastewater treatment and a more in-depth field assessment is needed.

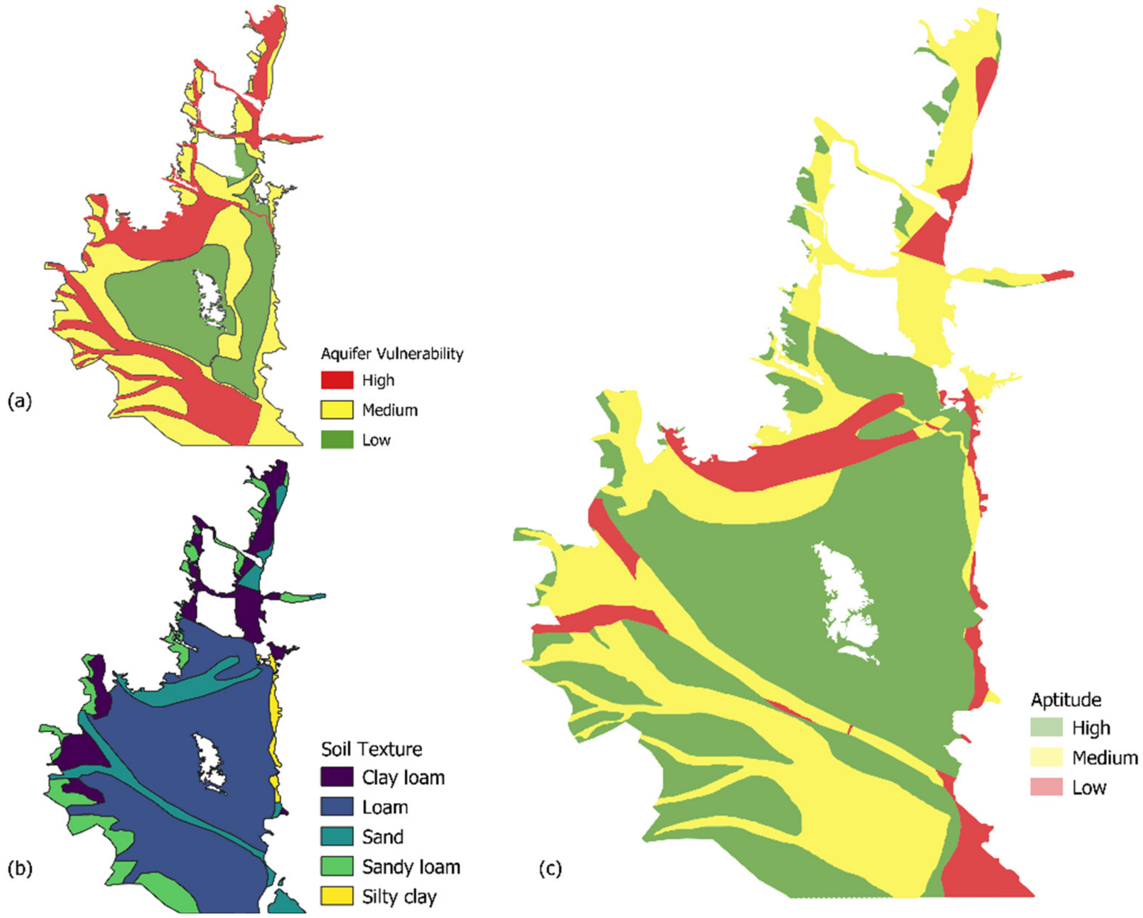

Figure 4. Aptitude map for ODWTS combining Environmental factors. (**a**) Aquifer vulnerability; (**b**) Soil texture; (**c**) Aptitude map for ODWTS installation.

Overlapping the Planning variables and the Aptitude Map shows a critical situation in several sectors. Residential areas have advanced during the last several decades over suburban areas without available sewer networks. Urban form and housing types are varied in terms of density and structure, and there is no alternative but to adopt ODWTS due to a lack of other options for sanitation. Many of these sectors also have a low aptitude for onsite wastewater treatment. Figure 5 shows the advance of urban sectors (in black) over the study area, and the different speed of development regarding sewer networks (in blue). The most critical situations occur in densified urban areas growing in low aptitude sectors for ODWTS combined with the absence of sewer networks (see in Figure 5a,b, for instance). These sectors configure a point of no return for urban sanitation planning, requiring short-term actions to mitigate the risk of human health and environ-mental contamination. The distance between new conglomerates and existing sewer net-works renders the connection very costly, being a crucial decision factor for sanitation planning. In addition, available centralized treatment plants are usually exceeded in their treatment capacity and adding more wastewater volumes from new urban sectors will only make the problem worse. The concentration of urban areas not served by sewer net-works in low aptitude sectors is not only a consequence of the absence of proper urban planning but also a sanitation policy focused on the centralized service and devoid of cri-teria based on environmental factors.

The areas of interest (AOI) selected (Figure 5a,b) are shown in more detail in Figure 6. These sectors were also chosen for testing the SDSS model against evidence from local research. In both cases there are already strong signs of the linkages between groundwater contamination and the incompatibility of local environmental and planning conditions for ODWTS. Urbanized areas have expanded without planning over areas associated with aquifer recharge zones, affecting the quality of groundwater with a high concentration of nitrates and pathogens. Problems worsen due to the non-existence of ODWTS monitoring, poor operation and over-densification. The northern part of the metropolitan area (Figure 6a) illustrates a serious situation resulting from the lack of sewer networks and the high density of lots having ODWTS. Codes presented in the red zone (M4 and H4) limit the use of onsite wastewater treatment due to the high risk of groundwater contamination (see Figure 3 and Table 1).

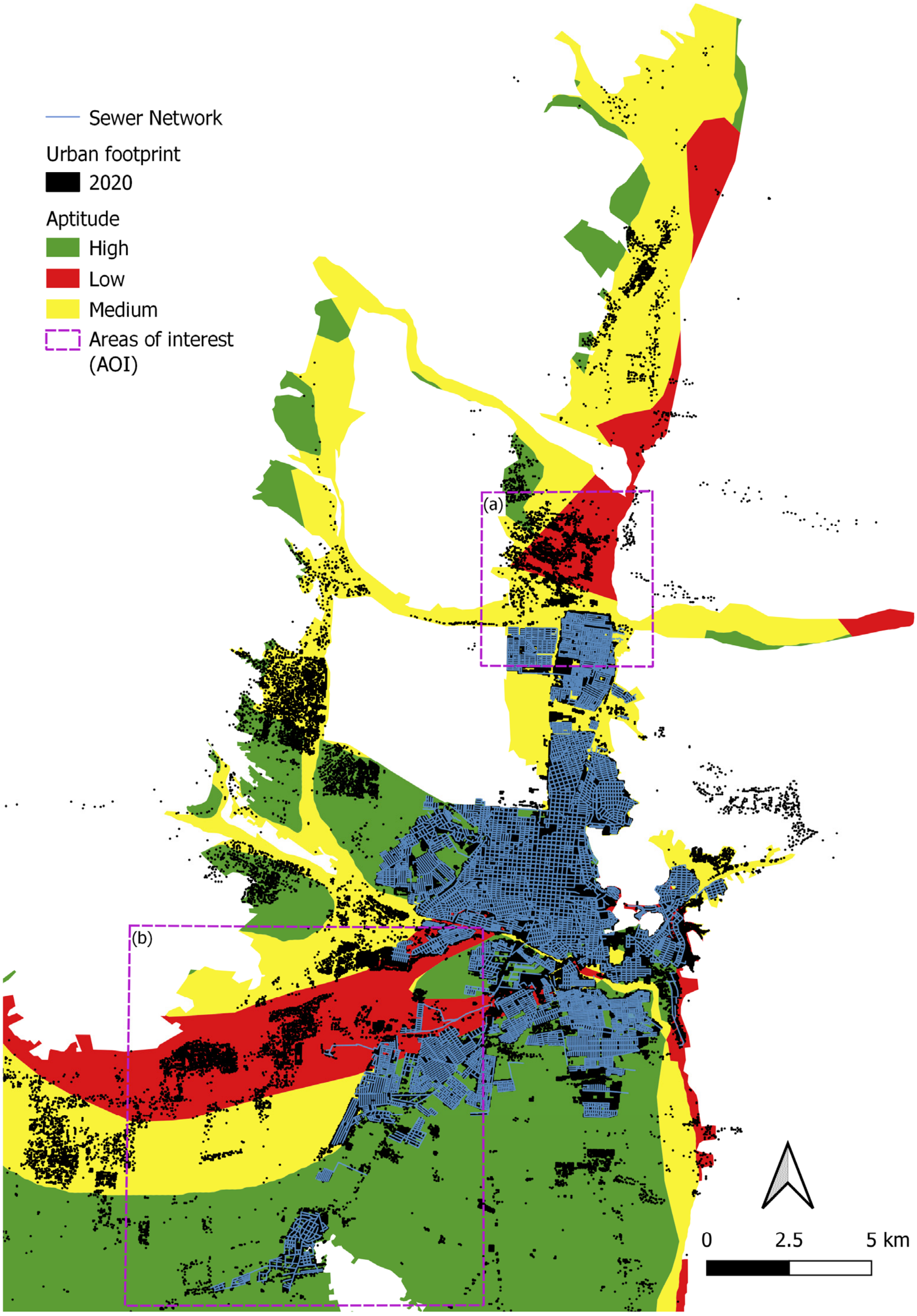

Figure 5. Aptitude map with urban areas and sewer network. AOI (**a**) and (**b**) are described in more detail in Figure 6.

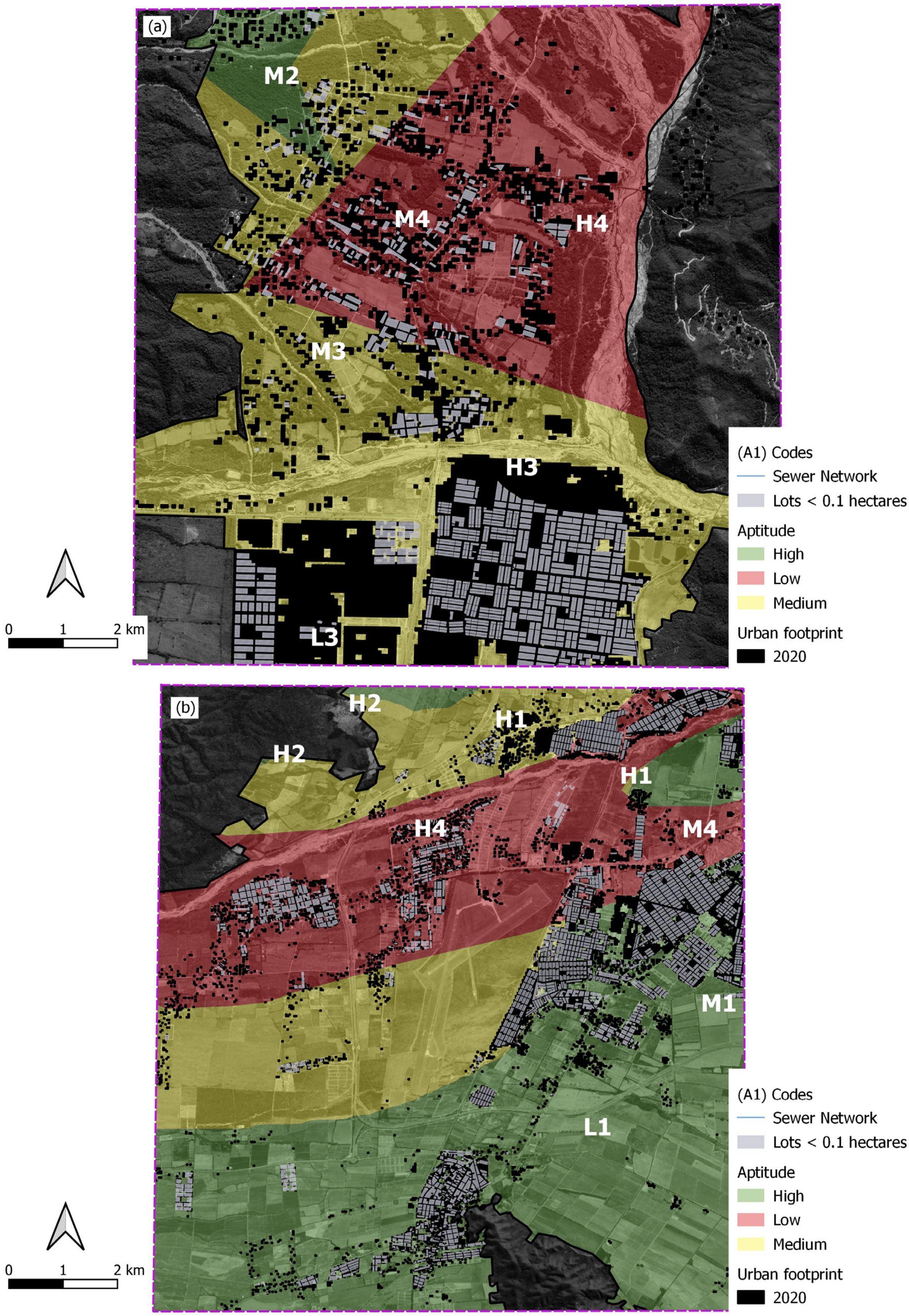

Figure 6. Detailed pictures of the selected AOI (**a**) and (**b**) in the Planning Map. Urban footprint and lots sizes less than 0.10 hectares are showed. For more details regarding presented codes please see Table 1.

Recent assessments in the area evidenced serious contamination of the shallow aquifer as a consequence of the lack of control of the ODWTS and the suboptimal Environmental and Planning Factors [9,30,46]. The sector is the recharge zone of La Caldera aquifer, which supplies water not only to the town of Vaqueros, but also to the north of the city of Salta, through extraction wells. In the sector located in the west of the study area (Figure 6b), the aquifer is already contaminated with nitrates and pathogens [47,48], as a consequence of sandy textures combined with high aquifer vulnerability. Codes presented in Figure 6b shows that the most important limitations are related to the coarse soils combined with high and medium aquifer vulnerability (H4, M4). This aquifer (called Arenales) is one of the most important water resources for the southern urban sectors of the study area and its importance will be greater in the future when urban areas continue to expand in this sector. Lot size is one of the most important issues in both sectors. Lots sizes less than 0.1 hectares have proliferated in these areas, which is considered a high-risk situation for human health and the local environment [31]. Now, this problem is very hard to solve without expensive investments in new sewer networks. Complementary, urgent actions must be taken to mitigate the impacts of OTWS failure until centralized infrastructure is built.

3.2. Onsite Wastewater Treatment and SDG6 Achievement

A common situation in most metropolitan areas of developing countries is the existence of a mixture of urbanized and non-urbanized sectors with different environmental and built features. The interaction of environmental conditions with urbanized areas and their wastewater related infrastructure exhibits critical areas where urgent actions must be taken in order to integrate natural conditions and sanitation strategies. The SDG6 is actually poorly measured by Argentine programs because only the centralized conception of sanitation is considered. Evidence of this is that the local SDG measurement program for Target 6.2 states that by 2030 the country must “achieve access to adequate and equitable sanitation and hygiene services for all and end open defecation. . . ” (https://www.argentina.gob.ar/objetivos-de-desarrollo-sostenible-ods/nacion, accessed on 13 June 2021), but this Target is measured only by the “Percentage of the urban population covered by sewer networks”.

The target of secure sanitation for all by 2030 urges us to think beyond centralized networks if we are to address the inescapable need for an adequate and universal treatment of domestic wastewater. Due to the (short-term) high investment needed to bring centralized sanitation services to unserved suburban and rural areas, the SDG6 will be fulfilled only if decentralized sanitation is formally integrated into urban planning. If environmental factors viable with ODWTS planning are missed due to the non-compatible urbanization features, the opportunity for well-planned decentralized sanitation could be missed and conventional and more expensive centralized infrastructure will become the only option for sanitation security. High-aptitude sectors, as shown in this case study, need to be identified early and they require special attention as they are the most important opportunities for SDG6 achievement in a decentralized management context. Unfortunately, the current scenario is not encouraging in most Latin American countries, where the formal inclusion of decentralized management in legislation is currently an unfulfilled task [18]. The inclusion will allow potential investment savings in centralized networks, more opportunities for wastewater reuse, and health and environmental risk minimization [16]. However, the achievement of SDG also requires an appropriate monitoring process supported by state-led institutions, besides private sector engagement.

In Figure 7 we present a simple to use flowchart to guide planning decisions based on SDSS outcomes. As stated above, compatible environmental factors allow secure onsite treatment and management to be implemented. When environmental factors are not compatible (low aptitude), these areas should ideally be urbanized only when centralized networks are available. A clustered sewer network, defined as a sewer infrastructure for a spatially limited urbanized area (a private neighborhood, for instance) connected to an exclusive treatment plant is a viable alternative [5]. However, clustered wastewater management generally requires different institutional arrangements between users and controllers. This alternative may also demand a greater complexity in the selection process of a suitable location for a middle-sized treatment plant within the boundaries of the private area of the neighborhood, the organization of the maintenance activities among many users, and the coordination of monitoring tasks with governmental agencies. Unplanned urbanizations lacking sewer infrastructure in low-aptitude areas is a very common scenario in our case study and other metropolitan areas of Argentina, as well as comparable developing countries. This scenario shows the need for urgent investments in new centralized sewer networks or the proper expansion of existent ones in order to limit environmental and human health risks. The potential impacts of unregulated ODWTS in low-aptitude sectors worsen with increasing housing density.

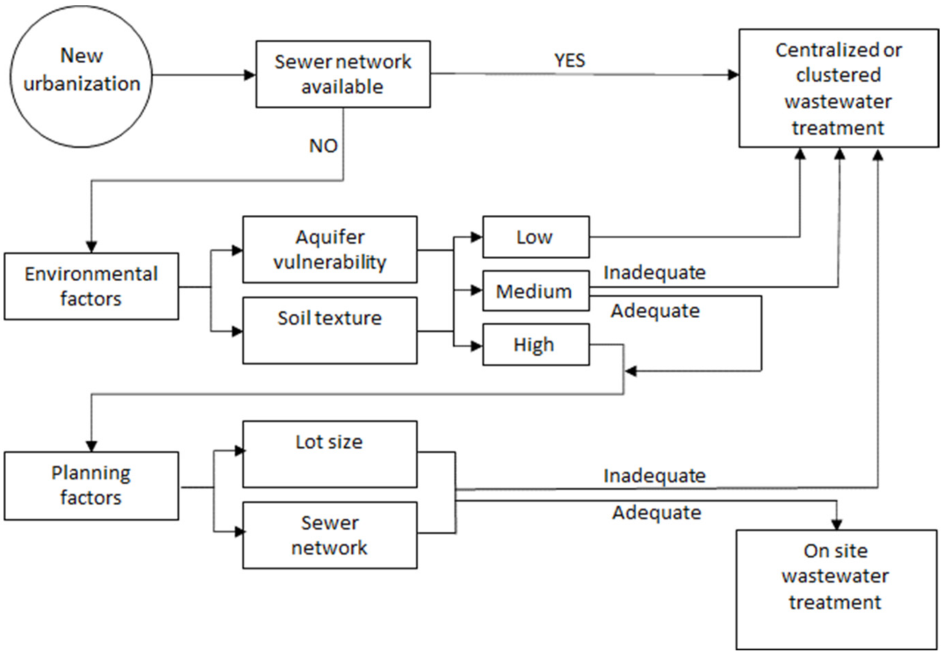

Figure 7. Flowchart to guide planning decisions based on SDSS.

Less restricted scenarios for the installation of ODWTS are the medium aptitude areas (yellow), also configuring a potential opportunity for wastewater treatment decentralization. A field evaluation could result in recategorization to high aptitude or, if medium suitability is confirmed, some alternatives could be the installation of high performance ODWTS or mechanical field improvements. Alternative onsite systems are becoming more common in areas with high water tables or soils unsuitable for conventional septic drain fields and for enhanced nutrient removal [16]. However, field improvements are only feasible at a limited scale and results are better when they are combined with high-performance ODWTS. High-performance ODWTS have the disadvantage that they are more expensive and complex to manage.

Early identification of high aptitude areas is the most important challenge for onsite sanitation planning. Achieving sustainable management in such areas implies a good balance among non-modifiable (or hard to modify) environmental factors and adaptable man-made planning factors. Lot size control is paramount for reliable and secure long-term onsite sanitation. Even if ODWTS are well designed and managed, the well-known limitation of basic septic systems in terms of nitrogen and pathogen removal efficiency is one of the most important limitations [5]. Once in the soil, pathogens are removed after infiltrating a few meters of soil but nitrogen is not sufficiently removed and sooner or later will affect groundwater quality. Lot sizes bigger than 0.1 hectares could be considered a minimum threshold and the normalization of this factor is key to maintaining a safe housing density [31].

3.3. Policy Challenges for Onsite Wastewater Treatment Implementation

Decentralized wastewater treatment management in most developing countries needs to migrate from a conjunctural and informal solution implemented as a consequence of the lack of centralized wastewater infrastructure to a planned and formal long-term technological alternative. Replicable and simple SDSS could be a useful tool for local governments to gather some technical information for the implementation of better planned onsite sanitation. Despite their potential, the implementation of SDSS is challenging at the local level, and some studies have found low adoption even when the tool is pilot tested in close collaboration with final users [28]. The potential instrumentation of SDSS in local governments and management institutions will be coupled to its simplicity, replicability and reliability, but socio-political factors also constitute an important dimension that can slow progress. Local governments regularly lack sufficient information about ODWTS use and environment-related aspects, especially in developing countries, and hence a technical tool such as the one presented in this study could support local governments' decisions and urban policy development [12].

A more comprehensive and integrated sanitation strategy in our case study and other comparable metropolitan areas demands urgent policy actions. First of all, the optimization of existing centralized sewer networks is a key issue due to the high environmental impact of leaks and other structural problems [49]. A simple SDSS, such as the one presented in this work, could be useful for the selection of critical areas where sewer networks are essential and unavoidable. The capacity to expand existing sewer networks to unserved areas and increase the treatment capacity of installed wastewater treatment plants is very limited in most of the developing world. Instead, financial efforts should be focused on the most neglected and informal neighborhoods, often peripheral to the served urban sectors and with high housing density. It is clear that the decentralized approach is not in conflict with the centralized one. In fact, integrating (fully decentralized) onsite sanitation into urban planning is also an opportunity for more reliable (centralized) conventional systems. Both system configurations are applicable to different situations, and it is up to sector managers to decide which system better applies to different environmental and planning contexts. Hybrid solutions could be applicable in some cases where too-densified sectors become non-viable for onsite septic options, allowing the septic systems to remain in use while collecting the effluent by sewer network. In these particular cases, if viable, the investment in a centralized treatment plant could be less due to pre-treatment in existent septic systems. Thus, it appears that the definition of the ideal system to be implemented in an area is linked to a deep analysis of regional characteristics, the evaluation of existing facilities and the specific demands of the population served [17].

It is necessary to relinquish the idea that in the future, the provision of drinking water and sanitation in metropolitan regions will be given only through the model of large networks. Rather, the image will correspond to "infrastructure islands", where large-scale planning models interact with local daily supply practices, adapted to the realities of each settlement [50]. The success of a decentralized management program for urban areas will depend largely on institutional support. The use of the decentralized approach is more convenient when (1) the population is located in rural, peri-urban or low-density regions; (2) when the community, condominium or housing development is located far from an existing sewage collection and treatment system; (3) when there are local opportunities and demands for water reuse; and (4) when existing centralized systems do not have the capacity to serve the entire population and resources for expansion are limited [51]. The identification and mitigation of malfunctioning and/or obsolete ODWTS is a management challenge faced by local governments [16]. Successful integration of onsite treatment and the implementation of SDSS will become operational by adding decentralized components into regulatory frameworks in order to normalize basic configurations for ODWTS, installation requirements and monitoring responsibilities, among other aspects. The use of these technologies lacks federal regulation that defines the responsibility for managing the systems [18]. Responsibilities are more distributed, diffuse and often lack clarity and accountability processes, and data availability is often partial and/or inadequate [52]. There already exists a well-known body of technical, normative information and guidelines from several governments and institutions around the world, which confirms that the root problem is more associated with political and planning capacities than with the lack of technical knowledge. The regulation of ODWTS could have a significant economic and environmental impact; on the one hand, it would decrease the cost and maintenance of sanitation infrastructure and, on the other, it would enable the concentration of economic efforts on the maintenance and improvement of centralized systems in the most densified and unserved peri-urban areas, thus increasing the social impact of the limited available financial resources for new centralized infrastructure. Creating new regulations that include ODWTS as a formal alternative is also a clear advantage for SDG6 achievement. Stronger institutional rules, users' incentives and education, monitoring plans and strengthening of human and economic capital by local governments are unavoidable. However, pursuing unreachable standards could lead to decentralized planning failure after the first advances and generate rejection from both users and decision makers. The most appropriate technology is the technology that is affordable, environmentally sustainable and socially acceptable [6]. The community should be able to afford ODWTS that are compatible with the local environmental conditions, including long-term operation and maintenance. Institutional strengthening and administrative reforms must be coupled with user participation. The social perspectives and knowledge of policymakers, environmental professionals and final users about decentralized wastewater treatment are also an important issue that requires further analysis. Technologies are not intrinsically sustainable if they are disconnected from users' perspectives and from the settings in which they are to be utilized [10].

Although they are based on only two factors, aptitude maps, as presented in this study, could in some cases still be difficult to obtain at the local institutional level, especially in developing countries. When technical information about aquifer vulnerability and soil texture are unavailable, a field verification task is sufficient to bring enough information to construct a SDSS for local level use. Field verification also is central for checking possible local inconsistencies of the model due to data layers or the scale used. Under the current scenario of unregulated and uncontrolled use of decentralized wastewater treatment technologies, urgent action from local management institutions is needed to establish a basic set of best practices in this field. It is important for planning to determine early on whether ODWTS are a conjunctural and temporary bridge to centralized systems within a clear timeframe, or permanent sanitation infrastructure [14].

4. Conclusions

The results of this study suggest that an Aptitude Map constructed using a few environmental factors could be useful for identifying distinctive areas for onsite wastewater treatment planning. By superimposing Planning factors such as lot size (as an indicator of housing density) and current (or also planned) sewer network coverage, a reliable outline of the most critical areas can be achieved. Sustainable onsite wastewater integration must include at least proper location studies, proper design (and the related economic aspects), monitoring and control issues, technical information availability at the local level and environmental education among institutional officials and final users. This work mainly deals with the first aspect, but the others need to be addressed in a more comprehensive way. However, in cases where technical information about aquifer vulnerability and soil texture is also unavailable, a field verification task is sufficient to collect enough local information to construct a SDSS. Experiences and studies with more complex SDSS are available around the word, but may not be appropriate at the municipal level or where basic data, technical knowledge and/or legislation are incomplete or fully lacking.

For sustainable implementation in developing countries, it is necessary to align land-use plans with water resource planning, taking into account the land uses, economic activities, spatial distribution, and the geographical features of metropolitan and suburban areas to determine the level of desired decentralization and evaluate the reuse potential in each sector. However, this implies reforms at the administrative and legal levels to promote decentralization as a solution not only for deficiencies in basic sanitation coverage but also as an alternative for economic return or added value through a resource-based sanitation approach. Enhancing and promoting an open governance process, including planning, development and management, can facilitate effective co-production of knowledge for sustainable infrastructure across diverse places and communities. The development and management of sustainable metropolitan sanitation infrastructure must focus on interactions across urban and rural environments. A research agenda focusing on urban–rural infrastructure systems, decision-making, institutional arrangements and effective co-production of knowledge is a priority for better knowledge of the complex socio-political limitations for sustainable and equitable sanitation in developing countries [53].

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