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Development of a Multicriteria Scheme for the Identification of Strategic Areas for SUDS Implementation: A Case Study from Gijón, Spain

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Abstract: Spain has been pinpointed as one of the European countries at major risk of extreme urban events. Thus, Spanish cities pursue new urban plans to increase their resilience. In this scenario, experiences in the implementation of Sustainable Urban Drainage Systems (SUDS) have increased substantially. Nevertheless, few cities have developed a global urban strategy for SUDS, lacking, in many cases, a method to identify strategic areas to maximize their synergetic benefits. Furthermore, there is still a need for a holistic Multicriteria Decision Analysis (MCDA) framework that considers the four pillars of SUDS design. The city of Gijón, NW Spain, has been selected as a case study due to its environmental and climatic stresses. This research presents the methodology developed for this city, which aims to analyze the need for SUDS implementation throughout the identification of strategic areas. With this aim, a combination of Geographic Information System (GIS) software and the MCDA Analytical Hierarchical Process (AHP) were proposed. The results show the potential for SUDS' implementation, according to nine criteria related to the SUDS' design pillars. We found that the areas where the implementation of SUDS would bring the greatest functional, environmental and social benefits are mainly located in consolidated urban areas.

Keywords: bio-urbanism; smart and resilient water cities; NBS; urban drainage planning; MCDA; AHP; SUDS location

1. Introduction

The increasing population of the world and migration from rural areas has caused a process of rapid urbanization. In 1950, 30% of the human population lived in urban areas, increasing up to 55% by 2018, and being projected to reach 68% by 2050 as depicted in the United Nations' (UN) latest study [1]. Large urban areas in Spain of over 50,000 inhabitants are home to 68% of the Spanish population [2,3]. As the urban areas grow and more land is used for human activities, the hydrologic functions of the natural water cycle become increasingly altered [4]. This urbanization process creates impervious surfaces and compacted soils that negatively impacts stormwater runoff characteristics and decreases their infiltration capacity, influencing groundwater recharge, evaporation and evapotranspiration [5,6]. In addition, numerous studies have shown that impervious surfaces are one of

the main causes for the generation of large volumes of surface runoff [7–10]. Besides, the frequency and intensity of extreme rainfall events have intensified as a result of climate change effects and are expected to continue rising in the upcoming years [11,12]. These changes denote that sewer surcharge or flooding events will occur more frequently, which will pose a significant footprint on future urban water management and planning [13]. Then, stormwater management represents a crucial element for the enhancement of urban resilience due to the escalation of unpredictability in storm events and their adverse effects on the environment, economy and society in urban areas [14,15].

Traditional urban stormwater management could be described as a single-objective oriented design with the aim to rapidly drain runoff water triggered during a rainfall event to the receiving environment or the treatment system [16,17]. However, when a high intensity rainfall event occurs, there is usually an imbalance between the capacity of the conventional drainage system and the amount of surface runoff generated, leading to an increased risk of flooding, especially in large urbanized areas with a high population density [18]. Moreover, this scenario contributes to a deterioration of the water quality in cities and, consequently, causes a reduction in the quality of receiving natural waters, particularly during the first flush event [19]. Conventional drainage system decay has become a serious problem in Spain, because the majority of the combined sewer system is beyond their operational life [20,21]. Along these lines, drainage malfunctions cause serious issues that impact public health and safety, and the subsequent infringement of the Directive 91/271/EEC of 21 May 1991, concerning urban waste treatment [22,23].

In this context, a complex legislative framework of directives, policies, communications and reports have been outlined over the most recent decades, intending to address this wide range of stresses both in urban and rural areas, promoting natural environments and improving urban resilience [24,25]. All the UN member states approved the 2030 Agenda for Sustainable Development in 2015. This document brings climate change forward as an essential element for sustainable development [26]. Further extending this logic, the Sustainable Development Goal 11 is about making “... cities and human settlements inclusive, safe, resilient and sustainable” [27]. In addition, the UN Sendai Framework for Disaster Risk Reduction 2015–2030 and the Spanish Urban Agenda emphasize the need to adopt and implement integrated policies and plans in cities towards the mitigation and adaptation to climate change effects alongside an increase in resilience to disasters [28,29].

Lately, urban flooding due to storm events, has been reported to be the primary risk to urban resilience [30]. Thus, a transition towards a paradigm shift in urban water management is increasingly necessary [31]. A commonly accepted definition for this new “integrated” and “sustainable” water management paradigm is “An approach to urban planning and design that integrates the management of the total water cycle into the urban development process” [32]. There are a number of frameworks which seek to implement this paradigm shift in stormwater management, highlighting Water Sensitive Urban Design (WSUD), the Adaptive Water Resources Management (AWM or AWRM) or the Integrated Urban Resource Management [33–36], amongst others.

These frameworks present associated concepts that vary between countries, presenting similarities nonetheless, for instance, the concepts of environmental protection and the deployment of decentralized water-reuse infrastructure. However, IUWM has a broader scope, encompassing water security, maintenance of environmental flows, energy, social equity, etc. [37–39]. Then, the problem tends to be ambiguous, which makes it difficult for urban water management agencies to implement these philosophies [40]. In addition, some of the major barriers to integrate these frameworks in the urban agenda are outlined, as follows: lack of political will and long-term planning, lack of regulatory incentives, poor communication between practitioners and regulators, limited previous experience, and, therefore, demand for increased capital and improved operations, increased maintenance costs and a need for performance efficacy [38,41]. One of the main sustainable solutions that have emerged to increase urban resilience, playing a key role in the implementation

of these philosophies, are the so-called Nature-Based Solutions (NBS), which are inspired, supported or copied from nature [42,43].

Sustainable Urban Drainage Systems (SUDS) are the main NBS techniques utilized to improve urban stormwater management, as well as to address the EU guidelines proposed by the Water Framework Directive (WFD) [14,44]. The implementation of SUDS also contributes to the achievement of the objectives established in the European Green Deal and the EU Biodiversity Strategy for 2030 [45,46]. These techniques emerged with the main purpose of mitigating the effects of climate change, reducing the alteration of the natural hydrological cycle of cities and the inefficiencies of the conventional drainage system. Furthermore, SUDS contribute to bring the concept of 'natural' back, recovering water processes in the urban environment such as infiltration, transport, storage and retention, amongst others [47], helping in laminating stormwater volumes, retaining and treating surface runoff pollutants. SUDS are well-known to offer a wide range of additional benefits such as: the improvement of public health, the provision of amenity values in the targeted areas, the supply of recreational spaces, the support of local ecology and biodiversity and carbon sequestration [48]. In addition, they have been extensively reported under varying conceptual names, highlighting the following ones: SUDS in the United Kingdom and Spain; Low Impact Development (LID), Stormwater Control Measures (SCM) and stormwater Best Management Practices (BMPs) in the United States; and Water Sensitive Urban Design (WSUD) in Australia [16,40].

The main SUDS techniques featured in the literature are green roofs, permeable pavements, bioretention areas and raingardens, ponds, swales and dry basins, amongst others [49]. On the other hand, infiltration trenches, porous pavements, rain barrels and wetlands have been also investigated in a lower degree of detail [50]. Therefore, SUDS have gained trust as key elements for urban flood control, becoming the most utilized drainage techniques to successfully adapt urban areas to these present and future climate challenges [51]. Nevertheless, there are some institutional factors limiting the implementation of SUDS, such as weak legislative backing, private commercial interests and the lack of resources in local authorities [52]. It is important to carry out interdisciplinary studies and holistic analyses of these techniques in their implementation and operation in urban areas. One of the fundamental aspects is the collaboration between researchers, stakeholders, public administration and communities [53]. The lack of transversal methodologies that allow the implementation of these techniques, from an integrative urban planning viewpoint, contributes towards the reduction of the beneficial effects provided by SUDS [14]. As a consequence, this issue has become central for administrators and academics involved in stormwater management and urban planning [54].

SUDS' selection, design and location is a high-level complex problem under the above-mentioned scenario. Thus, the modelling through the use of decision-making tools such as multi-criteria matrices and the optimization tools are paramount in order to efficiently locate SUDS, as well as to predict their behavior, whilst appraising their impact on the urban system [55]. Different Multi-criteria Decision Analysis (MCDA) have been reported to be implemented for the evaluation of stormwater management in dense urban areas, noting the following: Multi-Attribute Utility Theory (MAUT) [56], Multi-Attribute Value Theory (MAVT) [56], Analytical Hierarchy Process (AHP) [57], fuzzy AHP [58], Analytic Network Process (ANP) [59], fuzzy logic [60], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [61], fuzzy TOPSIS [58], Simple Additive Weighting Model (SAW) [62], Elimination and Choice Expressing the Reality (ELECTRE) [63], and PROMETHEE-GAIA [63]. One of the most popular is the AHP model [56,63–65], becoming the most common GIS-MCDA used for flood susceptibility analysis [66,67]. Various researchers have applied the weighted linear combination of GIS with AHP in this context [54,57,66,68,69]. AHP is a linear additive method based on pairwise comparison. Therefore, the results of this process are preference matrices, one for each criterion, which depicts the relative performance of each alternative according to that specific criterion [70,71].

Therefore, GIS-MCDA techniques have the most potential to serve the implementation of SUDS within urban planning purposes, due to their ability to reflect stakeholder preferences, to compute massive data, to visualize the results and due to its ease of use [72]. Although several GIS-MCDA tools can be found in the literature, most of them focus on functional aspects, where the target is to determine which SUDS typologies are the most suitable for a particular area of interest [60,73]. However, this study proposes a systematic geospatial framework combining an open-source GIS called Quantum GIS (QGIS) with AHP, where the main objective is to determine which areas have the greatest potential and constraints for SUDS implementation. This process of identification of suitable and unsuitable areas for SUDS implementation has been developed in a specific case study in which the four pillars of SUDS design (water quantity, water quality, amenity and biodiversity) have been considered [74].

In addition, the regulatory and policy framework connected to the case study were studied and considered in the operational process for the development of the framework to be used as part of the tool to support the planning for SUDS implementation.

The developed methodology was applied to the city of Gijón as a case study. This city was a suitable candidate as a consequence of the activities inherent to this industrial heritage and also due to significant problems reported in the stormwater management through the city's drainage and wastewater treatment system, resulting in an increasing number of episodes of flooding and water pollution [23].

2. Materials and Methods

2.1. Study Area

The selected case study subject was the city of Gijón, located on the northwest coast of Spain, with more than 270,000 inhabitants and a total area of 182.2 km², being the most populated city in the Principality of Asturias. Gijón presents an oceanic climate, which is characterized by well-distributed rainfall throughout the year, an average annual rainfall of 958 mm and an average annual temperature of 13.9 °C [75]. Gijón experienced a great deal of activity in the industrial and mining sectors during the 20th century. However, nowadays it has a wide variety of land uses such as residential, highly urbanized consolidated areas, commercial, industrial, as well as rural areas. The urban and industrial area represent 20% of the total surface of the municipality and concentrates 90% of the population [76]. The land use corresponding to green spaces with public access (e.g., parks, squares, community gardens) represents a high percentage of the total area of the municipality. The percentage of green space (%GA) is 57.9% and the Normalized Vegetation Index (NDVI) is 0.577 [77,78].

The hydrographic network, relatively dense but with short natural watercourses, is basically divided into two catchments (Figure 1): that of the river Piles to the East (A.6) and that of the rivers Pilon-Pinzales to the West (A.4-A.3). The main rivers are Aboño, Piles, Tremañes or Pilon, Cutis and Pinzales (Figure 1). These catchments occupied large extensions in the order of several tens of square kilometers and riverbeds with low average gradients. Although their headwaters can develop stretches of medium gradient, 39.85% of the surface area of the municipality is drained by the Piles river [79]. The final stretches of the rivers are affected by the influence of sea tides, forming estuarine environments that are really degraded by hydrological regulation and the occupation of meadows [80]. Gijón's sewerage network consists of a complex infrastructure of 745 km, mostly developed as a combined sewerage system. This network is divided into two principal different catchment areas: the East catchment area drains the water from a population of 80,000 inhabitants and takes it to the "El Pisón" Wastewater Pretreatment Plant (WWTP), located in A.8. On the other hand, the Western catchment area includes three catchment areas: Cutis (A.11), Pilon (A.4) and Calzada (A.2), and conducts wastewater to the La Reguerona wastewater treatment plant (WWTP), located on the boundary between A.3 and A.2 [81].

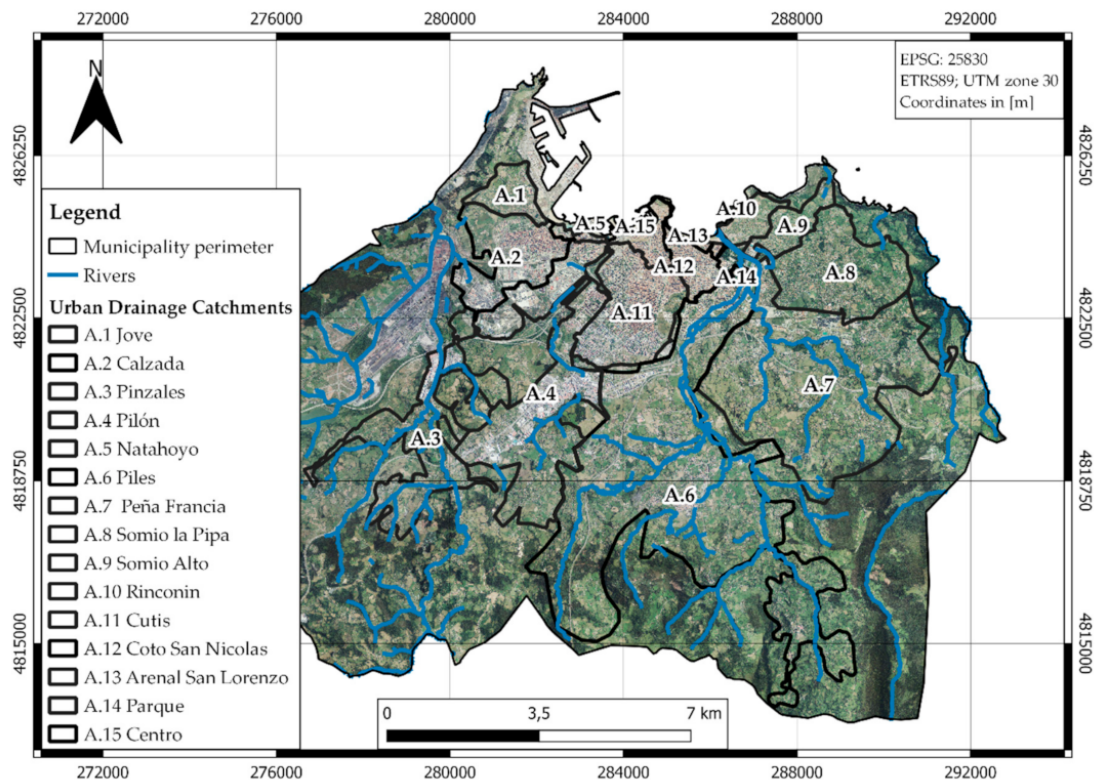


Figure 1. Main elements of Gijón's urban drainage system.

2.2. Methodology

The methodology proposed in this research aims to identify potential areas for the implementation of SUDS in the municipality of Gijón. Figure 2 represents a conceptual framework of the main steps to be followed.

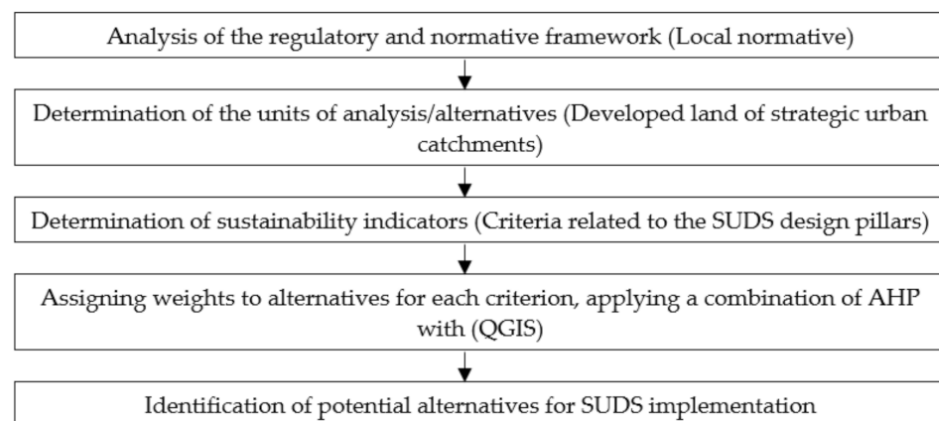


Figure 2. Main steps of the developed methodology.

2.2.1. Analysis of the Local Normative and Assessment of the Alternatives

Firstly, a detailed analysis of the local normative, which may have a direct or indirect impact on the implementation of SUDS, was carried out. The assessment of the regulatory and normative framework is based on the study of urban planning, particularly based on the General Urban Development Plan of Gijón [76] and on the open access data of the Territorial Information System and Spatial Data Infrastructure of the Principality of Asturias [82]. This information was used to generate an initial classification of those areas in which the implementation of SUDS will be unviable (undevelopable land) and, on the

other hand, those areas in which the introduction of these drainage techniques would be possible a priori (developable land).

This division was carried out in the determined units of analysis or alternatives, which are the principal urban catchment areas of the case study. The spatial data corresponding to these delimitations were 15 urban basins, which are the management and planning units used by the municipal water company of the city (EMASA, as per its Spanish acronym), which is the organization responsible for the management of the sanitation and sewerage system.

Therefore, the alternatives of the studied area were divided according to its urban structure (Figure 3). The developable areas were classified into Consolidated Urban Land (land that meets the condition of plot) (SU-C) and Unconsolidated Urban Land (SU-NC). At the same time, a classification of the typology of these land uses (residential, commercial or industrial) was established. Furthermore, undeveloped land was classified into the following categories:

1. Special protection land (SNU-EP): land with important ecological and environmental values that must be preserved from development;
2. Land of interest (SNU-I): land that includes agricultural, livestock and forestry activities, as well as the facilities associated with these activities;
3. Coastal land (SNU-C): corresponds to that delimited by the Special Territorial Plan for Undeveloped Coastal Land;
4. Infrastructure land (SNU-IF): land occupied by basic or transport infrastructures, in addition to those destined for public or social interest facilities;
5. Rural core land (SNU-NR): non-developable spaces in the rural area of the municipality.

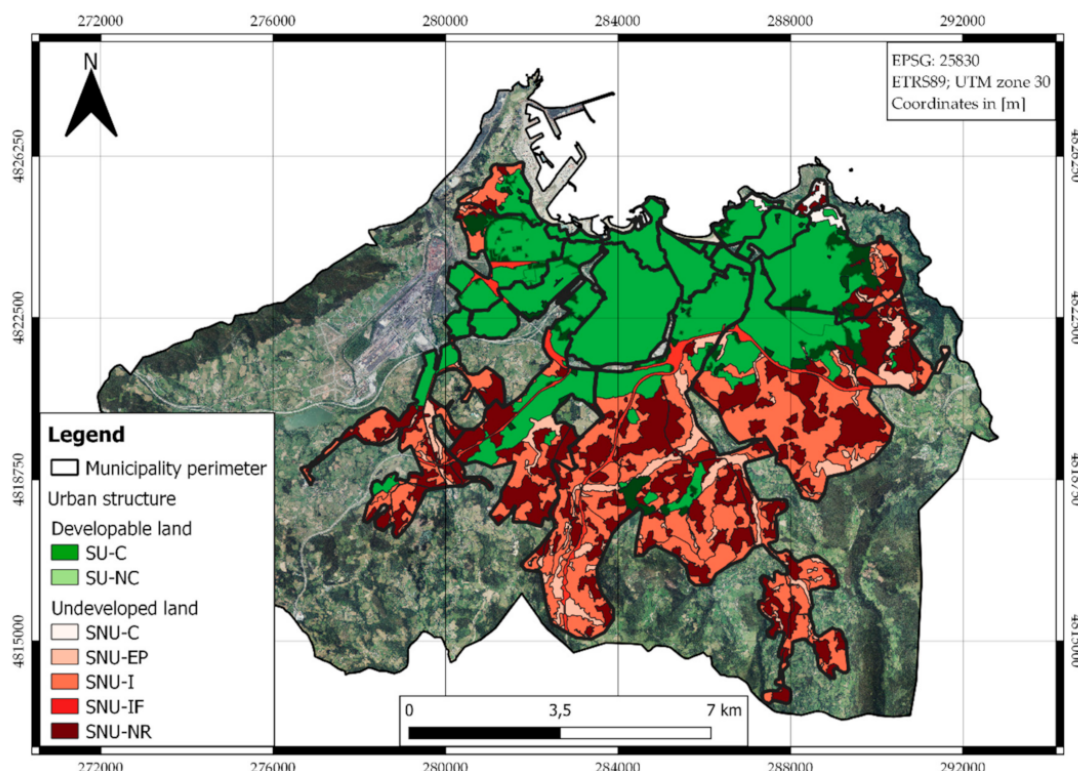


Figure 3. Division of the alternatives according to their urban structure.

2.2.2. Assessing Criteria

The four SUDS' design pillars were utilized in this multi-criteria methodology as criteria to support decisions on which the alternatives had the greatest potential for implementation. In this regard, Table 1 shows the criteria used in this study, followed by their

descriptions. Amenity and biodiversity were joined together following previous research and manuals.

Table 1. Water quantity (WQN1, WQN2, and WQN3), quality (WQL1, WQL2, and WQL3) and amenity-biodiversity (AB1, AB2, and AB3) criteria, with the main study variables.

Design Pillar	ID	Criteria	Variable/Units
Water Quantity	WQN1	Flooding risk	Percentage of area vulnerable to river and coastal flooding (% A_f)
	WQN2	Treatment volume	Water Quality Capture Volume (WQCV) (m^3)
	WQN3	Capacity sewerage system	Capacity and density of sewerage system elements (N°_{el}/km^2 , Vol/km^2)
Water Quality	WQL1	Qualitative analysis of water bodies	Concentration of pollutants in watercourses (BOD, COD, ...)
	WQL2	Land uses	Percentage of area of land uses susceptible to be a potential source of pollutants (% LU_{SP})
	WQL3	Population density	Number of inhabitants per surface area (hab/km^2)
Amenity-Biodiversity	AB1	Urban redevelopment or a new urbanization	Percentage of area to undergo new urban development (% A_{NUD})
	AB2	Green areas	Percentage of public green spaces (% A_{GA})
	AB3	Public areas	Percentage of public spaces (% A_{PS})

Where:

- WQN1: This criterion refers to the vulnerability of the different alternatives to river and coastal flooding. It helps in the measurement of problems associated with stormwater management in coastal and river environments, which is the case for the studied area. The analysis of these problems was carried out using open access data from the Spanish National Geographic Information Centre of the Ministry of Transport, Mobility and Urban Agenda [83]. The cartography included in this service contains the areas defined as flood zones associated to return periods in vector format (shapefile). Spatial data related to the high probability scenario, with a return period of 10 years, have been used as a usual return period for SUDS' practices and urban drainage [74,84]. Moreover, the overflow surface area of the receiving bodies and the percentage of flooding surface were calculated for each alternative. The following rating points were assigned depending on the different levels of risks: (1) no risk, (2) low (3) medium, (4) high, (5) very high;
- WQN2: the second criterion proposed was the estimated installed capacity of the municipality's sewerage system for receiving runoff volumes. The data required for this analysis were also provided by EMASA. These data contain information on the typology, materials, diameters and length of the pipes, level and date of installation. In addition, information is provided about the wells, sinks and sewers across the municipality. The density of the drainage elements per surface area and their capacity were estimated with the aim to assess the capacity of the sewerage network for each alternative. On the one hand, the volume of the reception pipes in each alternative were estimated, considering the total length of their connection lines and drains with their diameters. Furthermore, the density of the sumps, wells, and manholes per km^2 , responsible for collecting the volumes of surface runoff, was also calculated. Then, applying the AHP method, the relevance of each alternative was computed from this information. The rating points applied to the capacity of the sewerage system are listed as follows: (1) very high, (2) high, (3) medium, (4) low, (5) very low;
- WQN3: the inflow or treatment volume and the capacity criteria is the result of the application of the Water Quality Captured Volume (WQVC) methodology [85]. Using this method, the actual runoff factor of each alternative was obtained from its percentage of effective impervious area and a coefficient corresponding to the drainage time (WQVC) [86]. The percentage of impervious area for each alternative has been estimated from a complete classification of land uses. This categorization was developed through a manual process of verification and editing of the polygons

corresponding to each land use by means of satellite images. A drainage time of 40 h was selected to provide an effective pollutant removal, which is the value generally used for the brim-full basin and to obtain the standard water quality [87]. Nevertheless, this drainage time can be reduced for some SUDS such as those in which the removal of pollutants is mainly achieved through filtration. Then, it was decided to set the same value for the whole case study in order to be on the safe side. Once the runoff depth had been determined, it was multiplied by the upstream tributary catchment area and by a factor to account for the additional 20% of required storage for sediment accumulation [88]. Then, the following scoring system was applied based on the runoff depth and the influent volume: (1) very low, (2) low, (3) medium, (4) high and (5) very high;

- WQL1: The analysis of the criteria related with the qualitative status of Gijón's water bodies was carried out using different sources, prioritizing the results provided by the Cantabrian Hydrographic Confederation (CHC) in its program of monitoring for the Piles river basin. The analysis of the water quality on the San Lorenzo beach and the lower course of the river Piles, carried out by EMASA and the Department of Environment of Gijón City Council in October 2019 [89–91], were also considered and incorporated in the analyses. It is important to mention that no data are available on the water quality status of the other significant watercourse in the study area; such is the case of the Pinzales river. However, this river runs for most of its course outside the domain of the case study and, except for intense rainfall episodes, its average flow is not significant in comparison with the rivers belonging to the Piles basin [92]. Therefore, the general approach to this criterion was to compare the quality condition of these water bodies and to associate them to the area of each alternative. The following quality determinants for this analysis were involved in the water bodies assessment: Ammonium, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorus, Nitrates, Suspended Solids, Total Coliforms, Enterococci and Escherichia coli. As a consequence, the following rating points were assigned based on Tsuzuki (2014) [93]: (1) no data are available for this alternative, (2) low, (3) medium, (4) high (5) very high;
- WQL2: This criterion helps in the estimation of the level of contribution to the alteration of the physical–chemical characteristics of the surface runoff volumes from each land use to the study area. A classification was elaborated following the nomenclature of the European CORINE (Coordination of Information of the Environment) Land Cover project, using open access data from the Ministry for Ecological Transition and the Demographic Challenge [83]. The main sources of water quality degradation in urban areas include various activities, which are considered by the municipality of Gijon, such as residential, industrial, abandoned mining areas, commercial and recreational activities [94–96]. The land uses that have been studied in this phase are listed below according to their degree of impact on water quality: industrial, mining, continuous urban fabric, discontinuous urban fabric, commercial and recreational facilities. The percentage of surface area of these land uses has been determined for each of the 15 alternatives. The following scoring system was proposed based on the sources of discharge to surface runoff: (1) non-significant, (2) low, (3) medium, (4) high and (5) very high;
- WQL3: This criterion assesses the relationship between land uses and water quality. Another main cause of diffuse pollution in urban areas is population growth and migration. There is a correlation between population density and diffuse pollution, usually depicted as an additional person in a given area representing an extra demand for productive resources, and thus additional waste, added to that caused by the maintenance of the life process [97]. Therefore, the higher the population density, the greater the diffuse pollution [98]. The number of people per square kilometer was determined for each of the 15 alternatives in order to analyze this criterion. The

following rating points were given based on the diffuse pollution associated to the population density: (1) very low, (2) low, (3) medium, (4) high and (5) very high;

- AB1: This criterion refers to those areas that show greater deterioration and would potentially undergo urban redevelopment or new urbanization processes in the near future. The implementation of SUDS in those areas that pose a significant amenity and biodiversity deficit will produce a higher social and environmental impact. In addition, those areas that are included in new processes of urbanization present higher viability for implementation. The analysis of the urban structure of the municipality carried out, based on the general urban development plan, has been key to identify those areas that are going to be associated with urban redevelopment [76]. Therefore, the following rating points were proposed: (1) very low, (2) low, (3) medium, (4) high and (5) very high;
- AB2: This criterion is based on the percentage of public green spaces present on each alternative. SUDS implementation in those alternatives with a higher percentage of green spaces would improve the efficiency of the spatial distribution of the urban area and incentivize their implementation. The spatial data from the Electronic Cadastral Office of the Ministry of Finance [99], was fundamental to identify green areas under the public domain (e.g., parks, squares, roads). Moreover, a manual process of verification and editing of the Spatial Data Infrastructure offered by the Gijón City Council [100] was key to complete the analyses. Finally, the renaturation of water-courses was considered from an environmental standpoint, and green and blue green corridors were identified. The rating system used in this case was as follows: (1) very low, (2) low, (3) medium, (4) high and (5) very high;
- AB3: this criterion shows the percentage of public spaces for each alternative. Public spaces have been identified and classified using the open access data of the Electronic Cadastral Office of the Ministry of Finance [99]. This classification has been carried out taking into account the areas where the implementation of SUDS could be viable. Such areas were divided into the following options: communication routes (i.e., roads, pedestrian paths, cycle paths, service roads and planned new roads), green areas, green-blue corridors and parking lots. It was necessary to carry out a manual process of verification and editing of the polygons corresponding to each typology studied from satellite images in order to classify these public spaces, the reason being that the imported initial data were incomplete. Then, the rating system used in this case was: (1) very low, (2) low, (3) medium, (4) high and (5) very high.

2.2.3. Multi-Criteria Analysis

The AHP method has been applied using a combination of QGIS and Excel, automating the calculation and the import process, where each factor received a weighting coefficient and a score according to its importance, in terms of its overall impact on the entire decision-making process. A score from one to nine was assigned to each of the fifteen alternatives in accordance to each criterion studied, in the pairwise comparison matrices associated with the method. Once the weights had been obtained, the consistency of the method was checked by computing the consistency index (CI) and the consistency ratio (CR). Then, the comparisons and the results for weight determination were considered as acceptable if the $CR < 0.1$, as suggested by Satty (1980) [70,71,101]. A table with the results generated and all the data for each alternative were then exported to QGIS. Based on this, results were represented by applying the same scoring system from 1 to 5.

3. Results and Discussion

3.1. Water Quantity

Table 2 shows the weights of the different alternatives after applying the AHP method to the criteria related to the first SUDS pillar for design water quantity (stormwater volume control), whilst Figure 4 shows the graphic portrayal of the computed values. The outcomes of the analysis of the results associated with the criteria to measure the vulnerability to river

and coastal flooding (Figure 4a) pointed out that the alternatives A.13 and A.14 reached the highest values, due to their location by the estuary of the main river flowing through the study area (Piles). The scores registered were 63.74% and 43.10% of floodable area, respectively, considering a return period of 10 years. Other alternatives with a significant percentage of floodable area are A.15, A.6, A.3 (ranked with a score of 4 in Figure 4a). A.15 is the alternative with the highest percentage of floodable area because of coastal flooding (15.21%), A.6 is the alternative through which most of the route of the river Piles flows and A.3 is the location of the other main river in the municipality.

Table 2. Computed values for the criterion related to the water quantity design pillar.

Alternatives			Alternative Weights Water Quantity Indicators					
Id.	Name	Area (km ²)	WQN1	CR	WQN2	CR	WQN3	CR
A.1	Jove	0.734	0.016		0.078		0.017	
A.2	Calzada	3.527	0.016		0.027		0.048	
A.3	Pinzales	1.012	0.093		0.064		0.069	
A.4	Pilon	5.325	0.037		0.054		0.067	
A.5	Natahoyo	0.258	0.016		0.018		0.123	
A.6	Piles	4.093	0.097		0.038		0.025	
A.7	Peña Francia	4.411	0.038		0.151		0.012	
A.8	Somio la Pipa	4.012	0.018	0.089	0.192	0.073	0.012	0.051
A.9	Somio Alto	1.039	0.016		0.151		0.017	
A.10	Rinconin	0.836	0.052		0.109		0.017	
A.11	Cutis	4.687	0.016		0.027		0.091	
A.12	Coto San Nicolas	1.208	0.071		0.013		0.172	
A.13	Arenal San Lorenzo	0.161	0.168		0.013		0.172	
A.14	Parque	0.343	0.219		0.055		0.035	
A.15	Centro	1.023	0.128		0.013		0.123	

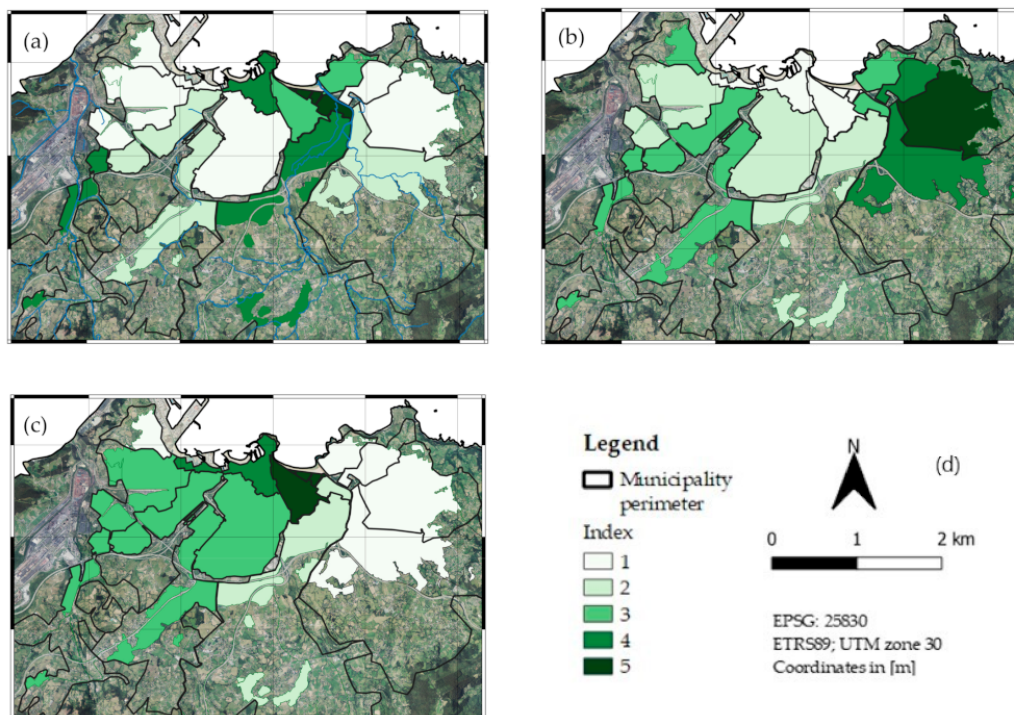


Figure 4. (a) vulnerability for river and coastal flooding index; (b) sewerage system capacity index; (c) treatment or influent volume index; (d) legend, north arrow, scale bar, Coordinate Reference System and coordinate units.

The alternatives with the highest weighting after applying the AHP method to the sanitation system capacity criterion are those located in the eastern urban periphery (A.8, A.9, A.7, A.10). Therefore, these alternatives are the ones with the lowest capacity considering the installed sewerage system (Figure 4b).

On the other hand, the criterion related to the hydrological design shows that the alternatives in which higher runoff depth values were computed were those in which percentage of imperviousness were higher and also located at lower elevations (A.13, A.12, A.15, A.5). Therefore, those areas are susceptible to receive a greater volume of surface runoff for the SUDS to treat (Figure 4c).

3.2. Water Quality

The alternative A.6 was the most suitable for SUDS' implementation considering the results from the multi-criteria analysis for the second water quality pillar for SUDS design (Table 3). In addition, alternative A.7 reached the second highest score (22.86%) after applying the AHP method. This alternative represented the main tributary of the river Piles, exemplifying the highest levels of pollutant concentrations.

Table 3. Computed values for the criterion related to water quality design pillar.

Alternatives			Alternative Weight Water Quality Indicators					
Id.	Name	Area (km ²)	WQL1	CR	WQL2	CR	WQL3	CR
A.1	Jove	0.734	0.034		0.022		0.034	
A.2	Calzada	3.527	0.034		0.171		0.098	
A.3	Pinzales	1.012	0.034		0.091		0.013	
A.4	Pilon	5.325	0.034		0.271		0.023	
A.5	Natahoyo	0.258	0.034		0.061		0.069	
A.6	Piles	4.093	0.327		0.061		0.034	
A.7	Peña Francia	4.411	0.229		0.036		0.015	
A.8	Somio la Pipa	4.012	0.034	0.002	0.035	0.018	0.022	0.042
A.9	Somio Alto	1.039	0.034		0.022		0.022	
A.10	Rinconin	0.836	0.034		0.022		0.022	
A.11	Cutis	4.687	0.034		0.061		0.098	
A.12	Coto San Nicolas	1.208	0.034		0.061		0.141	
A.13	Arenal San Lorenzo	0.161	0.034		0.036		0.198	
A.14	Parque	0.343	0.034		0.015		0.069	
A.15	Centro	1.023	0.034		0.036		0.141	

Besides, the results of the analysis for the criterion assessing the relationship between land uses and the water quality (Figure 5b) depicted that the alternatives placed towards the west bounds of the city are the ones reaching the highest scores (Table 3), therefore posing the highest problems related to diffuse pollution. A.4 was found to be the alternative that computed for the highest score (27.10%), being located in the largest industrial estate area of the municipality. The remaining alternatives scoring the highest values were A.2 and A.3, respectively. Both areas are defined as industrial in the municipal land uses.

Finally, the results of the criterion linked to the population density are outlined in Figure 5c. The alternatives located in the city center (A.13, A.15, A.12) received the highest score, representing population densities above 20,000 inhabitants/km². However, the alternatives located around the consolidated urban areas such as A.3, A.7, A.8, A.9 and A.10 presented density values below 1000 inhabitants/km², and therefore, the lowest weights after applying the AHP method.

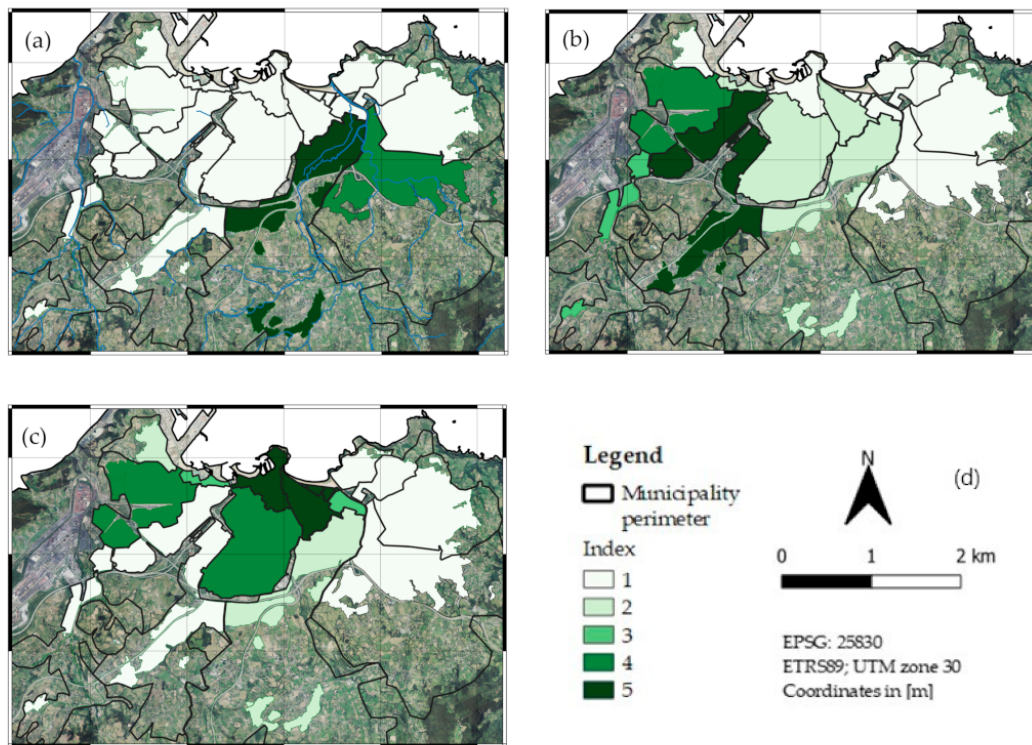


Figure 5. (a) quality of the rivers' index; (b) land use/water quality relationship index; (c) population density index; (d) legend, north arrow, scale bar, Coordinate Reference System and coordinate units.

3.3. Amenity and Biodiversity

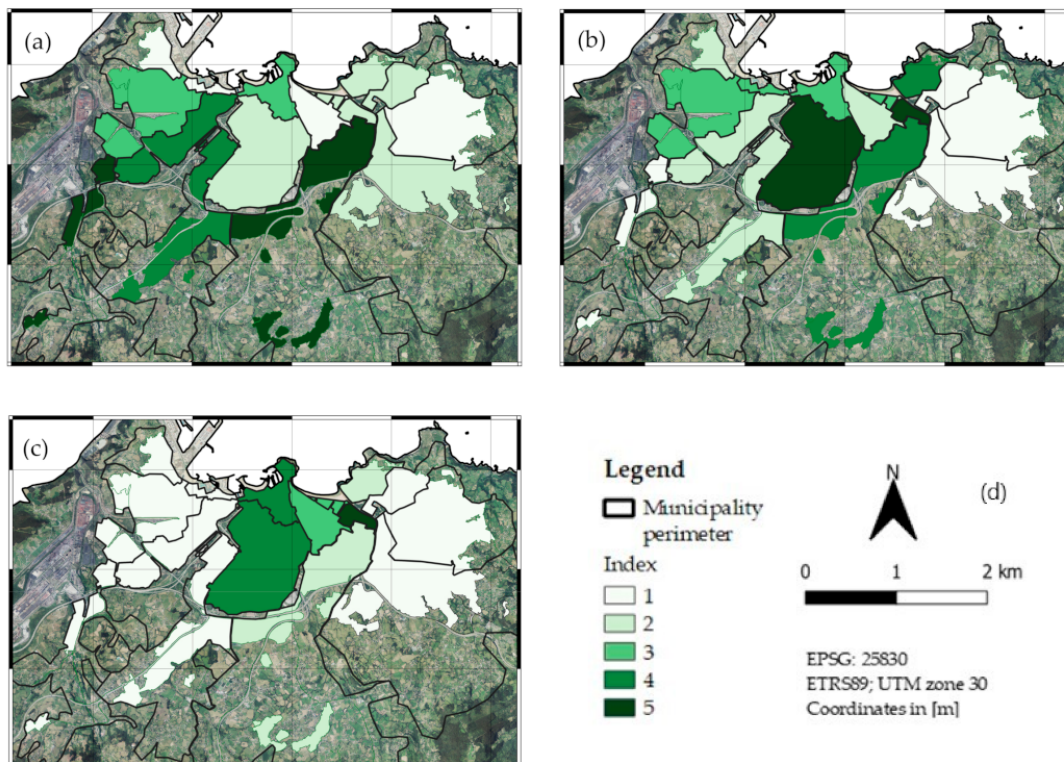
Table 4 summarizes the individual results of the 15 alternatives when applying the AHP method to the three criteria linked to the pillar for SUDS design based on amenity and biodiversity. The results of the criterion analyzing new urbanization or urban redevelopment processes depicted alternatives A.3 and A.6 as those with the highest values. The reason being associated to the fact that 28.18% and 26.20% of the surface area of these alternatives, respectively, are subjected to new urbanization processes. Furthermore, the future interventions proposed for A.3 are directed to the development of new, advanced, tertiary economical activities and the promotion of the industrial sector. On the other hand, alternative A.6 is mainly oriented towards the creation of new space of high residential value [76].

The results of the criterion linked to the percentage of public green spaces, exhibits that alternative A.14 presents the highest weight (21.51%), placing the alternative A.11 in second place (16.10%). These two alternatives are located in the main urban parks of the municipality. For instance, 28.98% of the surface of alternative A.14 is covered by green spaces, being located on the left bank of the estuary of the main river of the city, confirming it as one of the main green-blue corridors of the municipality.

Finally, if we analyze the results of the criterion that analyzes the percentage of public spaces where the implementation of SUDS could be viable (Figure 6c), we can see that the alternatives (A.15, A.13 and A.12), located in the center of the study area, are the ones that have obtained the highest weights and scores after applying the AHP method.

Table 4. Computed values for the criterion related to the amenity-biodiversity design pillar.

Alternatives			Alternative Weight Amenity and Biodiversity Indicators					
Id.	Name	Area (km ²)	AB1	CR	AB2	CR	AB3	CR
A.1	Jove	0.734	0.026		0.029		0.031	
A.2	Calzada	3.527	0.078		0.043		0.043	
A.3	Pinzales	1.012	0.171		0.020		0.013	
A.4	Pilon	5.325	0.127		0.029		0.022	
A.5	Natahoyo	0.258	0.026		0.062		0.063	
A.6	Piles	4.093	0.172		0.117		0.063	
A.7	Peña Francia	4.411	0.045		0.019		0.021	
A.8	Somio la Pipa	4.012	0.045	0.013	0.018	0.089	0.017	0.060
A.9	Somio Alto	1.039	0.026		0.013		0.015	
A.10	Rinconin	0.836	0.045		0.117		0.063	
A.11	Cutis	4.687	0.045		0.161		0.136	
A.12	Coto San Nicolas	1.208	0.026		0.029		0.093	
A.13	Arenal San Lorenzo	0.161	0.045		0.043		0.093	
A.14	Parque	0.343	0.045		0.215		0.193	
A.15	Centro	1.023	0.078		0.086		0.136	

**Figure 6.** (a) urban redevelopment or a new urbanization process index; (b) public green areas' index; (c) public spaces' index; (d) legend, north arrow, scale bar, Coordinate Reference System and coordinate units.

3.4. Priority Areas for SUDS

Figure 7 represents the results obtained for each criterion related to the main pillars for SUDS design. A scoring system has been applied in which the maximum value obtained for each urban drainage sub-catchment is established for all criteria considered [102]. The priority alternatives based on water quantity criteria are mainly located in the central and eastern areas of the city. Figure 7a shows that A.14, A.13, A.12 and A.8 are the urban catchments that have been rated with the highest possible score. The results show that the impact of SUDS implementation in all the alternatives studied would have a positive impact

from the point of view of the improvement of runoff management and the increase in the efficiency of the sewerage system, as well as reducing the vulnerability of the drainage infrastructure to river and coastal flooding. Figure 7b portrays the results of the combined prioritization of the water quality pillar for SUDS design. It can be seen that, except for the alternatives A.8, A.1, A.7, and A.9, the rest presented a significant water quality problem due to high concentrations of pollutants in the watercourses. This scenario fed from the types of land uses, which are susceptible to become potential sources of pollutants or as a direct consequence of anthropogenic activities. Finally, Figure 7c shows that the alternatives where the implementation of SUDS would bring the greatest social and environmental benefits are in the urban consolidated alternatives located in the center of the municipality (A.14, A.11, A.15, A.13, A.12, A.5 and A.2). Moreover, there are two other alternatives (A.6 and A.3) located in the peri-urban area, which have been assigned the highest rating because of the new urbanization and urban redevelopment processes that are planned in them.

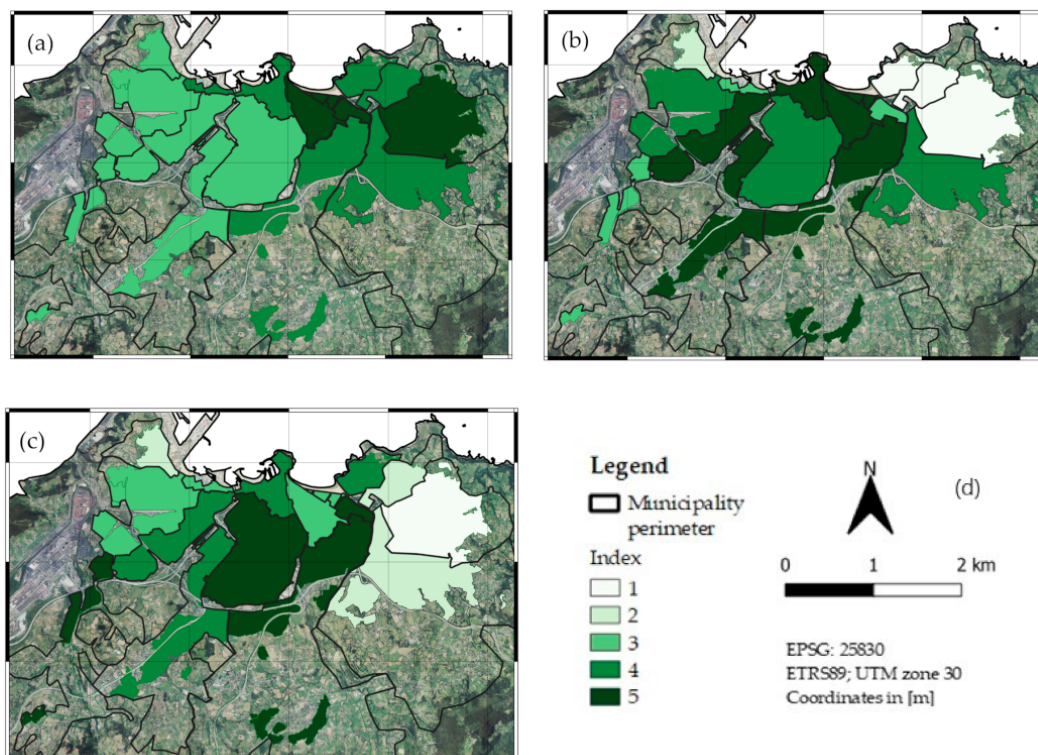


Figure 7. (a) priority alternatives according to the water quantity pillar; (b) priority alternatives according to the water quality pillar; (c) priority alternatives according to the amenity-biodiversity pillar; (d) legend, north arrow, scale bar, Coordinate Reference System and coordinate units.

Finally, the potential for SUDS implementation has been represented by analyzing the design pillars all together. (Figure 8). With this aim, a scoring system has been applied in which the score for each alternative is the maximum value obtained in the previous ranking (Figure 7). Figure 8 shows that all the priority urban catchment areas studied posed the need for SUDS' implementation. The lowest rated alternative after this later analysis (A.1) obtained an intermediate score (3) in terms of the degree of need for implementation. Those alternatives where the implementation would bring more functional, social and environmental benefits were A.4, A.11, A.12, A.13, A.14, A.15. These alternatives were located mainly in the central part of the studied area and were characterized for being consolidated urban areas. Those areas were those ones where the introduction of SUDS would contribute at a higher degree towards maintaining and protecting the natural hydrological cycle, as well as supporting flood risk management by controlling surface

runoff volumes and reducing peak flows from impervious areas. In addition, it would improve the quality of the surface runoff in these areas, retaining the pollutants and reducing the effects of diffuse pollution. Finally, it would also enrich the urban landscape by creating green spaces and increasing biodiversity.

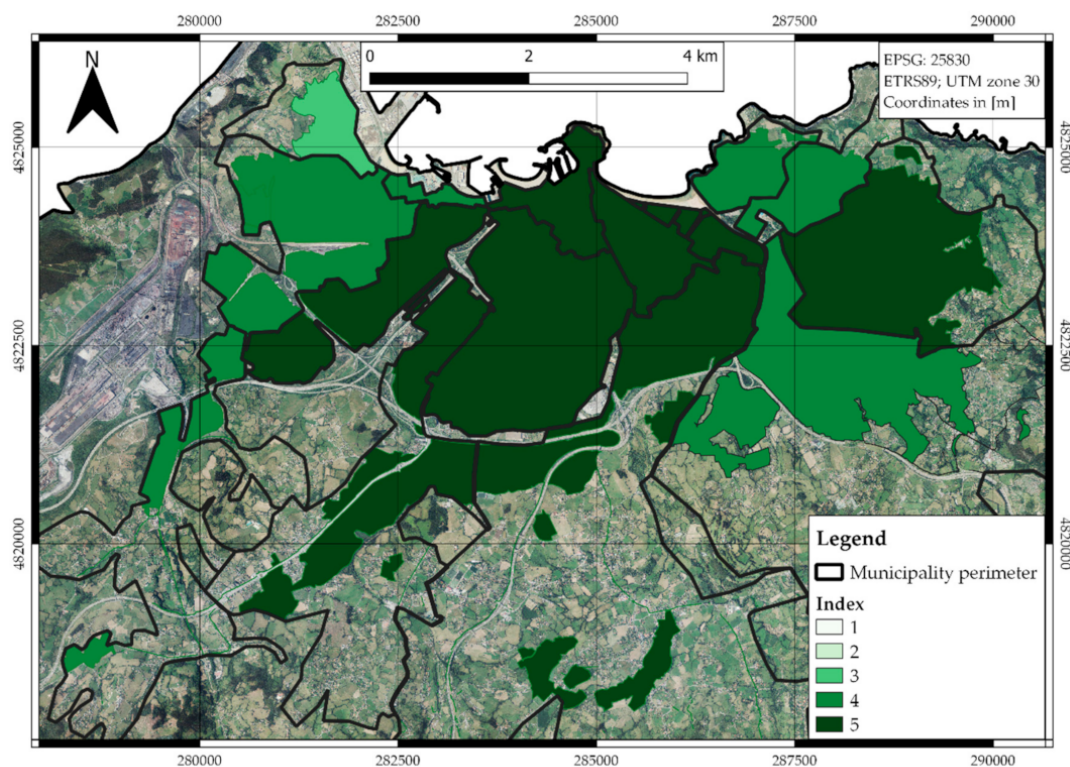


Figure 8. Priority alternatives according to the SUDS' design pillars.

The proposed conceptual framework was designed to serve as a useful tool to be used prior to the selection of the most appropriate typologies of SUDS for a given area. Following this logic, water management bodies involved in this case study will be able to have a holistic view at the city scale about the real needs for SUDS implementation, as well as which urban basins would bring more functional (volume control and pollutant treatment), social (amenity) and environmental benefits (biodiversity).

The methodology developed in this study differs from previous research in the design of the MCDA tools for SUDS implementation. In this case, the potential areas for SUDS implementation have been identified according to sustainable criteria linked to their comprehensive design, in contrast to other studies where MCDA have been applied to the identification of potential areas for specific SUDS typologies [60,64,73] or a number of limited pillars of design [57] or gave more emphasis to a single criterion such as the vulnerability to flooding [66].

Another differentiating aspect is that the studied alternatives of the MCDA are the priority urban catchments. Therefore, a total of 15 alternatives have been studied based on a series of sustainable criteria, unlike most studies that analyze the level of need for implementation in a given area [69,103,104].

4. Conclusions

The proposed methodology integrated the four pillars for SUDS design (water quantity, quality, amenity and biodiversity) into urban planning by identifying priority and strategic areas for SUDS implementation at the city scale. A systematic geospatial framework combining GIS and AHP is proposed for the study of nine sustainable indicators related to

these pillars. The city of Gijón has been selected to apply the proposed methodology due to its complex scenarios.

The empirical results, after applying the AHP to all the criteria linked to the SUDS design pillars, made it possible to identify in which alternatives the introduction of these drainage techniques would bring the greatest functional and social benefits. The consistency analysis applied to these results shows that they were acceptable, and it can be concluded that in general terms the need for SUDS implementation in the case study is scientifically justified. The results have shown that in the alternatives located in the northern part of the study area, which are categorized as continuous urban fabric or consolidated urban land, the introduction of SUDS would primarily help to reduce the volumes of surface runoff and improve its quality. In this part, alternatives A.13, and A.14 are among those with the greatest potential for implementation, because the introduction of SUDS would help to reduce flooding risks, as well as contributing to the renaturation of the river that flows through it and would greatly increase the positive social impact. The western part, characterized by the industrial zone of the city, also identified alternatives with great potential, mainly because of the results obtained in the criterion of the relationship between land use and water quality.

Therefore, the proposed framework presents satisfactory and consistent results in terms of the degree of need for SUDS implementation in the case study. Practically all the alternatives studied reached at least a significant weighting in some of the criteria related to the design pillar of water quantity (Table 2), water quality (Table 3) and amenity-biodiversity (Table 4). It can be concluded that the introduction of SUDS will help the conventional drainage system of the case study to reduce flood risks, improve the quality of its water bodies and on the other hand increase the biodiversity and quality of life of the inhabitants of the municipality. In addition, the detailed study of the regulatory framework of the municipality (land use and urban structure according to the General Urban Development Plan) and the fact that the alternatives selected were the urban catchments used by the stormwater management company, will help the proposed conceptual framework to become a tool for the authorities in charge of water management in the case study and even in the incorporation into local policies.

Based on the results of this holistic methodology, more research is proposed to be carried out in the future in which a selection and location of the most appropriate SUDS' typologies could be developed in terms of the reduction and a more efficient improvement of the quality of the volume of effluents from the surface runoff for the strategic areas identified in the case study. In addition, the study of the implementation of a sequential multifunctional scheme of SUDS (treatment train) is recommended.

More research is required in order to address the full implications from the outcomes of this investigation in the urban planning and water management activities of the water company and the city council. This future direction should feed from stakeholder engagement, including the needs and capabilities of the sewer system, allowing the identification of further barriers and hidden opportunities for implementation.

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