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Políticas Publicas de Infraestructuras Verdes para la Gestión Territorial y Lucha contra la Despoblación

(Green Infrastructure and Public Policies for Territorial Planning and Rural Depopulation)

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POLÍTICAS PÚBLICAS DE INFRAESTRUCTURAS VERDES PARA LA GESTIÓN TERRITORIAL Y LUCHA CONTRA LA DESPOBLACIÓN ANDALUCÍA.

(Green Infrastructure and Public Policies for Territorial Planning and Rural Depopulation)

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A la memoria de mis abuelas y abuelos

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Tengo claro que estas breves palabras nunca serán suficientes para expresar la gratitud que siento hacia todas las personas que me han ayudado a culminar este reto personal. Aún así vamos a ello.

Permitidme que en primer lugar recuerde a mi Familia.

Antonia, Alba y Mario si he llegado hasta aquí os lo debo principalmente a vosotras. Una vez más, gracias a vuestro apoyo, estímulo, paciencia y cariño diario he conseguido finalizar otro proyecto muy deseado.

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Hermano, te estoy infinitamente agradecido porque siempre estás cuando te necesito, por pequeño o grande que sea el problema o el reto. Nuestros actuales debates sobre la gestión de nuestro patrimonio natural y los baños de naturaleza del pasado que vivimos de niños en Purchena, en la Rambla de Oria o en Suflí han sido mi principal fuente de inspiración para el planteamiento de los objetivos de esta tesis.

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Gracias a mis compañeros de trabajo de Medio Ambiente de la Junta de Andalucía, pasados y actuales. Durante todos estos años de trabajo vinculado a la conservación y puesta en valor de nuestro patrimonio ambiental he tenido la gran fortuna de rodearme de grandes servidores públicos los cuales han contribuido a que crezca tanto profesional como personalmente. Me resulta imposible listar aquí todos sus nombres, pero no puedo olvidarme de aquellos compañeros y compañeras, amigos y amigas, que más han influido en mi visión sobre el medio ambiente. Rosa Mendoza, Pepe Guirado, Ramón Huesa, Javier Navarro y Antonio Martínez esta tesis también es vuestra. Por favor, no me faltéis nunca.

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“Gracias a ti también”.

José Luis Caparrós Martínez

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RESUMEN:

Se propone para la región de Andalucía una metodología para identificar y planificar líneas de gestión pública destinadas a priorizar los servicios ambientales prestados por las infraestructuras verdes que contribuyan a corregir los desiquilibrios económicos y demográficos existentes.

Los resultados ponen de manifiesto la existencia en Andalucía de dos realidades ambientales y sociales contrapuestas. Por un lado, una franja litoral y grandes zonas metropolitanas, donde se concentra la mayor parte de la población de la región con unas infraestructuras verdes degradadas y contaminadas. Y, por otro lado, unas zonas rurales con problemas de despoblación en las que se ubican infraestructuras verdes claves para la prestación de servicos ambientales a la totalidad de la sociedad andaluza.

Ante esta situación, en la franja litoral y áreas metropolitanas es necesario adoptar políticas de recuperación de las funciones ambientales de las infraestructuras verdes urbanas y en las áreas rurales interiores los mecanismos de financiación pública deberían considerar la corrección de los desequilibrios demográficos existentes por medio del establecimiento de posibles compensaciones por prestación de servicios ambientales.

ABSTRACT:

This paper proposes a methodology for the area of Andalusia to identify and plan lines of public management aimed at prioritising the environmental services provided by green infrastructures in the region that contribute to correcting the economic and demographic imbalances existing in the region.

The results of the study have revealed the existence in Andalusia of two contrasting environmental and social realities. On the one hand, a coastal strip and large metropolitan areas, where most of the region's population is concentrated, with degraded and polluted green infrastructures. On the other hand, there are rural areas with depopulation problems in which green infrastructures are located that are key to providing environmental services to the whole of Andalusian society.

In view of this situation, in the coastal strip and metropolitan areas it is necessary to adopt policies to recover the environmental functions of urban green infrastructures. Furthermore, in inland rural areas, public funding mechanisms should consider correcting existing demographic imbalances by establishing possible compensation for the provision of environmental services.

Índice

1 INTRODUCCIÓN

1.1. Motivación Personal

Dentro de este apartado se recogen aquellos motivos que han despertado en mi el interés de llevar a cabo la realización de la presente tesis doctoral, así como las razones que han propiciado la elección del área de investigación objeto de estudio.

En primer lugar, ha jugado un papel fundamental la estrecha relación existente entre el tema de la tesis y mi carrera profesional.

Licenciado en Ciencias Ambientales y Diploma de Estudios Avanzados en Ecología de Zonas Áridas por la Universidad de Almería, desde el año 2001 he desarrollado mi vertiente profesional como empleado público de la Junta de Andalucía, ejerciendo diferentes puestos, todos ellos relacionados con la gestión, conservación y puesta en valor de las infraestructuras verdes (en adelante, IVs) y nuestro patrimonio natural.

En un primer momento, como técnico del Parque Natural Cabo Gata-Nijar, posteriormente como técnico de conservación de biodiversidad y geodiversidad y, más recientemente, entre los años 2017 y 2019, ejerciendo labores de dirección como Gerente Provincial de la Agencia de Medio Ambiente y Agua en Almería.

Durante el ejercicio de mi profesión como técnico de Medio Ambiente de la Junta de Andalucía en los puestos anteriormente señalados, siempre ha despertado para mí un enorme interés las interfaces ciencia-gestión, en las que científicos y gestores se unen para abordar soluciones conjuntas a los distintos retos y problemas ambientales a los que nos enfrentamos como sociedad.

A lo largo de casi dos décadas, he tenido la oportunidad de colaborar con multitud de investigadores, muchos de ellos de la Universidad de Almería a través de diversos proyectos. En ellos, los resultados de los estudios científicos han servido para orientar los trabajos de gestión ambiental que ejecutaba la Administración Ambiental. En este sentido, destacan varios proyectos europeos como el LIFE Adaptamed, el LIFE Conhabit o el LIFE Posidonia, destinados a la mitigación de los efectos del cambio climático en IVs de gran valor ecológico de la provincia de Almería.

Por otro lado, durante este tiempo, esta actividad profesional la he compaginado puntualmente con labores de docencia y de investigación en la Universidad de Almería. Primero como profesor asociado en la Universidad de Almería en el Departamento de Didáctica de las Ciencias Experimentales y, más recientemente, como profesor externo del Master "Desarrollo y Codesarrollo Local Sostenible" y como investigador del proyecto "Marca Pueblo" de lucha contra la Despoblación desarrollado por el Grupo de Investigación Almeriense de Economía Aplicada.

Fruto de esta trayectoria, tanto profesional como académica, supone para mi un gran motivación llevar a cabo una investigación en la que se aporten evidencias ambientales, sociales y económicas sobre la necesidad de llevar a cabo políticas dirigidas a mantener y restaurar nuestras IVs.

1.2. Contexto Científico

Tras la epidemia del COVID 19 hemos podido comprobar lo frágil y vulnerable que es la especie humana y lo interconectado que esta el planeta ante fenómenos globales, tanto ambientales, sociales o sanitarios.

Desde hace décadas, la comunidad científica nos viene avisando de ello, en relación con el Cambio Climático y otros problemas ambientales globales. Sus informes nos recuerdan que, si seguimos alterando y sobreexplotando nuestros ecosistemas, seguiremos propagando enfermedades infecciosas e incrementando el riesgo de sufrir pérdidas económicas como consecuencia de eventos ambientales extremos (Ogen *et al*, 2020; Gibb *et al*, 2020; Waldron *et al*, 2020).

Ello demuestra que los desafíos ambientales a los que nos enfrentamos como sociedad, tales como el cambio climático o la pérdida de biodiversidad, no son sólo un problema ecológico, si no también económico e incluso sanitario.

Históricamente, la economía convencional no ha valorado los servicios ambientales prestados por los ecosistemas naturales pero investigaciones recientes demuestran que el valor económico de los ecosistemas naturales en términos de su contribución al bienestar y salud humanas tienen un valor económico entre 10 y 100 veces mayor que el coste relacionado con su conservación (Kumar, 2012, Hamann *et al*, 2020 *&*

Buckley *et al*, 2019).

Lo que vienen a concluir todas estas investigaciones es que los hábitats naturales no sólo son una fuente de recursos o energía para producir bienes y servicios, también son los responsables de la prestación de otros servicios ambientales claves para el bienestar humano, tales como la protección frente al cambio climático, la seguridad alimentaria y la disminución del riesgo de desastres y enfermedades ambientales.

En este nuevo contexto, adopta un enorme protagonismo en el ámbito de gestión ambiental las conocidas como Soluciones basadas en la Naturaleza (SbN), que abarcarían todas las acciones dirigidas a gestionar integralmente los sistemas naturales y sociales con el fin de aumentar los beneficios que la naturaleza proporciona tanto para el bienestar, salud y desarrollo humano (Kubiszweski *et al*, 2017).

Entre estas soluciones, destacan las relacionadas con la gestión y puesta en valor de las IVs.

Una IV consiste en una red estratégicamente planificada de espacios naturales y seminaturales y otros elementos ambientales diseñados y gestionados para ofrecer una amplia gama de servicios ecosistémicos. (Comisión Europea, 2014).

En el contexto andaluz, estas valiosas IVs se ubican, en su práctica totalidad, en municipios del interior y en zonas rurales de la comunidad que, precisamente, también son las zonas con mayor biodiversidad y conectividad ecológica de nuestra región.

Por todas estas razones, las zonas rurales de Andalucía, son fundamentales para la prestación de servicios ambientales claves para el bienestar humano no solo de sus poblaciones, si no de toda la población andaluza.

Sin embargo, el futuro ambiental y social de estas poblaciones, en la actualidad, también esta comprometido por otra amenaza global, la Despoblación.

Los datos son contundentes. Más de un tercio de los municipios de Andalucía, 270, tiene menos de 1.500 habitantes; 409 municipios, el 52,57%, son menores de 3.000 habitantes y dos tercios de los municipios andaluces, 522, tienen una población inferior a 5.000 habitantes (FAMP, 2018).

Los municipios de menos de 5.000 habitantes ocupan el 51,08% del territorio con el 11,01% de la población en tanto que las grandes ciudades ocupan el 7,95% del territorio concentrando al 50,75% de la población (FAMP,2018).

En este contexto, de crisis ambiental y sanitaria global, y de perdida de población en nuestras zonas rurales, surge esta tesís por compendio de publicaciones, la cual pretende investigar sobre el papel que pueden jugar la IVs ante los retos futuros de transición ecológica y de lucha contra la despoblación.

1.3. Objetivo

Sin dejar de lado el máximo rigor científico que requiere un proyecto de Tesis he tratado de aprovechar la experiencia adquirida durante el ejercicio de mi profesión como técnico de medio ambiente de la Junta de Andalucía para realizar una aproximación a la materia objeto de estudio desde la evidencia científica y ajustando la investigación a los problemas reales de gestión.

Fruto de lo expuesto, el objetivo que nos planteamos con ésta Tesis es proponer para la comunidad autónoma de Andalucía una metodología que sirva para identificar y planificar líneas de gestión pública destinadas a priorizar los servicios ambientales prestados por las IVs y que contribuyan a corregir los desiquilibrios económicos y demográficos existentes en la region.

1.4. Unidad y coherencia temática y metodológica de la tesis

La manera seleccionada para afrontar esta investigación ha sido el formato de compendio de publicaciones de acuerdo a los requisitos establecidos en el art. 24 de la Normativa de Estudios Oficiales de Doctorado de la Universidad de Almería tanto en lo referente a las condiciones que deben cumplir las publicaciones como el contenido y estructura de la tesis.

El sistema de Tesis por compendio de publicaciones, por un lado, nos ha facilitado abordar la problemática objeto de estudio con distintos enfoques tanto temáticos como de escala de trabajo y, por otro lado, nos ha permitido disponer de un aval externo de calidad conforme íbamos finalizando cada una de las partes que engloban este proyecto de investigación.

En este sentido, podemos afirmar que el desarrollo de este proyecto de investigación se ha abordado a través de tres fases, que han sido evaluadas por diferentes revistas científicas de la base de datos Journal Citation Report (JCR).

Una primera fase de análisis bibliométrico, incluidas en los artículos ***"Green Infrastructure and Water: An Analysis of Global Research"*** y ***"Green Infrastructures and Grand Environmental Challenges: A Review of Research Trens by Keyword"***. En ambos artículos, tomando como referencia las dos bases datos científicas más importantes Web of Science (WoS) y Scopus, estudiamos la evolución del concepto y las últimas tendencias de investigación en materia de IVs, haciendo un especial hincapié en la relación de éstas con la gestion de recursos hídricos y con los grandes desafíos ambientales a los que enfrentamos como sociedad, tales como, el cambio climático.

Esta fase nos resultó de gran utilidad para establecer y concretar el marco teórico de la investigación, para detectar las instituciones, autores y publicaciones más relevantes y, sobre todo, para plantear estrategias de gestión dirigidas a promover el potencial de las IVs.

La segunda fase fue desarrollada en el artículo ***"Public policies for sustainability and wáter security: The case of Almeria (Spain)"***, el cual recoge un análisis descriptivo de la repercusión ambiental del modelo agrícola almeriense. Se valora la gestión realizada hasta la fecha en materia de gestión de recursos hídricos, así como, la implicación futura de las IVs a la hora de plantear políticas públicas relacionadas con la sostenibilidad y seguridad hídrica en un escenario de Cambio Climático.

A partir de las conclusiones obtenidas, se propone un modelo de gestión de los recursos hídricos para zonas semiáridas y áridas del planeta, en el que se plantean tanto medidas para priorizar y restaurar los servicios ambientales prestados por las IVs como para impulsar la Economía Circular, a través de la desalación y la reutilización de aguas.

Finalmente, en el cuarto artículo ***"Mapping green infrastructure and socioeconomic indicators as a public management tool: the case of the municipalities of Andalusia (Spain)"***, presentamos una aplicación metodológica basada en un modelo de análisis espacial de indicadores ambientales y socioeconómicos de gran utilidad para la gestión territorial en situaciones en las que existan distintos contextos ambientales, demográficos y económicos.

En concreto, el resultado de la investigación ha sido un Sistema de Información Geográfica (SIG) formado por 11 indicadores (cinco relacionados con las IVs y seis relacionados con la sostenibilidad socioeconómica de los municipios de Andalucía) a través del cual se ha identificado tendencias y desequilibrios respecto a la gestión ambiental, usos del suelo y evolución demográfica y económica en la región.

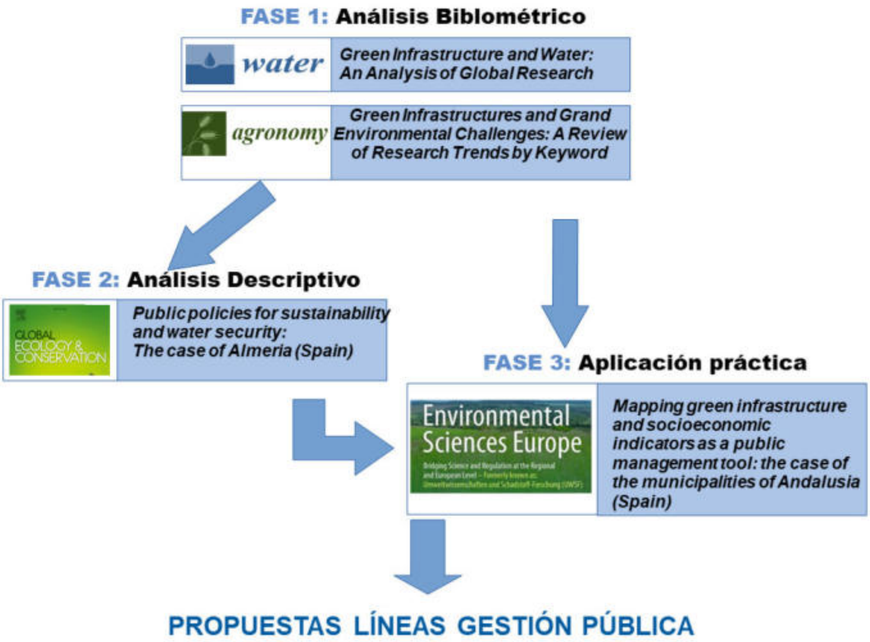

Figura 1.1 – Relación entre fases de la investigación y artículos publicados

2. PUBLICACIONES ORIGINALES QUE CONFORMAN LA TESIS DOCTORAL

2.1. Green Infrastructure and Water: An Analysis of Global Research

water

MDPI

Article

Green Infrastructure and Water: An Analysis of Global Research

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Abstract: Green infrastructure (GI) is a nature-based solution that encompasses all actions that rely on ecosystems and the services they provide to respond to various societal challenges such as climate change, food security or disaster risk. The objective of this work is to analyze the state of the art and latest trends in research on GI related to the water cycle for the period 2002–2019. For this purpose, a bibliometric study is carried out taking as reference the two most important scientific databases, Web of Science (WoS) and Scopus. The results show that, as of 2013, there is an exponential increase in the number of publications. This is due to the fact that significant regions of the planet, such as Europe, have adopted strategies aimed at promoting the use of GI since 2013. The keyword analysis points out that ecosystem services is the most relevant concept, which shows the capacity of these infrastructures to facilitate multiple goods and services related to the water cycle. New lines of research are opened up which are based on the analysis of other elements of GI related to water, such as groundwater.

Keywords: green infrastructure; water resources; environmental services; sustainability; nature-based solutions; bibliometric analysis

1. Introduction

Water is an element of nature that is essential for human health, well-being and development, as well as for the conservation of the planet's ecosystems and natural habitats [1–3]. In July 2010, the United Nations General Assembly recognized its importance, establishing that every human being has the right to between 50 and 100 liters of safe and affordable water per person per day, and that access should be within 1000 meters or a maximum of half an hour from home [4].

However, the extensive urbanization and the accelerated change in land uses that are taking place in different regions of the world are causing the over-exploitation and degradation of natural ecosystems, especially those related to the water cycle, such as rivers, aquifers or wetlands [5,6]. In this regard, it should be emphasized that agriculture currently represents about 70% of global freshwater use [7]. This damage and over-exploitation of water resources produces a series of environmental conditions such as the decrease in rainwater infiltration and aquifer recharge, the widespread loss of water quality, and an increase in the problems derived from floods and torrential rains [6,8]. The gradual deterioration of water resources together with the continued increase in worldwide consumption, 1% per year since the 1980s [9], has resulted in more than two billion people living in water-scarce countries; four billion people suffering from severe water shortages for at least one month a year; three out of ten people in the world without access to safe drinking water; and six out of ten people not having access to safe sanitation services [9–11]. Both the decrease in freshwater resources by 40%

and the increase in the world population for 2030, as foreseen by the United Nations World Water Assessment Programme (WWAP) [12] could generate a world water crisis.

If we add to this situation the potential expected effects of climate change, such as increases in catastrophic storms and long periods of drought, we can affirm that in the near future and in many regions the security and sustainability of water for local populations is at risk [6–8,13]. There are climate models that predict that by 2050 an increase of 1.5 °C in the average global temperature of the planet could cause drought and habitat degradation that would make life difficult for 178 million people around the world, while the effect on the population of an increase of between 2 °C and 3 °C would be significantly higher, affecting between 220 and 277 million people, respectively [7].On the other hand, the number of people at risk of flooding is expected to increase from 1.2 billion today to 1.6 billion in 2050 (about 20% of the world´s population), which will cause the economic value of assets at risk to be about $45 trillion by 2050, a growth of more than 340% compared to 2010 [14].

In view of this scenario of climate change, demographic growth, increased urbanization rates and intensification of pollution, and degradation of water resources, it is essential and urgent that different countries and regions promote the implementation of measures that help transform the way water is managed. To respond to these great challenges, the different regions of the world can adopt, on the one hand, engineering or technological strategies; and/or, on the other hand, an alternative approach based on comprehensively managing natural and social systems in order to increase the benefits that nature provides for both human well-being, health and development [15]. In the latter case, this refers to Nature-based Solutions (NbS), a concept defined by the International Union for Conservation of Nature (IUCN) that "encompasses all actions that rely on ecosystems and the services they provide, to respond to various societal challenges such as climate change, food security or disaster risk” [16].

For too long human-made infrastructure, so-called gray infrastructure, has been used to solve water problems. Consequently, NbS which focus their attention on GI based on using natural and semi-natural areas to provide alternative water resource management have been neglected [17,18]. The great attraction of GI lies in the fact that it offers important environmental services related to water from three fundamental perspectives: smart growth, climate change adaptation, and health and wellbeing (Figure 1).

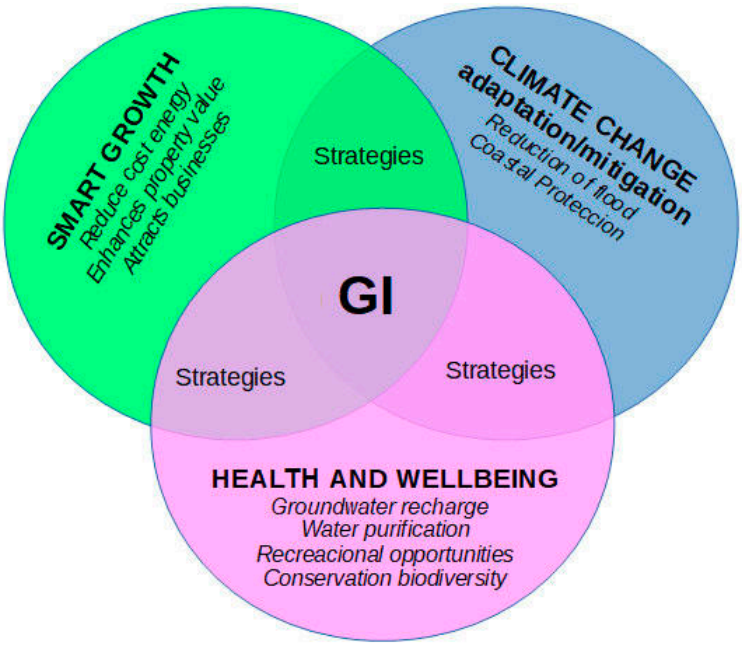

Figure 1. Environmental services provided by green infrastructure (GI) related to the water cycle. Source: Own elaboration.

Despite the fact that the term GI has recently become popularized, there is no universally accepted definition, as it is applied at different scales, for different issues, by different actors, including public managers, researchers and the general public [19].

Consequently, GI is defined by researchers in different ways (see Table 1), although there is general agreement that this term is multi-functional and delivers both ecological and social benefits [20]. Although water issues are usually included in the various definitions of GI, when processes and components related to water and aquatic systems become particularly relevant to the solution of management problems, some authors use the term Blue Infrastructures as an alternative approach to GI [21]. Within the framework of this concept, water bodies (lakes, lagoons, marshes, swamps), rivers, streams, springs and coastal ecosystems would be included.

Table 1. Definitions of GI.

Author	Definition
[22]	"Green infrastructure is an engineered intervention that uses vegetation, soils, and natural processes to manage water and create healthier built environments for people and the natural resources that sustain them. GI can range in scale from small-scale technologies such as rain gardens and green roofs to regional planning strategies targeting conservation or restoration of natural landscapes and watersheds. GI approaches may be interconnected with existing and planned grey infrastructure networks to create sustainable infrastructure that can enhance community resilience to disasters and climate change as a result of increased water retention and groundwater recharge, flood mitigation, erosion control, shoreline stabilization, combatting urban heat island effect, improving water quality, conserving energy for buildings."
[23]	Urban GI relates to a planning approach aimed at developing networks of green and blue spaces in urban areas to deliver a wide range of ecosystem services.
[24]	A strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services in both rural and urban settings. The European Commission's definition of green infrastructure also incorporates "blue spaces" in reference to aquatic ecosystems, including coastal and marine ecosystems.
[25]	Green infrastructure is the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services. Green infrastructure can be strengthened through strategic and coordinated initiatives that focus on maintaining, restoring, improving and connecting existing areas and features as well as creating new areas and features.
[26]	Green infrastructure is an approach to wet weather management that uses soils and vegetation to utilize, enhance and/or mimic the natural hydrologic cycle processes of infiltration, evapo-transpiration and reuse.
[27]	All natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales.
[28]	Green infrastructure is a concept that is principally structured by a hybrid hydrological/drainage network, complementing and linking relict green areas with built infrastructure that provides ecological functions.
[29]	An interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife.
[30]	Green infrastructure comprises the provision of planned networks of linked multifunctional green spaces that contribute to protecting natural habitats and biodiversity, enable response to climate change and other biosphere changes, enable more sustainable and healthy lifestyles, enhance urban livability and wellbeing, improve the accessibility of key recreational and green assets, support the urban and rural economy and assist in the better long-term planning and management of green spaces and corridors.

Table 1. *Cont.*

Author	Definition
[31]	The abundance and distribution of natural features in the landscape like forests, wetlands, and streams. Just as built infrastructure like roads and utilities is necessary for modern societies, green infrastructure provides the ecosystem services that are equally necessary for our well-being.
[32]	Our nation's natural life support system - an interconnected network of protected land and water that supports native species, maintains natural ecological processes, sustains sir and water resources and contributes to the health and quality of life for America's communities and people.
[33]	An interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations.

Source: Own elaboration.

Investment in GI is based on the logic that it will always be more profitable to invest in NbS than to replace these environmental services with human technological solutions [34]. The development and conservation of a region´s GI is considered a sound strategy for nature, the economy and employment with a series of advantages [21,35–37], among which the following are worth noting (Figure 2):

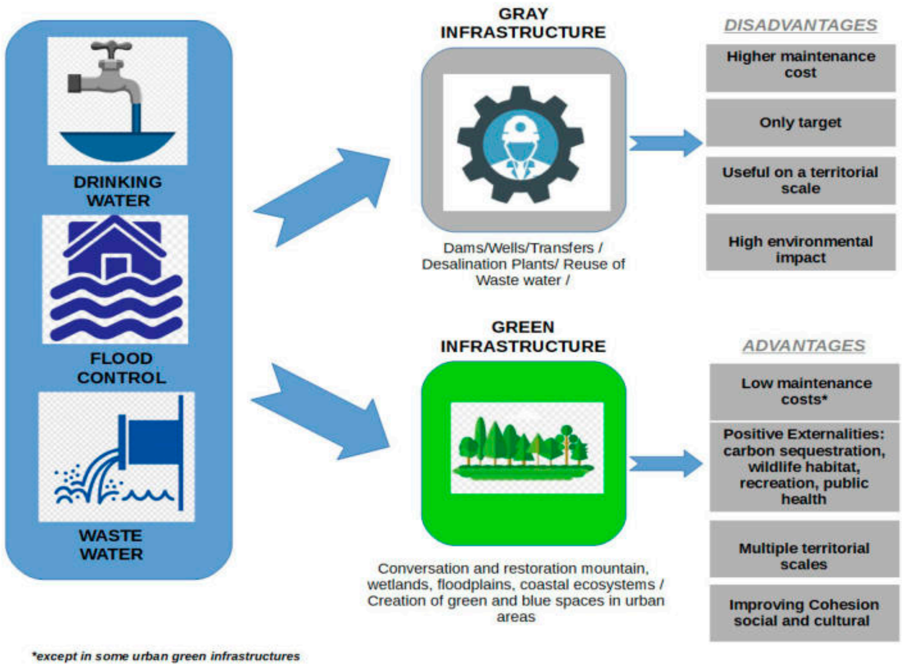

Figure 2. Gray vs. GI. Source: Own elaboration.

Economic cost savings. When GI is properly managed and maintained, it can lead to considerable cost savings, as it tends to improve the environmental services it provides over time, through the establishment of healthy ecosystems, the recovery of damaged habitats and the reconnection of natural and semi-natural fragmented areas. In contrast, gray infrastructure requires continuous investments to adapt to the rate of population growth and to cover its wear and tear [35]. A clear example of gray infrastructure is the control of coastal erosion through the restoration of dunes, compared to the alternative of using coastal levees and breakwaters that tend to degrade over time.

Multifunctional character and lower environmental cost. Unlike gray infrastructure, which usually has a single objective, investments in water-related GI usually produce other positive externalities. Thus, for example, a treatment plant only serves to purify wastewater, while a natural wetland, in addition to purifying water, conserves biodiversity and is a carbon sink, among other advantages.On the other hand, investments in the conservation and improvement of the forests of receiving basins, in addition to improving the filtration and natural recharge of aquifers, also have other advantages, including help in controlling erosion, generating greater carbon sequestration, improving habitats and creating new recreational opportunities for the population. However, for this to happen, the ecosystem must be healthy [35,37,38].

This multifunctionality of the GIs, which allows synergy and compensation between different environmental services, not only includes ecological aspects, but also includes important social aspects, especially in urban areas, which are important to identify, such as sustainable development, environmental justice and social cohesion [39,40].

Ability to adapt to different territorial scales. Unlike gray infrastructure, which normally operates locally, GI is close to a fractal structure, with elements ranging from the continental scale (for example, a large transnational mountain range that functions as an ecological corridor), to elements of smaller dimensions with value for the provision of environmental services at the local or urban level (for example, a wetland, which is responsible for purifying water and protecting against possible floods).

In this sense, if the interactions between ecological processes and human activities taking place at the local scale in the GIs of urban landscapes and socio-ecological systems are properly planned and managed, GIs will contribute to the conservation of biodiversity, the improvement of environmental quality, the reduction of the ecological footprint of urban environments, the adaptation of cities to climate change, social cohesion through the provision of spaces for social interaction, the alleviation of stress and fatigue and the promotion of volunteerism [27,41–43].

GI is configured as a very effective management tool, since from this approach alternatives can be proposed at different territorial levels.

Despite these advantages of GI, this type of action is frequently neglected by managers when making decisions or planning investments. This is largely due to the fact that, unlike what happens in gray infrastructure, the evidence of the benefits of GI is more difficult to quantify than the costs associated with its implementation [24]. In general, this type of action requires more time for the results to be visible and it is difficult to assess their contribution in market terms. A reason for this is that in most of the territories there are gaps regarding the availability of historical data and economic valuation tools for environmental services [38]. Despite this, studies carried out to date in different areas worldwide show greater profitability in the alternatives proposed from the GI approach than those proposed from the perspective of gray infrastructure [37]. There is also scientific evidence that the gradual loss or degradation of the GIs that exist in or around urban areas causes long-term economic losses and affects the social and cultural values of cities [44]. Furthermore, epidemiological studies show a positive relationship between longevity, health and access to elements of urban GIs [45,46].

Although it is considered to be in the early stages of development, various studies have shown the effectiveness and benefits of using GI for stormwater management, improving water quality, or retaining runoff [6,47,48]. Regarding water resources, GI is presented as an important instrument for achieving and maintaining the health of aquatic ecosystems and offers multiple benefits related to increasing the availability of water for different uses, water purification, and conservation and protection of aquatic biodiversity, as well as for the adaptation and mitigation of the effects of climate change, such as floods, torrential rains or long periods of drought [49].

On the other hand, in the scientific field, the number of publications focused on environmental services provided by natural ecosystems has increased considerably in the last three decades. Countries in Europe and North America have been the first to delve deeply and investigate these issues. Although it started publishing later, China has also rapidly promoted this line of research [6,50,51].

For the above reasons, it is of great interest to understand the evolution of the publications that relate to these two concepts, GI and the water cycle, as well as the main areas of knowledge in which they have been developed. The knowledge generated by these studies is a very useful tool for the environmental policy agenda. The aim of this bibliometric study is to analyze the evolution of the scientific literature related to GI and the water cycle, that is, not only to analyze the current state of research on this specific topic but also identify trends and future lines of research. Bibliometric analysis permits the researcher to evaluate developments in knowledge on a specific subject and assesses the scientific influence of researchers and sources [52]. There are already systematic reviews of the literature based on GI [53] or related to a specific type of GI, such as greenways [54], meta-analysis [55] and other type of literature reviews [27]. There are, as well, bibliometric analyses about water quality [56], conservation [57–59] or irrigation [60]. However, to the best of our knowledge, there are no studies in the specialized literature that link the concepts of GI and water from a bibliometric perspective. In fact, the main contribution of this work is that it presents the current state of knowledge about GI that serves as a basis for the study, design and implementation of new water management models for both scientists and policy-makers.

2. Materials and Methods

In order to analyze the link between GI and water, a bibliometric analysis has been performed. It is a method that mixes statistical and mathematical techniques to analyze research results [61,62], which is widely accepted by leading research institutions [63]. According to the Organisation for Economic Co-operation and Development (OECD) [64], it is defined as "the statistical analysis of books, articles, or other publications to measure the output of individuals/research teams, institutions, and countries, to identify national and international networks, and to map the development of new (multi-disciplinary) fields of science and technology". This work also uses the h-index to explain the performance or production of a research work. This is defined as the number "x" of articles with a total number of citations ≥ "x", so that those articles have been cited at least "x" times [65].

A series of steps have been followed in the bibliometric analysis (Figure 3). First, the search criteria, the keywords and the study period were defined. In this article, we have chosen to use the words "green infrastructure" and "water". These terms have been selected in order to obtain the most consistent results in relation to the central theme of this study, that is, a scientific mapping which demonstrates the importance of GI for the sustainable management of water resources. Scopus and Web od Science (WoS) were the databases selected to perform the analysis, since they are the two most relevant data sources given the rigorous protocol to which they adhere that ensures that the articles they include have a high level of quality [66]. The period analyzed runs from the year in which the first article on this subject is registered in each database (2002 in the case of WoS and 2005 in the case of Scopus) until 2019.

With regards to articles, books, conference proceedings and other research documents included in the main collection of WoS and Scopus, the number of documents added up to 891 and 1249 publications, respectively (Table 2). Similarly to the selection of the databases mentioned above, both results have been filtered to only include articles, thus guaranteeing the quality of the research, as these types of documents must undergo a process of review (thus excluding proceedings, reviews, books and book chapters). Furthermore, by type of document, research articles represent a high percentage of the distribution of the scientific contribution. Therefore, the exclusive analysis of articles reflects the state of the art of the importance of GI in water management. Finally, the main results were codified and analyzed, identifying common and divergent elements between both databases with respect to the fields of GI and water.

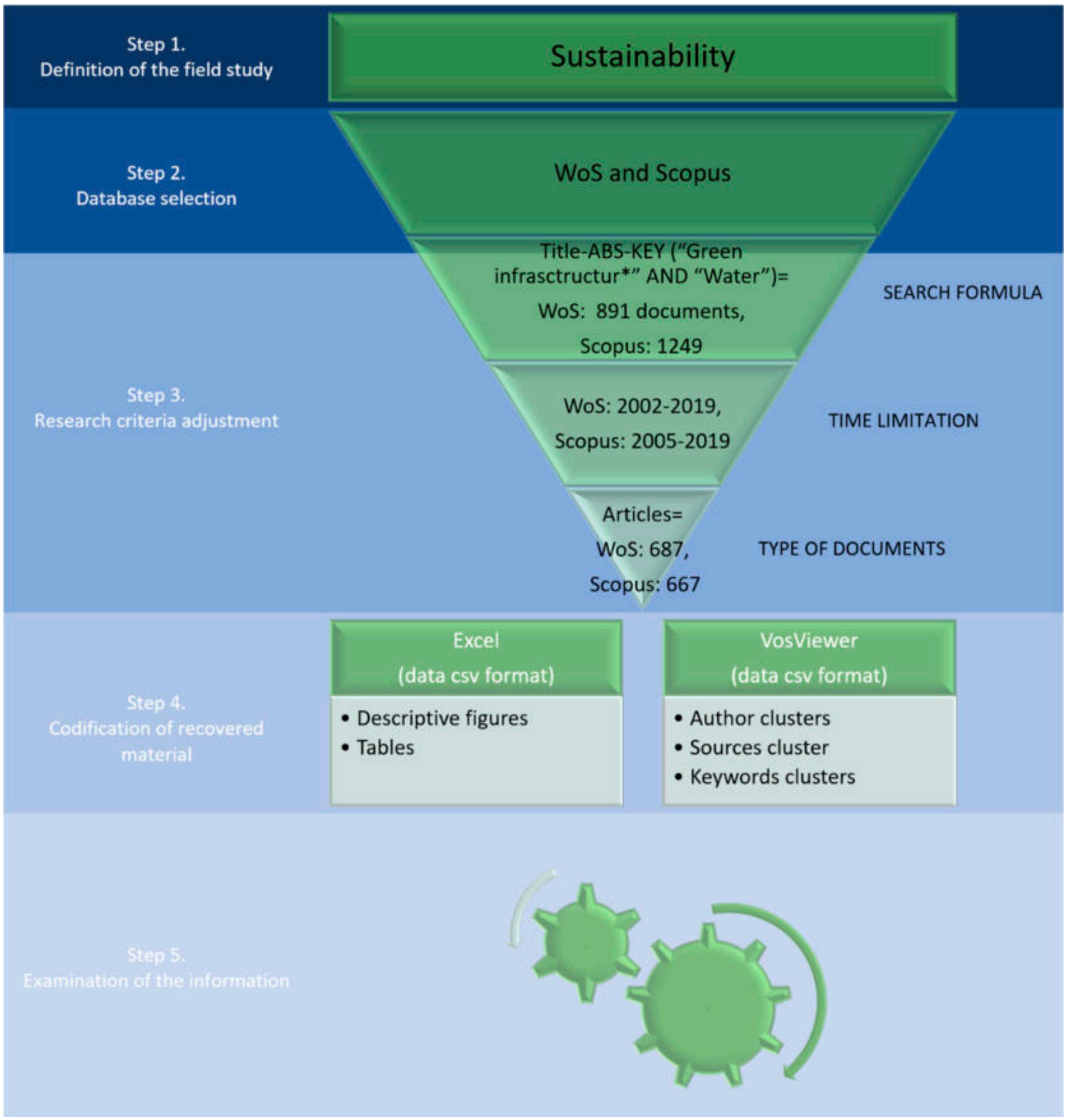

Figure 3. Data Gathering Process. Source: Own elaboration.

Table 2. Distribution of publications by type of document.

Type of Document	WoS	Scopus
Article	687	667
Proceedings	114	405
Review	62	97
Book and Book Chapter	28	80

Source: Own elaboration with Web of Science (WoS) and Scopus data (2019).

3. Results and Discussion

3.1. Number of Publications per Year

Research on GI and water began in the 21st century in both databases, which shows that the term is relatively novel, and is now being widely discussed among scientific circles. Specifically, the first article registered in the WoS database corresponds to the study by Marsalek & Chocat [67] entitled "International report: Stormwater management" in which stormwater management is analyzed through expert surveys. However, in Scopus, the first work identified is that of Scholl & Schwartz [68] entitled "Making your resources count", in which they analyze the importance of natural resources for economies based on activities in the service sector (Table 3).

Table 3. Annual Distribution of Publications.

	WoS				Scopus			
Year	**A**	**TC**	**TC/A**	**H-Index**	**A**	**TC**	**TC/A**	**H-Index**
2002	1	63	63	1	-	-	-	-
2005	-	-	-	-	1	1	1	1
2007	1	11	11	1	3	17	5.67	1
2008	3	276	92	3	5	348	69.6	4
2009	4	118	29.5	4	3	52	17.33	2
2010	8	247	30.9	5	12	284	23.67	6
2011	8	503	62.9	5	8	295	36.87	5
2012	16	331	20.7	9	13	305	23.46	8
2013	37	1541	41.6	20	39	1336	34.26	22
2014	33	630	19.1	15	39	691	17.72	17
2015	50	721	14.4	16	54	1208	22.37	19
2016	77	1138	14.8	21	84	1500	17.86	24
2017	122	1388	11.4	19	97	1528	15.75	20
2018	154	896	5.82	14	148	972	6.57	14
2019	173	282	1.63	7	161	261	1.62	8

Source: Own elaboration with Web of Science and Scopus data (2019). Notes: Y: Year; A: Articles; TC: Total Cites; H: H-index.

Since the publication of these studies, the number of articles has increased steadily and regularly over time. Until 2016, Scopus generally includes a higher number of articles (except in 2009, 2011 and 2012) than WoS. From this point on, this trend is reversed with WoS registering the largest number of articles in this area (Figure 4). In addition, it is observed that from 2013 there is an exponential increase in the number of publications in both databases. More precisely, it is in 2013 when, in different regions such as Europe, strategies are adopted aimed at promoting the use of GI [49] by recognizing that it is one of the main tools for addressing threats to biodiversity and for developing NbS. In addition, trends indicate that the number of publications on GI and water cycle is growing steadily, particularly over the last three years in both databases.

In contrast, the evolution in the number of citations does not present as regular a trend as the number of articles (Figure 5). Throughout the study period, several ups and downs are observed, also reaching the maximum value in 2013 in both databases for the same reason discussed above in the case of the number of publications.

Likewise, the most cited articles (Table 4) correspond to the studies by Gomez-Baggethun & Barton [69], with 483 citations, who value ecosystem restoration and conservation services when configuring urban planning; and Pataki et al. [70] with 386 citations, who follow the previous theme with regards to the incorporation of green solutions. These articles are followed by the studies by Barthel & Isendahl [71], with 143 citations, in which the influence of urban gardens, agriculture and water management on long-term agri-food security is analyzed; that of Coutts et al. [72], with 130 citations, where the existing literature is reviewed in order to demonstrate the potential of water-sensitive urban design to help improve thermal comfort in urban areas; and that of Lee et al. [73], also with 130 citations, who study the integrated rainwater analysis and treatment system developed by the US Environmental Protection Agency.

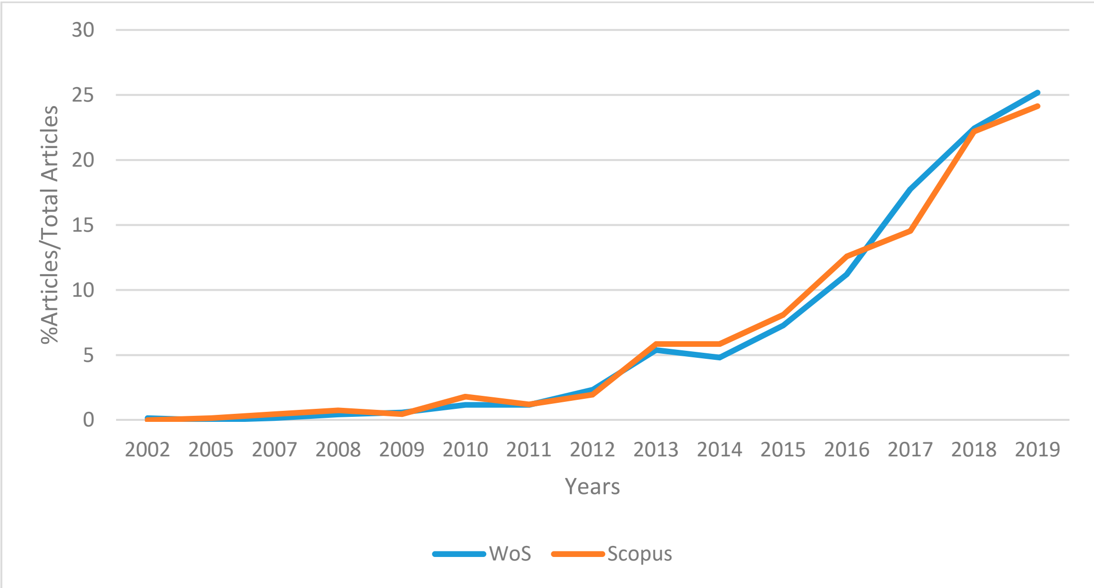

Figure 4. Evolution in the Number of Published Articles. Source: Own elaboration with Web of Science and Scopus data (2019).

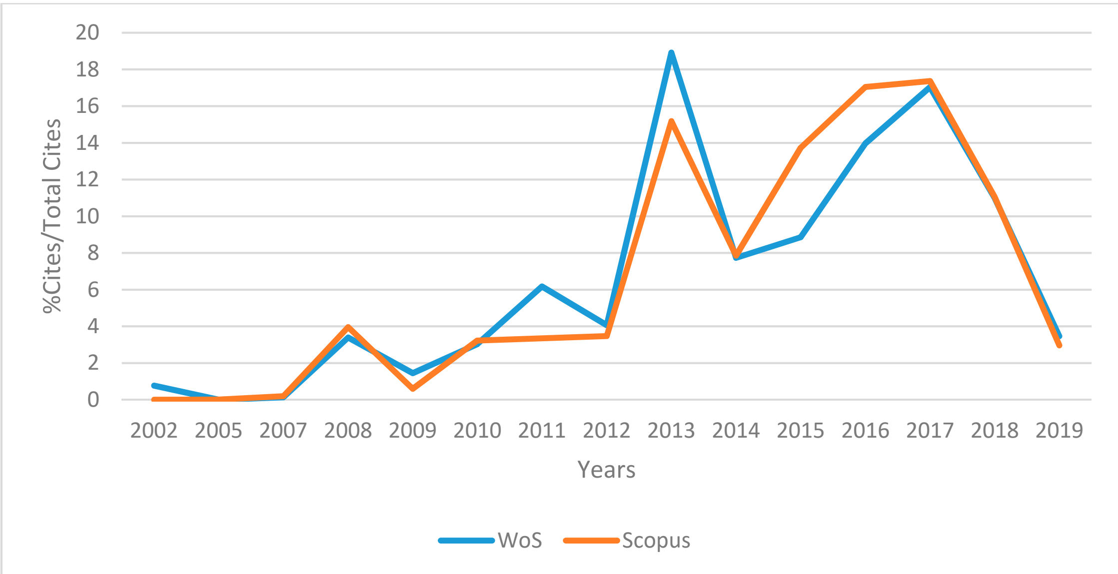

Figure 5. Evolution in Number of Citations. Source: Own elaboration with Web of Science and Scopus data (2019).

3.2. Distribution by Knowledge Area

There is a certain degree of diversity in the distribution by areas of knowledge, the most common being those related to environmental sciences, social sciences, engineering and ecology, among others (Table 5). This result confirms that the term GI is a broad and interdisciplinary concept, capable of responding to both small and large-scale geographical issues, and by both public managers, researchers and the general public [19]. In this sense, the literature review [27] on the relationships between the concepts of GI, ecosystem health, and human health and well-being already underlined the importance of the multidisciplinary character of this term, as well as the framework in which it must be analyzed.

Table 4. Ten most productive articles.

No.	Authors	Title	Journal	Country/Institution	TC (Average WoS/Scopus)
1	[69]	Classifying and valuing ecosystem services for urban planning	Ecological Economics	Spain/Univ. Auton.Barcelona and Auton.Univ.Madrid	483
2	[70]	Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions	Frontiers in Ecology and the Environment	USA/Univ.California, Univ. Louisville, US Forest Serv. and Cornell Univ.	386
3	[71]	Urban gardens, agriculture, and water management: Sources of resilience for long-term food security in cities	Ecological Economics	Sweden/Stockholm Univ.	143
4	[72]	Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context	Progress in Physical Geography-Earth and Environment	Australia/Monash Univ. and Belgium/Katholieke Univ. Leuven	130
5	[73]	A watershed-scale design optimization model for stormwater best management practices	Environmental Modelling & Software	USA/US EPA and Tetra Tech Inc.	130
6	[74]	Characterizing the urban environment of UK cities and towns: A template for landscape planning	Landscape and Urban Planning	UK/Univ. Manchester	115
7	[75]	A rainwater harvesting system reliability model based on nonparametric stochastic rainfall generator	Journal of Hydrology	USA/Drexel Univ. and Columbia Univ.	103
8	[76]	Utilizing green and blue space to mitigate urban heat island intensity	Science of the Total Environment	UK/Univ. Bath	90
9	[77]	Permeable pavement as a hydraulic and filtration interface for urban drainage	Journal of Irrigation and Drainage Engineering	USA/Univ. Florida, Louisiana State Univ. and Italy/Bari Polytech Univ.	84
10	[78]	Life cycle implications of urban green infrastructure	Environmental Pollution	USA/Drexel Univ.	81

Source: Own elaboration with Web of Science and Scopus data (2019). Note: TC: Total Cites.

Table 5. Distribution by Knowledge Area.

Research Areas WoS	Articles	Research Areas Scopus	Articles
Environmental Sciences	404	Environmental Sciences	552
Water Resources	205	Social Sciences	200
Ecology	101	Agricultural and Biological Sciences	128
Engineering	99	Engineering	105

Source: Own elaboration with Web of Science and Scopus data (2019).

3.3. Distribution by Institution

The US Environmental Protection Agency is the institution with the largest number of articles published in both databases. In WoS, the second and third position is occupied by the University of California System and the State University System of Florida, while in Scopus, these positions are occupied by Villanova University and Chinese Academy of Sciences (Table 6). The majority of the most influential institutions in this field of research are located in the United States, followed by China.

Table 6. Distribution of Articles by Institution.

Institution	Articles		Total Cites		TC/A.		H-Index	
	W	S	W	S	W	S	W	S
US Environmental Protection Agency	44	41	732	1138	16.64	27.76	15	16
University of California System	22	-	588	-	26.73	-	8	-
State University System of Florida	21	9	595	269	28.33	29.89	8	6
Drexel University	18	12	319	348	17.72	29	5	6
US Department of Agriculture	17	3	504	3	29.65	1	7	1
Villanova University	17	16	261	325	15.35	20.31	8	10
Chinese Academy of Sciences	16	17	251	305	15.69	17.94	9	10

Source: Own elaboration with Web of Science and Scopus data (2019). Notes: W: WoS; S: Scopus.

The US Environmental Protection Agency is an organization dedicated to protecting the environment and human health. The University of California System is one of the most relevant institutions of higher education in the world, being made up of ten branches throughout the state. It stands out for its training and research work in biotechnology, computer science, environmental science, art and architecture.On the other hand, the State University System of Florida is a system of higher education centers that stands out in areas such as environmental science, engineering and economics and business. For its part, Villanova University is an American training and research center that stands out for its academic offering in areas such as law and economics and business. Finally, the Chinese Academy of Science is an institution that stands out for its contribution to the field of environmental protection and human health.

3.4. Distribution by Author

The distribution by authors shows that the largest number of documents published on this subject are by Montalto & Garg (each with 11 articles) in WoS, and Shuster (with 16 articles) in Scopus; these authors are followed by researchers such as Borst (Table 7). These authors have furthered their research career in this branch of knowledge in the second decade of the 21st century. Montalto's most cited article, "A rainwater harvesting system reliability model based on nonparametric stochastic rainfall generator" [75] (102 citations), assesses the viability of rainwater for residential uses through a rainwater harvesting model. Shuster presents as his most cited article "The role of trees in urban stormwater management" [79] (83 citations). This article is in line with the previously mentioned article by Montalto and analyzes the role of trees in stormwater management. Garg's most cited work is titled "A new computational approach for estimation of wilting point for green infrastructure" [80] (51 citations), which proposes the development of a wilting point model based on the optimization approach of genetic programming in plant transpiration processes. Finally, Borst's most cited article, "Evaluation of Surface Infiltration Testing Procedures in Permeable Pavement Systems" [81] (25 citations), analyzes which surfaces are the most suitable for developing permeable pavements.

Table 7. Distribution by Author.

Authors	Articles		Total Cites		TC/A.		H-Index		1st Article	Last Article
	W	S	W	S	W	S	W	S		
Garg, A.	11	8	130	45	11.82	5.63	6	4	2017	2019
Montalto, F.	11	12	217	348	19.73	29	5	6	2010	2019
Borst, M.	10	10	98	137	9.8	13.7	6	7	2013	2019
Shuster, W.D.	9	16	118	722	13.11	45.13	6	10	2012	2019
Brown, R.A.	8	8	90	126	11.25	15.75	5	6	2013	2016
Engel, B.A.	8	4	83	78	10.38	19.5	5	4	2016	2019
Liu, Y.Z.	8	4	83	78	10.38	19.5	5	4	2016	2019
Deletic, A.	7	6	99	95	14.14	15.83	5	5	2017	2018
Gadi, V.K.	7	6	40	23	5.71	3.83	3	3	2017	2019
Traver, R.G.	7	8	161	259	23	32.38	6	7	2008	2019

Notes: W: WoS; S: Scopus. Source: Own elaboration with Web of Science and Scopus data (2019).

If the results are analyzed from the perspective of collaboration between authors, and taking into account those authors who have published a minimum of five research articles and 65 citations per document [82], it is observed that only six meet this condition (Figure 6). These are distributed in three clusters, Lee, J.G. and Shuster, W.D. being the most influential in terms of citations received and documents published.

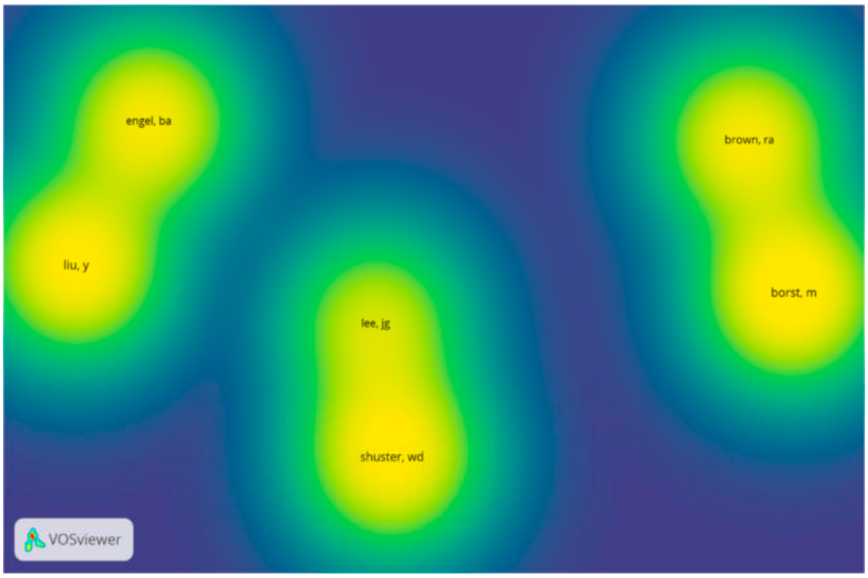

Figure 6. Density map of co-authorship network. Source: Own elaboration with Web of Science and Scopus data (2019) processed with VOSviewer software, developed by the Centre for Science and Technology Studies, Leiden University, The Netherlands.

3.5. Distribution by Journal

The distribution by journals shows that, in WoS, *Sustainability* has published the largest number of articles (33 articles) on GI and water, while in Scopus, the journal *Water* leads this ranking with 32 articles (Figure 7). The first of these journals, *Sustainability* promotes research in the environmental, social, cultural and economic sustainability of human beings, focusing on areas such as climate change, sustainable education or the creation of sustainability assessment tools.On the other hand, the journal *Water* focuses on water technology, governance and management. For example, it covers topics such as hydrology, water scarcity and flood risk. Therefore, the common ground of these journals is the concept of sustainability of water resources through GI as one of the fundamental aspects in managing the current situation of progressive climate change. They are followed in the ranking, in the case of WoS, by *Science of the Total Environment*, *Landscape and Urban Planning and Urban Forestry & Urban Greening*. In the case of Scopus, the following journals can be highlighted: *Science of the Total Environment*, *Ecological Engineering* and *Journal of Environmental Management*. In fact, if these data are supplemented with Table 4, it can be seen that *Science of the Total Environment* also includes one of the most frequently cited articles. It must be emphasized that the journals that publish the greatest number of articles on the importance of water in the operation of the GI are indexed in the first two quartiles of both databases, a guarantee of the quality of their editorial production. Furthermore, the journals previously mentioned in this section are also considered to be the most influential in terms of citations (Figure 8).

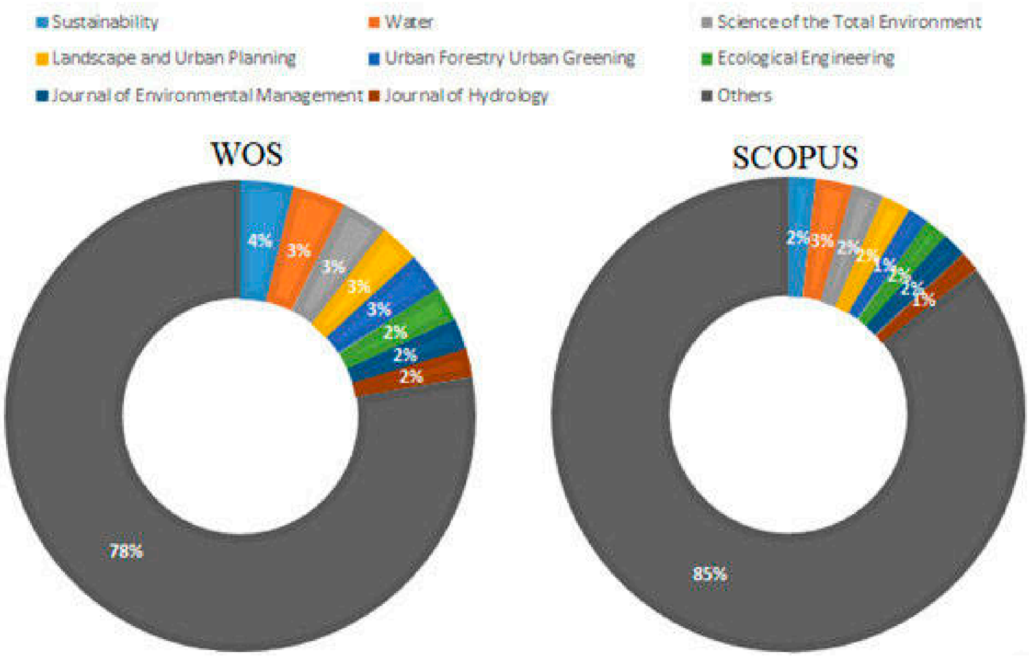

Figure 7. Distribution by most publishing journals. Source: Own elaboration with Web of Science and Scopus data (2019).

3.6. Distribution by Country and Language

The distribution by country shows that the United States, China, the United Kingdom and Australia are the most relevant countries in terms of publications in this scientific field, both in WoS and Scopus (Figure 9). They are followed by Italy, Germany and Canada, coinciding with the results obtained in the distribution by institutions. However, when adjusting the results according to population of each country, it is noted that Denmark and Australia are the most productive countries (Figure 10). As expected, the results of the distribution of articles by language confirm those obtained on the distribution by institutions, with English being the most predominant language, far above the rest.

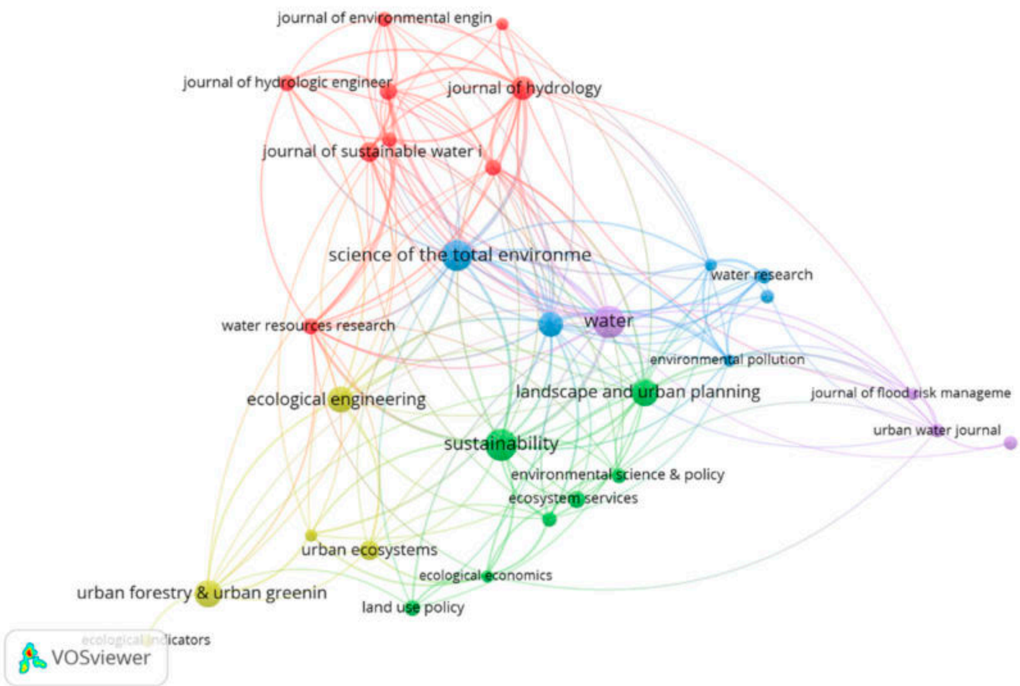

Figure 8. Science map of sources. Source: Own elaboration with Web of Science and Scopus data (2019) processed with VOSviewer software.

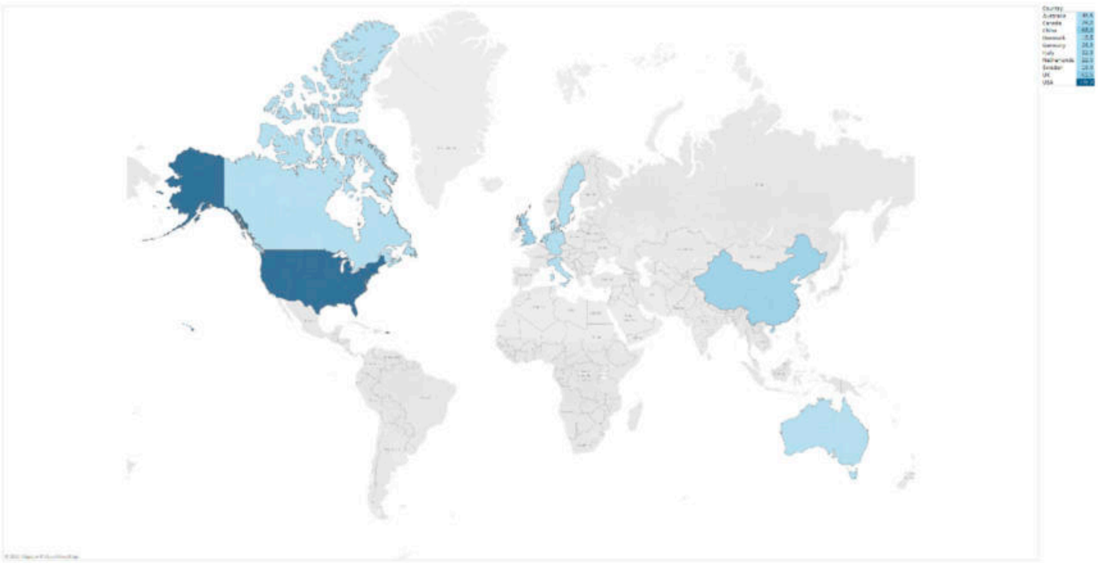

Figure 9. Distribution by Country. Note: The countries colored in blue are those with published articles. The darker the shade of that color, the greater the number of articles published. Source: Own elaboration with Web of Science and Scopus data (2019).

3.7. Analysis of Keywords and Latest Trends

In the analysis of the keywords, in the whole period from 2002 to 2019, the most prevalent concept in this type of research related to the importance of water in GI corresponds to that of *ecosystem services* (Table 8), which is defined as the conditions and processes in those ecosystems that generate and support human life [83].

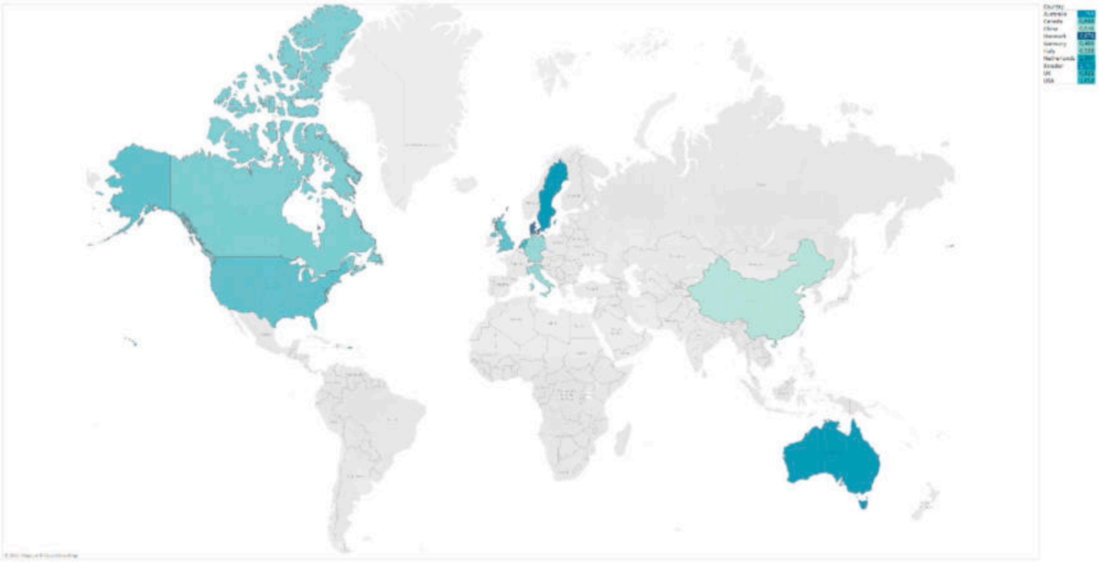

Figure 10. Distribution by Country adjusted by population. Note: The countries colored in blue are those with published articles. The darker the shade of that color, the greater the number of articles published. Source: Own elaboration with Web of Science and Scopus data (2019).

Gomez-Baggethun & Barton [69] indicate the suitability of the GI in the operation of ecosystem services to improve resilience and quality of life in urban cities, also mentioning the great socio-economic losses that would occur in the absence of ecosystems. Along these same lines, La Rosa & Privitera [84] propose the use of undeveloped areas as places of empowerment of ecosystem services through GI against a process of extensive and indiscriminate urbanization. Furthermore, Voskamp & Van de Ven [85] reinforce the role of ecosystem services as softeners of extreme weather conditions in urban environments, emphasizing the management of GI. Taken together, the importance of the concept of ecosystem services seems to demonstrate that the scientific community, within the wide range of existing definitions of this term, accepts to a greater extent those approaches that consider GI as a natural network of green and blue spaces that provides a wide variety of environmental services that contribute to human development and well-being [24,25,31].

In terms of most prevalent keywords, the above is followed in the ranking by the concept of management, more specifically, *stormwater management*. Keeley et al. [86] propose the use of GI to achieve the stormwater management objectives of urban revitalization and economic recovery. Part of the process of stormwater management, an effective and efficient way to reduce flood risks in urban areas, is the use of trees as GI [79]. Closely related to the concept of stormwater management is that of *Low Impact Development (LID)*, which consists of the use of GI in stormwater management processes in order to improve water quality [87]. Along with these terms there are also others of a more generic nature such as *runoff*, *performance*, *urban* and *quality*.

Nevertheless, it should be noted that *climate change* and *sustainability* are among the most widely used terms in the specialized literature, which shows the growing interest of the research community in planning GI solutions to guarantee sustainability in the global context of climate change. In fact, taking a look at the distribution based on Keywords Plus, *climate change* is the second most used. Therefore, from this perspective it is understood that the scientific community sees the use of GI as a tool or strategy to adapt spaces (especially those of an urban nature) to the new conditions imposed by climate change in order to mitigate its harmful effects [20].

Table 8. Most used keywords.

2002–2019			2002–2013			2014–2019		
Keywords	**A**	**%**	**Keywords**	**A**	**%**	**Keywords**	**A**	**%**
Green infrastructure	382	12.37	Green infrastructure	39	7.69	Green infrastructure	343	11.95
Ecosystem services	115	3.72	Water	10	1.97	Ecosystem services	109	3.80
Management	97	3.14	Stormwater management	9	1.78	Management	92	3.20
Stormwater management	87	2.82	Climate change	8	1.58	Runoff	78	2.72
Runoff	84	2.72	Energy	8	1.58	Stormwater management	78	2.72
Water	84	2.72	Low impact development	8	1.58	Water	75	2.61
Climate change	74	2.40	Runoff	8	1.58	Performance	69	2.40
Performance	74	2.40	Stormwater	7	1.38	Stormwater	66	2.30
Stormwater	73	2.36	Sustainability	7	1.38	Climate change	65	2.26
Low impact development	67	2.17	Biodiversity	6	1.18	Low impact development	59	2.06
Urban	62	2.01	Reuse	6	1.18	Urban	58	2.02
Urbanization	52	1.68	Ecosystem services	5	0.99	Urbanization	48	1.67
Quality	50	1.62	Management	5	0.99	Quality	47	1.64
Sustainability	48	1.55	Performance	5	0.99	Systems	46	1.60
Systems	48	1.55	Vegetation	5	0.99	Impact	43	1.50
Impact	46	1.49	Water reuse	5	0.99	Sustainability	42	1.46
Cities	45	1.46	City	4	0.79	Bioretention	41	1.43
Bioretention	44	1.42	Climate	4	0.79	Cities	41	1.43
Design	44	1.42	Design	4	0.79	Design	40	1.39
Biodiversity	43	1.39	Hydrology	4	0.79	Model	40	1.39

Source: Own elaboration with Web of Science and Scopus data (2019).

The evolution of the number of published articles represented in Figure 4 shows that the year 2013 is the turning point from which the number of publications in which GI is related to the water cycle increases. A comparison of the most commonly used keywords before and after that year shows that, in the first subperiod (2002–2013), the relationship between both concepts materialized in terms such as stormwater management, climate-change or energy, among others. Therefore, in this first period the focus of the scientific community seems to be on terms related to new approaches to engineering, urbanism and land use planning to achieve a better integration between the urbanized space and the natural environment in terms of reducing and controlling the amount and energy of rainwater and better adapting to the phenomena of Climate Change. In the second period, when the number of publications is increasing, the concept covers a wider field of action and the key term *ecosystem services* gains special relevance. This fact shows that, during this period, the concept covers a wider spectrum of scales, and the multifunctionality of GIs as a source of a wide variety of key environmental services for human well-being and as a tool for solving environmental problems through nature-based solutions takes on special relevance.On the other hand, it is in this period when in a great number of institutions globally the concept is assumed as a central element in their strategies of nature conservation, adaptation to Climate Change and urban sustainability.

Similarly to earlier comments on the analysis of Keywords Plus, despite the fact that climate-change and sustainability have fallen in the ranking of the most used keywords before and after the turning point year, the percentage in relation to the total number of keywords used is higher, which is in line with the previous reflection on a trend towards the search for strategies against climate change based on sustainable GI solutions.

However, at the beginning of the study period it was observed that neither green infrastructures nor water were found in the key words of the works published in the 2002–2005 period (Figure 11), and they were only mentioned in the concept of sustainability and best management practices (BMPs).

Furthermore, Figure 12 represents a cluster analysis of all keywords in specific time periods, in this case by yearly intervals from 2013 (the moment at which the great increase in the number of publications occurs, as shown in Figure 4) to 2019. Hence, as can be seen in purple, the most frequently used in 2013 are *green infrastructure, stormwater management/runoff, urban, hydrology, health* and *benefits*. Thus, it is detected that, at the beginning of the period analyzed, one of the key aspects of GI is the management of rainwater for the benefit of the well-being of cities. In subsequent years, shown in green or greenish-yellow, new terms such as sustainability, rainwater harvesting, ecological design, water quality or microclimate begin to appear. Finally, in yellow, the most recent terms represent aspects such as air quality, urban trees, nature based solutions, adaptation or urban stormwater. In light of this, an evolution of the relationship between GI and water is made apparent which, starting from the concern for stormwater management, has reached a stage in which scientific awareness has increased in adapting urban environments to the requirements of environmental sustainability through natural solutions that not only improve the well-being of society and the quality of water, but also of the air.

In addition, a cluster analysis of the distribution of the keywords by topic is performed and the result shows a classification into five main groups, differentiated by color (Figure 13). The first cluster, shown in blue (both light and darker blue) refers to the relationship of GI with the collection and increase of water availability, and what tools can be articulated to carry out this task. A second cluster, shown in yellow, represents those concepts referring to the environmental quality of urban spaces that are related to GI. The red cluster revolves around concepts related to ecology, environmental services, and climate change adaptation and mitigation policies, which could be grouped within NbS. The green cluster revolves around the concept of rainwater and management of this source, as well as in the elements that enhance pavement permeability. Finally, the group in purple represents the concept of sustainability, linked to efficiency in the management of groundwater and reservoirs.

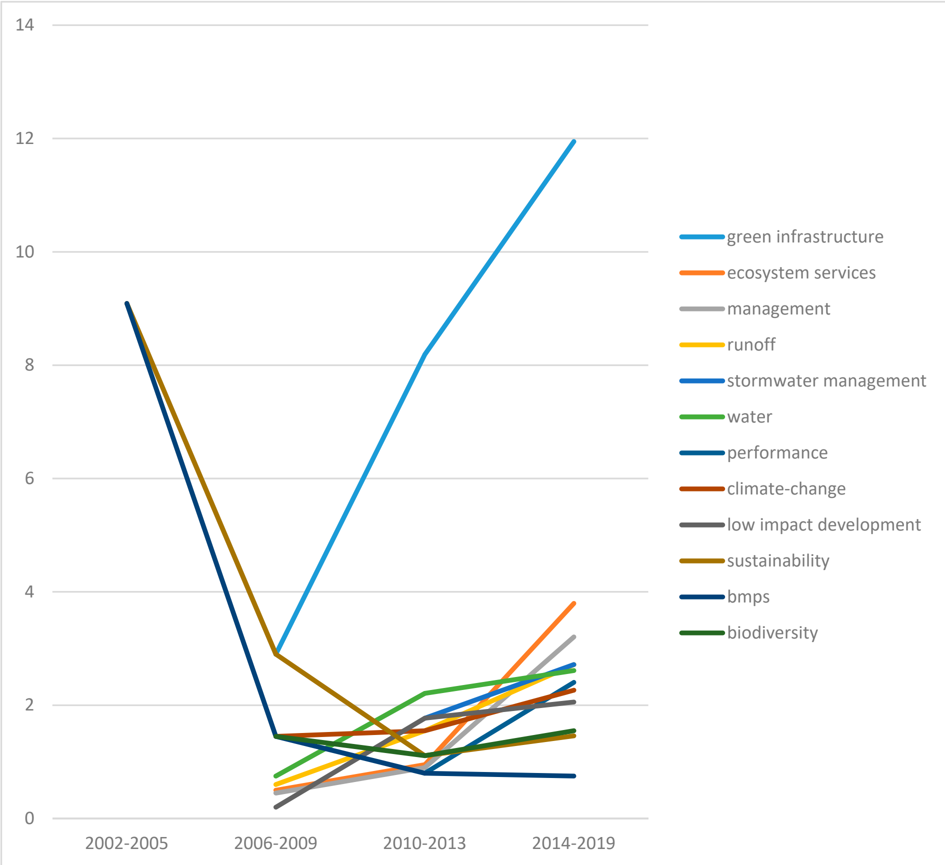

Figure 11. Normalized frequency of occurrence for each keyword among papers published in the time period considered. Source: Own elaboration with Web of Science and Scopus data (2019).

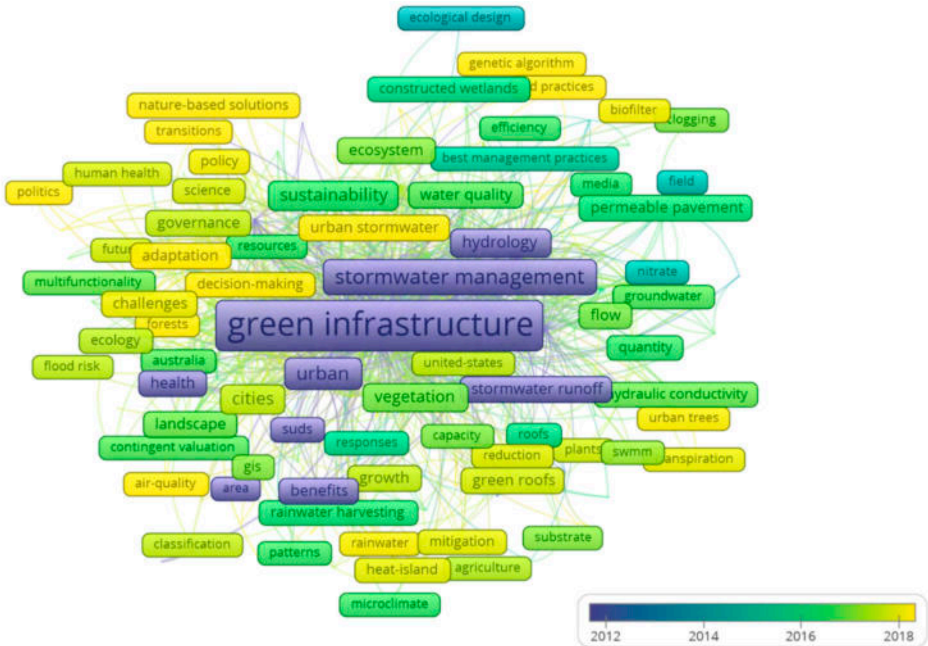

Figure 12. Keyword Cluster by Year. Source: Own elaboration with Web of Science and Scopus data (2019) processed with VOSviewer, developed by the Centre for Science and Technology Studies, Leiden University, The Netherlands.

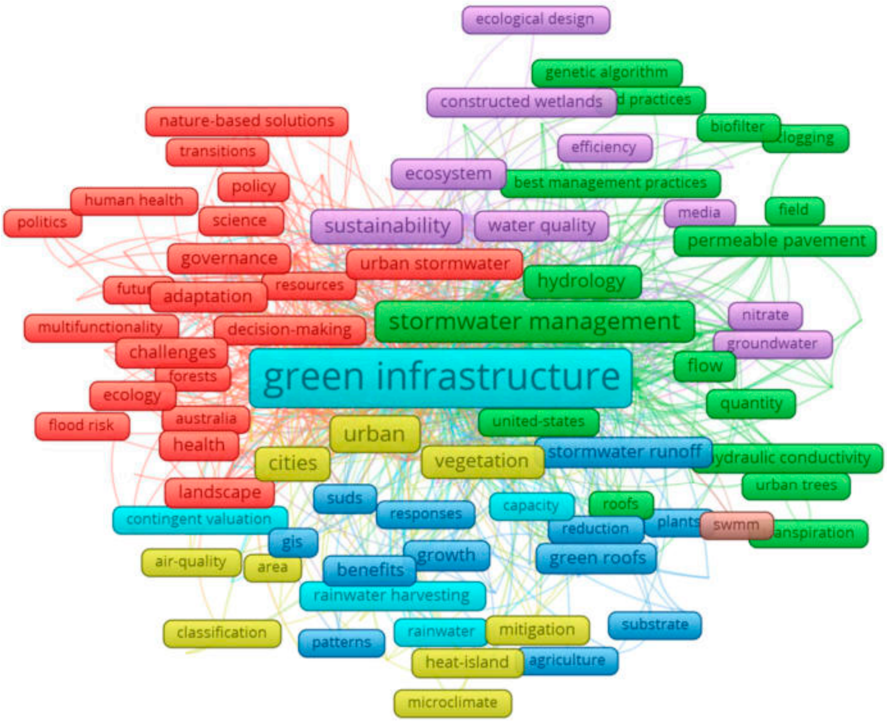

Figure 13. Keyword Cluster by Topic. Source: Own elaboration with Web of Science and Scopus data (2019) processed with VOSviewer software, developed by the Centre for Science and Technology Studies, Leiden University, The Netherlands.

This distribution in clusters becomes even more precise in three groups if we analyze the words used only in titles and abstracts of articles that deal with the relationship between green infrastructure and the water cycle (Figure 14).On the one hand, in red, the concepts of ecosystem service, sustainability, policy and challenges are highlighted, indicating that the sustainable management of ecosystem services is a challenge to be met by the authorities; in blue, nature based solutions such as trees, forests and other types of vegetation are represented, and in green, aspects related to stormwater management such as runoff or low impact development are found. Overall, the three fundamental pillars of the abstracts and article titles that relate green infrastructure to the water cycle are ecosystem services, nature based solutions and stormwater management.

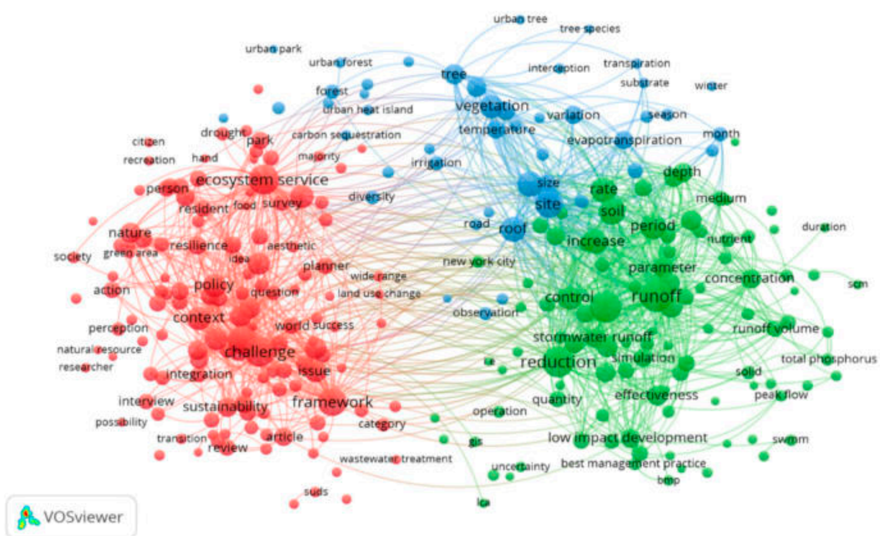

Figure 14. Cluster by topic of words in abstracts and titles of published articles. Source: Own elaboration with Web of Science and Scopus data (2019) processed with VOSviewer software, developed by the Centre for Science and Technology Studies, Leiden University, The Netherlands.

4. Conclusions

This work serves to confirm that, in the field of water study, the term GI is relatively new, since it first appeared in the early 21st century. The use of this term grew exponentially from 2013, coinciding with the increase in work and research related to the environmental services of ecosystems and the possibilities that nature offers to tackle problems related to urban planning, the management and purification of water, agri-food security, flood control or adaptation to climate change. In the case of Europe, it coincides with the GI strategy of the European Commission to improve the economic benefits of this tool and thus achieve its biodiversity objectives for 2020. This growth in the volume of publications on GI is expected to continue in the future, not only because of the economic benefits that GIs generate but also because of the ecological, social, and public health and welfare benefits.

On the other hand, it is worth mentioning that the most cited articles during the period studied, to a large extent, deal with issues related to the conservation and management of IGs for the improvement of the environmental quality of urban environments, which shows a growing involvement of urban planning professionals in this field.

The non-existence of a universally accepted definition of GI calls for further efforts in this type of literature that favor consistency and clarity in this field of research. Despite this, it appears from this analysis that we are dealing with a field of research widely spread across all continents (with the exception of Africa), with the United States, China, United Kingdom and Australia publishing the greatest number of articles on GI and water. Likewise, its multidisciplinary character is reflected in the diversity of areas of knowledge with which it interacts, including topics such as those related to protection against natural disasters, the provision and regulation of water resources such as groundwater and reservoirs, the planning and environmental improvement of urban spaces, health, the ecology and conservation of biodiversity, and adaptation to the effects of climate change.

This research indicates that in the scientific literature related to GI and water management the concept with greatest relevance is ecosystem services, a fact that values the capacity of these infrastructures to facilitate multiple goods and services related to the water cycle, such as the potable water supply, climatic regulation, flood control, water purification or disposition of spaces of recreation for the population.

The scientific literature focusing on the importance of GI in water management has been dominated by concepts such as ecosystem services, stormwater management, climate change and sustainability, terms which are considered to be the most widely used in this field. In fact, the importance of the concept of ecosystem services indicates that green infrastructure is an essential tool for improving human well-being by NbS. Also, the latest keyword trends focus on aspects related to NbS such as stormwater management, forests and green rooves, among others. Therefore, from this perspective, the opportunity is opened for new lines of research based on the analysis of other elements related to GI, such as groundwater.

On the other hand, GI offers the opportunity to lessen the adverse effects of climate change and, thus, generate important benefits from the perspective of human health and well-being. In the current context of the global health crisis, another recommendation for future research is to continue advancing precisely the analysis of the role of GI from the perspective of public health. Consequently, it is also necessary to improve the definition of GI and future work is needed to advance the search for new methodologies that facilitate an assessment of the monetary and non-monetary benefits of GI.

Likewise, the current global crisis opens up lines of research in the field of green infrastructure as an emerging sector in the process of economic reconstruction after the harmful consequences of the Covid-19 pandemic.

This work is not exempt from certain limitations as it has been limited to an analysis of the role of GI in water management. It would be interesting to repeat this analysis process for other types of infrastructure of a similar nature. Likewise, another proposal for a future line of research consists of not limiting the analysis to water resources but rather extending it to other natural resources.

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2.2. Green Infrastructures and Grand Environmental Challenges: A Review of Research Trends by Keyword.

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Green Infrastructures and Grand Environmental Challenges: A Review of Research Trends by Keyword

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Abstract: This article aims to analyze research trends on the role played by green infrastructures as a tool seeking to address current environmental challenges, such as climate change, that put human well-being at risk. For this purpose, a bibliometric analysis was used on documents obtained from the WoS database, and selecting the combination of words "green infrastructures", "ecosystem services", and "climate change". The results of this study point to the potential for Green Infrastructures to become a major strategic factor in addressing the global environmental and social challenges facing cities. The findings obtained are relevant to researchers, professionals, and others working on green infrastructure research as tools to address current global environmental problems, such as climate change, urban pollution, loss of biodiversity, or the risk of emergence of new epidemics or diseases.

Keywords: bibliometrics; green infrastructures; climate change

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1. Introduction

Recent studies show the relationship between the degradation and pollution of natural ecosystems and the increased risk of disease or economic losses for the human population as a result of extreme environmental events [1–3].

This seems to show that the environmental challenges we face as a society, such as climate change or loss of biodiversity, are not only an ecological problem but also a health and economic one.

Therefore, it is essential to change the mindset when addressing economic, health, and spatial planning policies and strategies to include measures aimed at integrating natural and urban systems and protecting biodiversity.

These policies should not treat natural habitats as merely a source of resources or energy to produce goods and services; it is also important to remember that they also provide other environmental services that are key to human well-being, such as climate change, food security, and reducing the risk of environmental disasters and diseases.

Historically, conventional economics has not valued these environmental services. However, recent research shows that the economic value of natural ecosystems in terms of their contribution to human well-being and health have an economic value between 10 and 100 times higher than the cost related to its conservation [4–6].

In this new context, Nature-Based Solutions that embrace actions that support ecosystems and provide services that increase and protect human well-being, health, and development [7,8] become crucial.

Included among these solutions are Green Infrastructures (GI), a strategically planned network of natural and semi-natural spaces and other environmental elements designed and managed to offer a wide range of ecosystem services (Figure 1) [9].

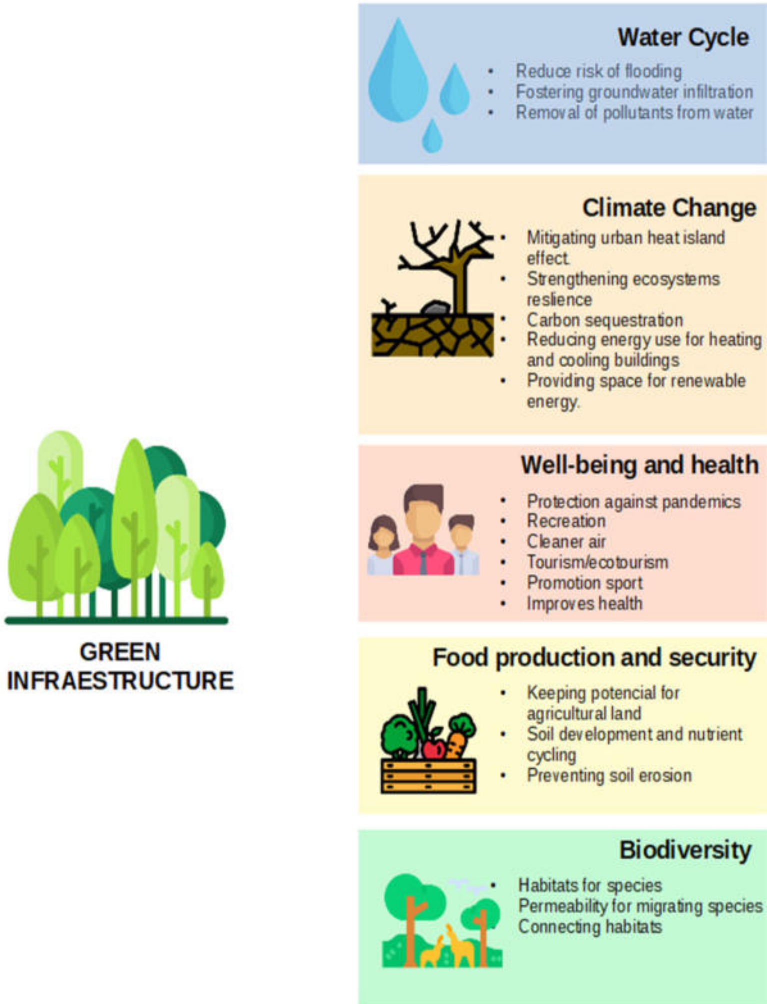

Figure 1. A Potential Ecosystem of Green Infrastructure Services.

Investment in GI is based on the logic that investing in nature-based solutions will always be more profitable than replacing these environmental services with human technological solutions [10].

GI is a new term that seeks to simplify complex ecological concepts related to ecosystems' functioning and the environmental services they provide by making an analogy between the infrastructure of natural systems and the gray infrastructure of artificial human systems, such as roads, electrical networks, or hydraulic infrastructures. It encompasses both green spaces in land (natural, rural, and urban) and marine areas.

In essence, we can specify that the term GI is based on three fundamental mainstays: ensuring the maintenance of ecosystem services, recovering and improving ecological connectivity to promote biodiversity conservation and applying measures to correct environmental imbalances in ecological restoration [9].

In the European context, this concept of GI is fully established, having been assumed as the primary element of the strategies of European institutions to achieve a climate-neutral Europe and protect natural habitats for the benefit of people, the planet, and the economy [9]. In this regard, the European Commission draws attention to the formulation of the Green Pact, a new growth strategy based on a green and just transition, which plans to mobilize at least EUR 100 billion during the period 2021–2027 [11].

These European policies suggest that GI could become a significant strategic factor for European cities and municipalities in addressing global environmental challenges and the economic and social reconstruction that will be necessary following the coronavirus epidemic.

As a result of the future relevance of GI, this study presents research trends on the subject regarding environmental challenges. The contribution of this paper focuses on research into scientific production from a global dimension of green infrastructures through the analysis of keywords. The findings obtained are relevant to researchers, professionals, and others working on green infrastructure research as tools to address current global environmental problems, such as climate change, urban pollution, loss of biodiversity, or the risk of emergence of new epidemics or diseases.

2. Materials and Methods

To this end, the Web of Science (WoS) database was used, selecting the combination of words "green infrastructures", "ecosystem services", and "climate change". The documents' complete metadata were filtered to include only articles. The data were then extracted and subsequently processed using two bibliometric analysis tools, *VOSviewer* and *Biblioshiny* [12], through the analysis of Keywords Plus and Author Keywords [13]. The research techniques that use bibliometrics facilitate the discovery of trends in a particular research field by exploiting their keywords. Through these, it is possible to know which themes are of eminent topicality and understand their evolution [14].

WoS records provide two useful indicators for analysis: the keyword field as provided by the author and that expresses the essence of the research document and the Keywords Plus field, an algorithm that provides extended terms derived from the cited references or the bibliography of the record [15]. Moreover, Keywords Plus provides additional search terms, as they are extracted from the titles of the documents cited in their bibliographic records [16].

In the present case, to study the link between green infrastructures, environmental services they provide, and their contribution to adaptation and mitigation processes of climate change effects, the following three terms were selected: "green infrastructure", "ecosystem services", and "climate change".

Data for this study were extracted from the WoS database due to its breadth and high quality [17–19]. Likewise, WoS collates articles published in impact journals, with Journal Citation Report (JCR) being the best-known quality indicator and the most valued by research evaluation bodies, measuring the impact of a journal according to the citations received.

Figure 2 depicts the methodological process applied. The following search for terms was applied: "green infrastructur*" and "ecosystem servic*" and "climate change". A dataset of 216 documents was retrieved, of which 175 are articles. It was necessary to apply the filter to limit the sample to those documents that have a certain quality since impact journals have a very rigorous review process. As the first article found in the WoS database with this combination of terms is from 2008, the topic is deemed to be a recent one.

For the development of this research, two software programs, *VOSviewer* and *Biblioshiny*, were used for bibliometric mapping. In the case of the latter, it takes into account the advantages of the calculation algorithms and the graphical representations generated [20]. The justification of choice was determined mainly because *VOSviewer* can analyze clusters, co-occurrence, and display trends in their entirety using a full counting method. On the other hand, *Biblioshiny* offers a broader descriptive analysis, segregation by two indicators (Author Keywords and Keywords Plus), and more attractive visualization, being more user-friendly and easier to use than other tools [21].

In the case of *VOSviewer*, this program facilitates the visualization of bibliometric networks supporting a significant quantity of metadata [22,23]. From the download of records from WoS, produced by Clarivate Analytics of complete records and quoted references in plain text, 175 articles were analyzed from the period 2008–2020.

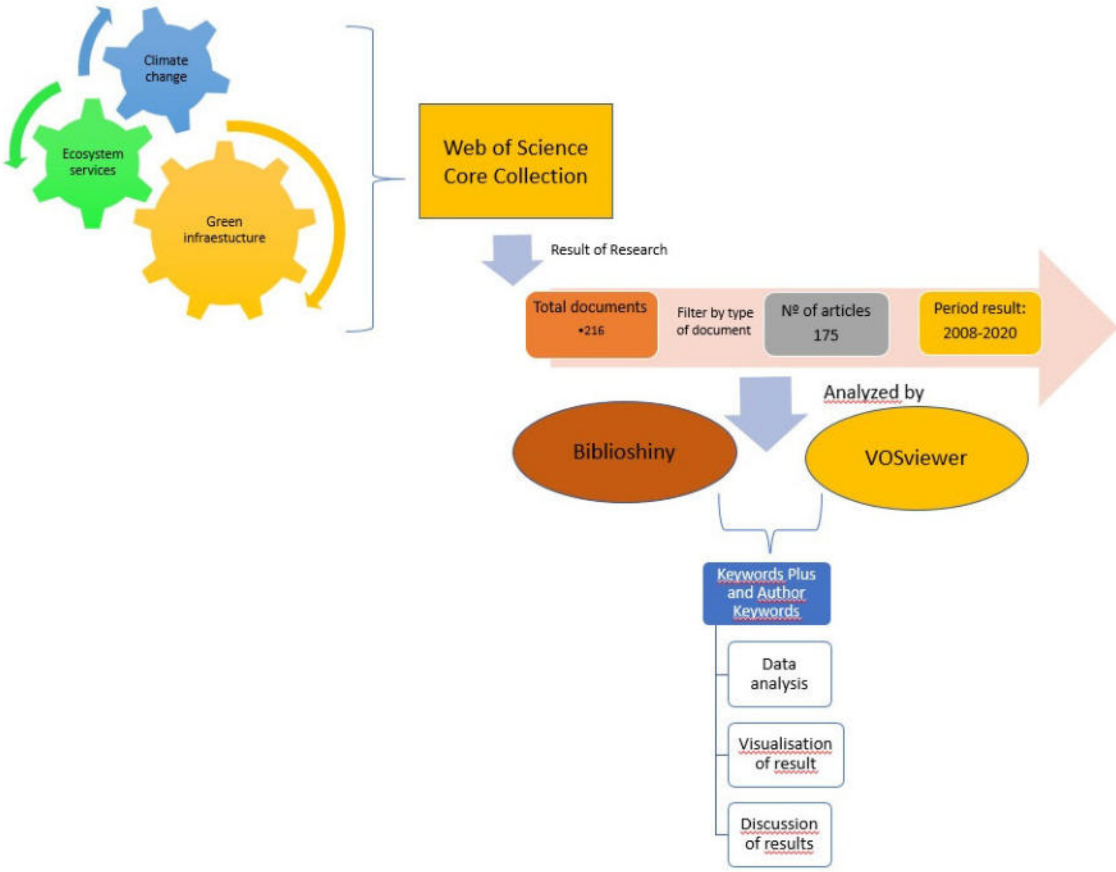

Figure 2. The Data Processing Procedure. Source: Own compilation.

In parallel to this analysis, the *bibliometrix* package offers a set of tools for quantitative research in bibliometrics using the R programming language [24] to identify research streams and topics through the use of keywords found in the literature [25]. It uses the same file as the previous case and runs it through the R-studio console loading *library (bibliometrix)*; *biblioshiny*. Once the action was executed, we deployed the "*biblioshiny*" interface as it is easier and more intuitive to use, thus avoiding the R language [20,26]. Following this step, we selected the database to obtain the results and view the visualization maps. The program is organized according to the scientific mapping workflow.

Three levels of metrics are presented in the graphs and analysis (source, author, and document). There are three knowledge structures (conceptual, intellectual, and social). For this research, particular interest is placed on two specific bibliometric indicators, those of Author Keywords and Keywords Plus, in order to assess the documents.

Firstly, to discover the most prominent topics using *VOSviewer*, the words extracted from the titles, abstracts, Author Keywords and Keywords Plus of the articles were analyzed, where, from 1087 words retrieved, 71 matches were found. From this point, we analyzed the links between the words grouped into five clusters and the topic trends of the selected database (175 journal articles).

Secondly, to identify the corresponding research field, scientific articles were analyzed where Author Keywords and Keywords Plus were analyzed separately. The cluster map was created using the *Biblioshiny* tool [24] using the conceptual-structure function where the themes highlighted by the Author Keywords and by Keywords Plus are expressed.

With these tools, it is possible to study research trends by analyzing the words given by the author and Keywords Plus to answer the following question: Are there any discrepancies in trends between the two bibliometric indicators (Author Keywords and Keywords Plus) in the case of green infrastructures? The results of the analysis and discussion are presented simultaneously.

3. Results and Discussion

In the bibliometric map, the clusters' size was determined by different factors such as Keywords Plus and Author Keywords within the clusters, the frequency of occurrence and their weight. As a result, five thematic clusters were obtained that defined the main lines of research on green infrastructures (Figure 3).

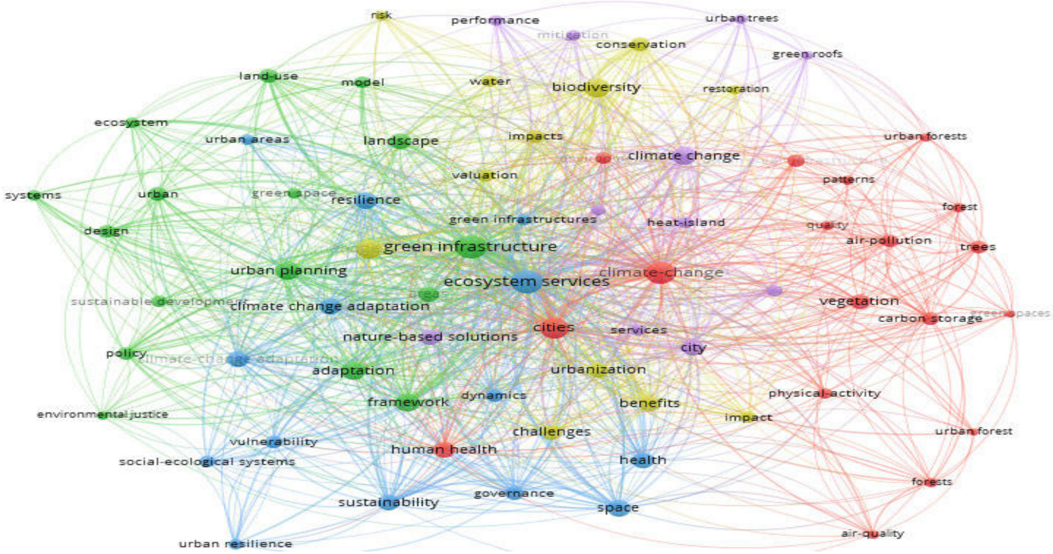

Figure 3. Visualization of Cluster Network of all Keywords Source: *VOSviewer*. Own Compilation.

Cluster 1 (green) This cluster is closely related to the concept of urban green infrastructures and the need to reconnect more than half the planet's population living in urban areas with the biosphere [27].

This cluster groups articles investigating the possible involvement of GI with aspects related to urban planning, land-use management, climate change mitigation and adaptation policies, and other environmental risks faced by cities.

In this sense, more and more research is showing the multifunctionality and resilience of green infrastructures, especially in urban areas, which if properly planned and managed can contribute to improve both social and environmental aspects, favoring resilience and quality of life in cities [28–33].

On the other hand, there is also evidence that the gradual loss and degradation of green infrastructure elements in urban areas can lead to economic losses and impacts on the social and cultural values of cities [34].

The importance of green urban infrastructure lies in the growing number of studies showing that adequate urban planning and management can lead to health benefits such as adequate physical condition, mental health recovery, or stress reduction, or reducing the risk of cardiovascular diseases. They can also provide greater social capital and, finally, can provide us with numerous environmental services such as better air quality, greater biodiversity, reduction in noise pollution and heat island effects frequent in cities [28,35,36].

Cluster 2 (blue) The central pillar of this group is the close link between environmental services provided by GI and the health and resilience of socio-ecological systems.

This cluster includes research related to the beneficial contribution of Green Infrastructures on the health and human well-being of populations in the current scenario of Climate Change [37,38].

Cluster 3 (yellow). This cluster groups articles dealing with the potential of GI to contribute to biodiversity conservation, focusing on improving spaces where species and habitats have been lost as a result of urbanization, changes in land use, or as a result of climate change [39–42].

This cluster also includes studies relating to the positive impacts of biodiversity on environmental services provided by GI, such as adaptation to the adverse effects of climate change, human health benefits, or protecting against infectious diseases or pandemics [43–45].

In Cluster 4 (red) and Cluster 5 (purple) are articles that address green infrastructures from a local scale and from the specific field of the importance of urban vegetation to mitigate the effects of climate change [46]. The impacts can occur in the form of floods, an increase in the urban heat island effect, increased water deficit, or various forms of pollution, causing severe damage to the environment, human health, and the economy.

More specifically, Cluster 4 includes research articles related to elements of urban green infrastructure, such as trees and urban gardens, urban vegetable gardens, peri-urban forests, green roofs or wetlands, and how they provide climate change benefits, such as carbon sequestration, local climate regulation, or protection from floods or other extreme effects [35,47,48].

It also encompasses articles focused on the benefits that vegetation in urban areas produces in relation to the reduction in air pollution, which promotes human well-being, health and development [7,36,37,49].

Consistent with this group, Cluster 5 (purple) contains a group of articles that refer to concrete solutions offered by green infrastructure in urban environments to mitigate the effects the heat island effect, such as urban trees or green roofs [50,51].

An analysis of future trends (Figure 4) shows the terms landscape, policy, environmental justice, nature-based solution, adaptation, urban resilience, health, space, air-quality, and benefits.

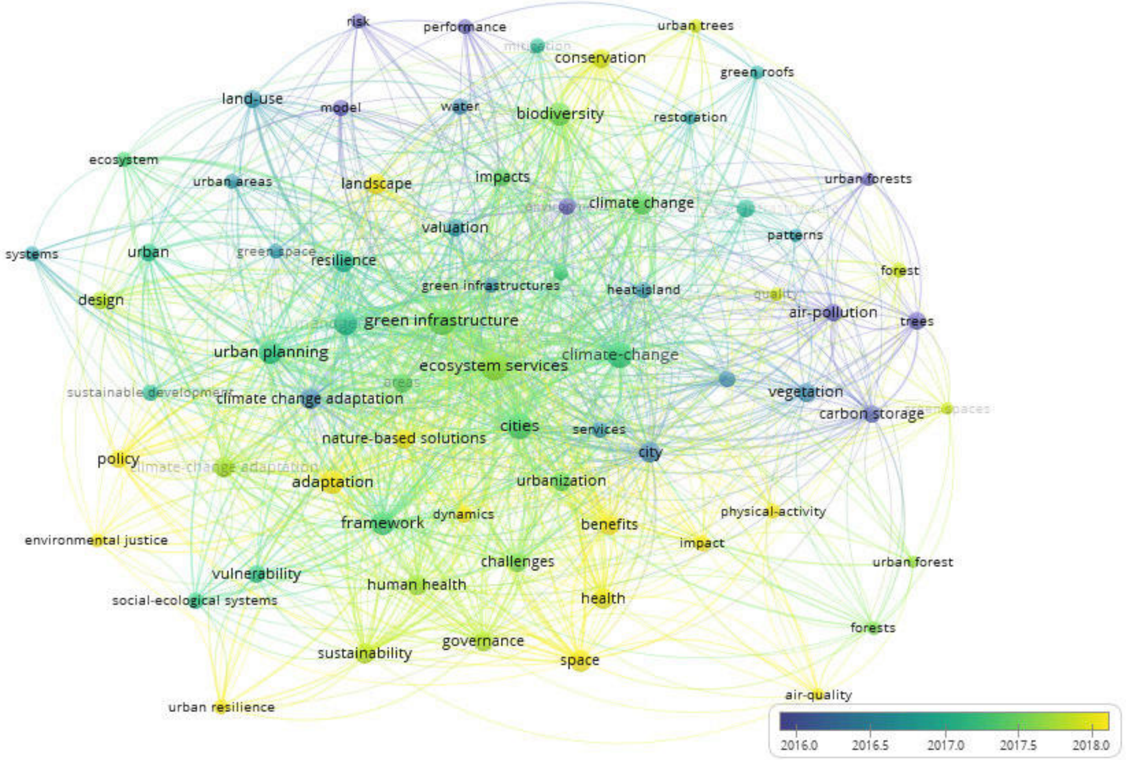

Figure 4. Overlay Visualization of Future Trends by all Keywords. Source: VOSviewer. Own Compilation.

If we analyze the importance of words according to the two criteria (Author Keywords and Keywords Plus), it is observed that the terms “green infrastructure”, “ecosystem services”, and “climate change” coincide in both cases, with the only exception that its position varies according to their frequency of use.

Figures 5 and 6 show the Author Keywords and Keywords Plus that appear most frequently. They also display the three keywords selected for the study (“green infrastructure”, "ecosystem services", and "climate change"), which, in both cases, are terms that relate to urban green infrastructure (urban planning, cities), biodiversity and the resilience and adaptation capacity of green infrastructures (climate change adaptation, resilience, adaptation).

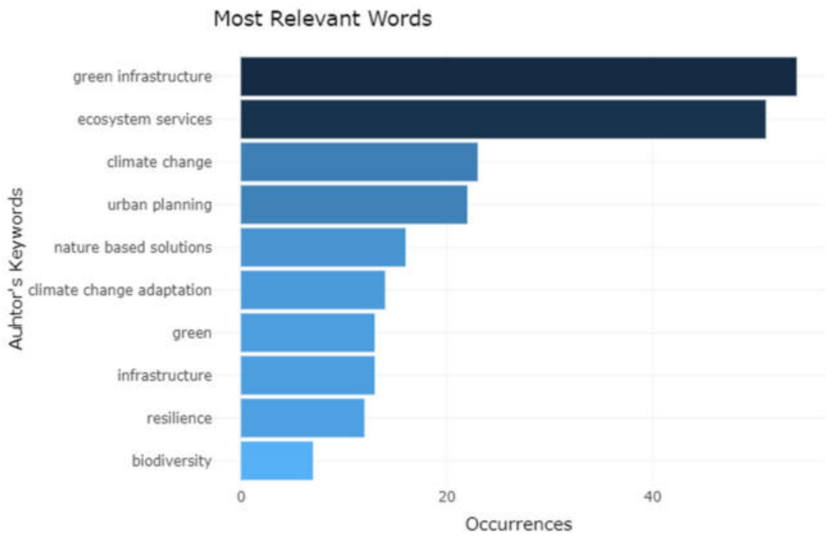

Figure 5. Comparison of Author Keywords by number of occurrences. Source: Biblioshiny. Own compilation.

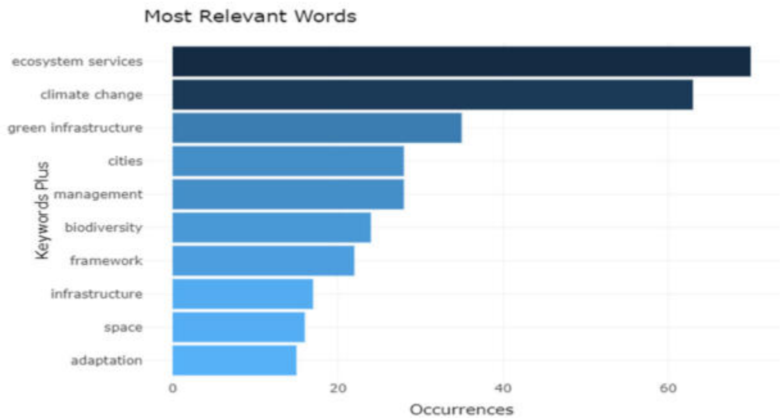

Figure 6. Comparison of Keywords Plus by number of occurrences. Source: Biblioshiny. Own compilation.

According to the thematic evolution of Keywords Plus (Figure 7), it can be observed that the term "ecosystem services" in the 2019–2020 period has been integrated with climate change issues in the same way that climate change is included into biodiversity research in the 2019–2020 period.

Both results are in line with the current scientific consensus on the suitability of applying nature-based solutions to address the challenge of climate change and on the fundamental role that biodiversity plays in this model.

If we compare the thematic evolution concerning Author Keywords (Figure 8), only two main themes appear where "ecosystem services" diversifies towards "urban-planning" and "green infrastructure" and for the current period branches out to become "climate change".

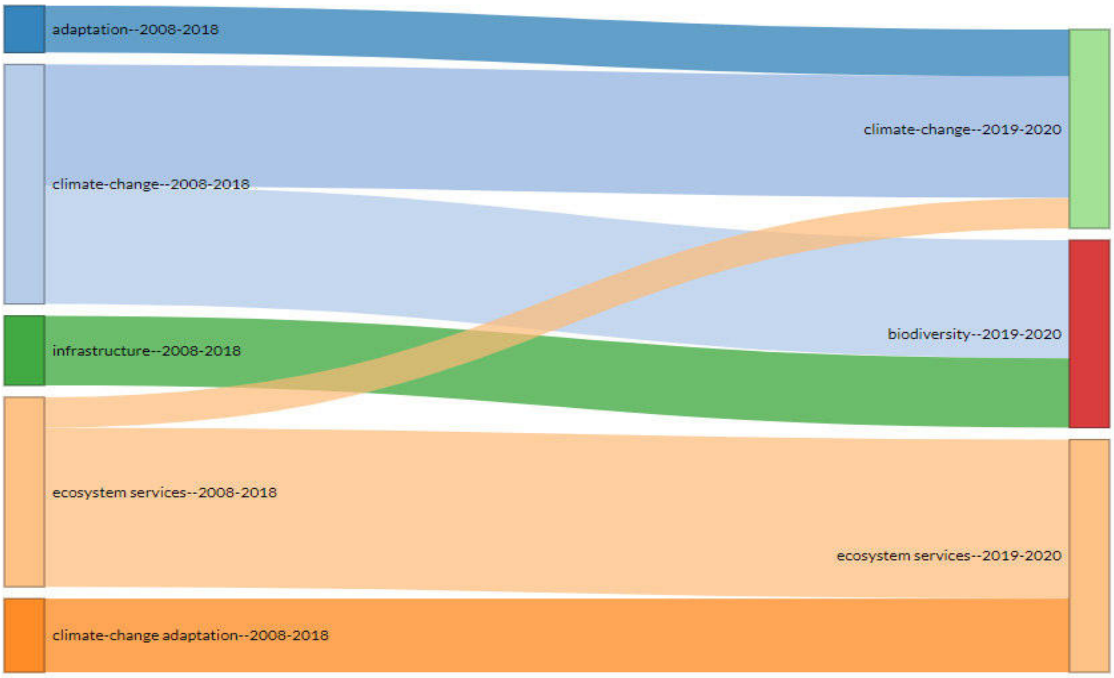

Figure 7. Topic Evolution by Keywords Plus. Source: Biblioshiny. Own compilation.

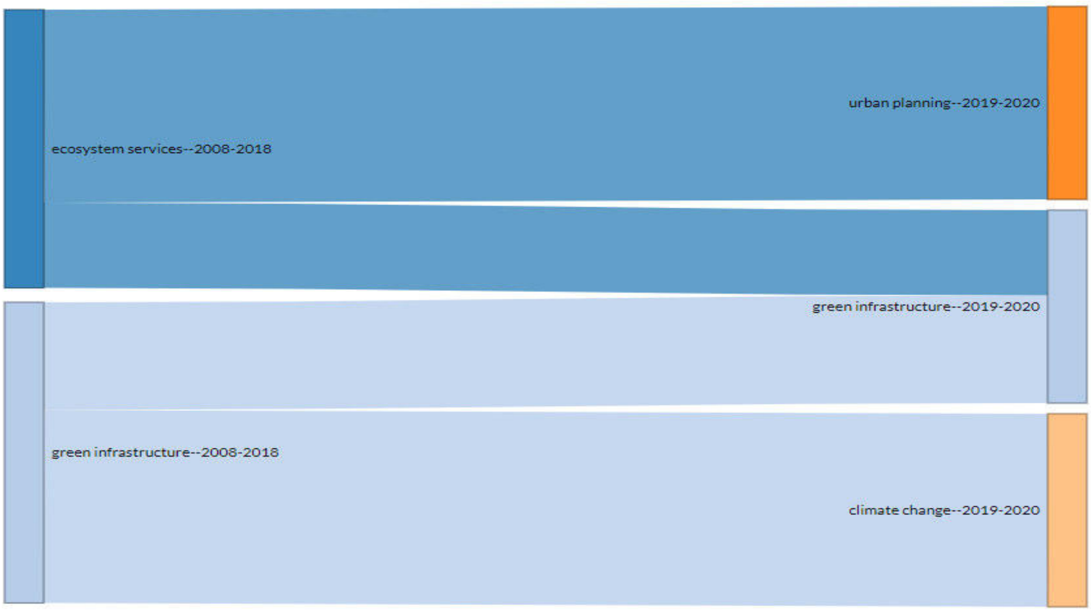

Figure 8. Topic Evolution by Author Keywords. Source: Biblioshiny. Own compilation.

In the strategic diagram based on Keywords Plus (Figure 9), four zones consider two variables: centrality and density. The first refers to the degree of interaction of one cluster with another, and density refers to the internal cohesion. In other words, the higher the centrality, the higher the relevance of the term, and the higher the density, the higher the development of the term [52–54]. Biodiversity is found in the upper right quadrant as a driving theme of this research field, evidence of the crucial importance of this variable in environmental services and green infrastructures. On the other hand, issues related to "green infrastructures", "climate change", and "ecosystem services" are located in the lower right quadrant, evidence that they are essential and fundamental cross-cutting and general topics in this field of research.

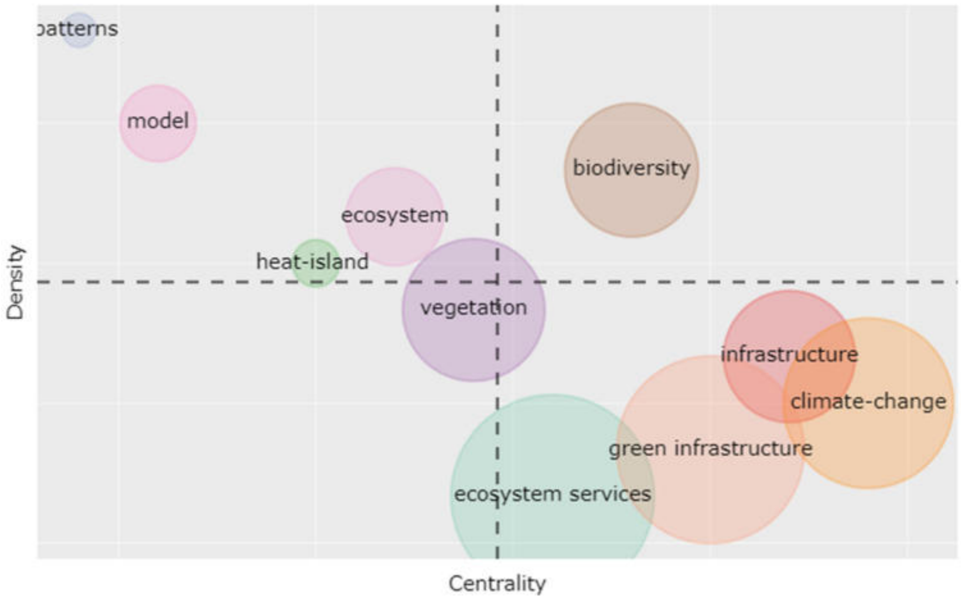

Figure 9. Thematic Map by Keywords Plus. Source: Biblioshiny. Own compilation.

There are very specialized and peripheral themes in the upper left quadrant (Figure 9): model, ecosystem model, and heat-island. Immediately at the bottom of the quadrant, vegetation could be considered a declining issue, which could be related to the greater weight that ecosystem solutions have taken in recent times compared to those in which only vegetation implantation actions were contemplated.

The following results are shown below using the Author Keywords (Figure 10). As with Keywords Plus, biodiversity remains the driving theme of the specialty. The term "green infrastructure" remains in the lower right quadrant, evidence that it is a very cohesive cluster with associated terms (ecosystem services, climate change, and urban planning) followed by the developing terms of resilience and ecosystem.

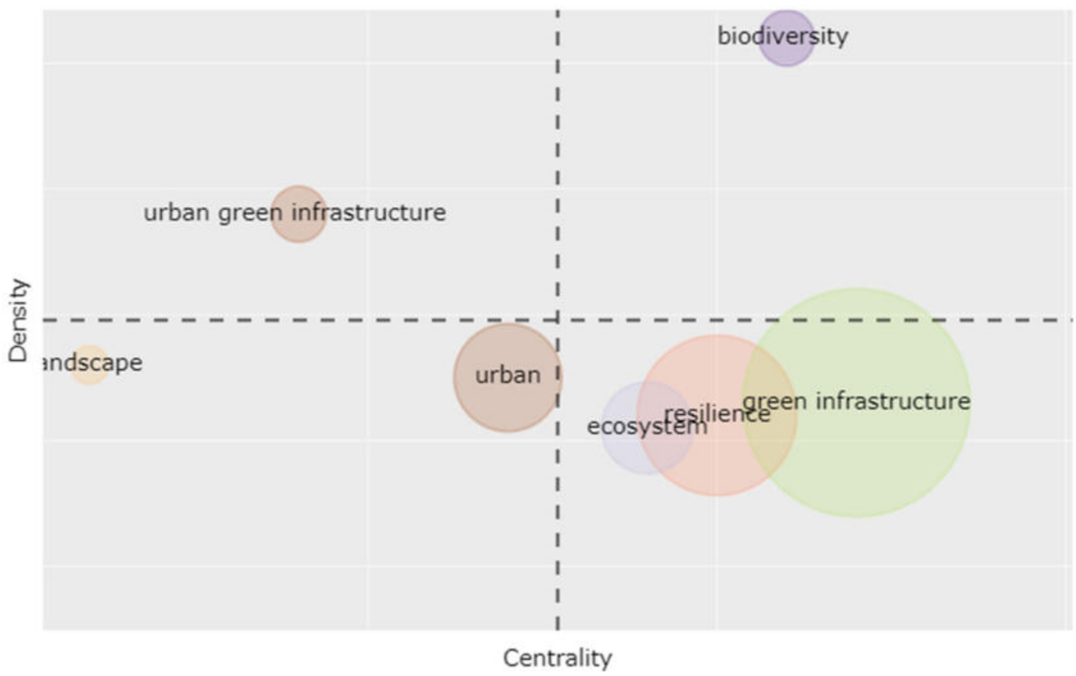

Figure 10. Thematic Map by Author Keywords. Source: Biblioshiny. Own compilation.

In the upper left quadrant, the urban green infrastructure cluster is characterized by marginal importance for the field. On the other hand, urban, located in the lower left quadrant, is considered a critical, though declining term which has less interest in the research scenery on GI and environmental challenges. Both issues may be related to the emergence of a new term, “urban resilience”, understood as a way of building cities that adapt to any natural threat or crisis [55].

This concept seems to be replacing that of green urban infrastructures among the scientific community. On the other hand, according to Author Keywords, the aforementioned concepts of resilience and landscape have appeared as the most innovative terms in the field of research [56–59]. This aspect is also reinforced in the results obtained in the *VOSviewer* trend chart.

Figure 11 shows the more innovative terms in this research field, such as “urban resilience” and “landscape”, which confirm their fundamental role in the scientific research field of green infrastructures in addressing urban planning and territorial management policies from a social, environmental, and economic sustainability perspective [38,54,55].

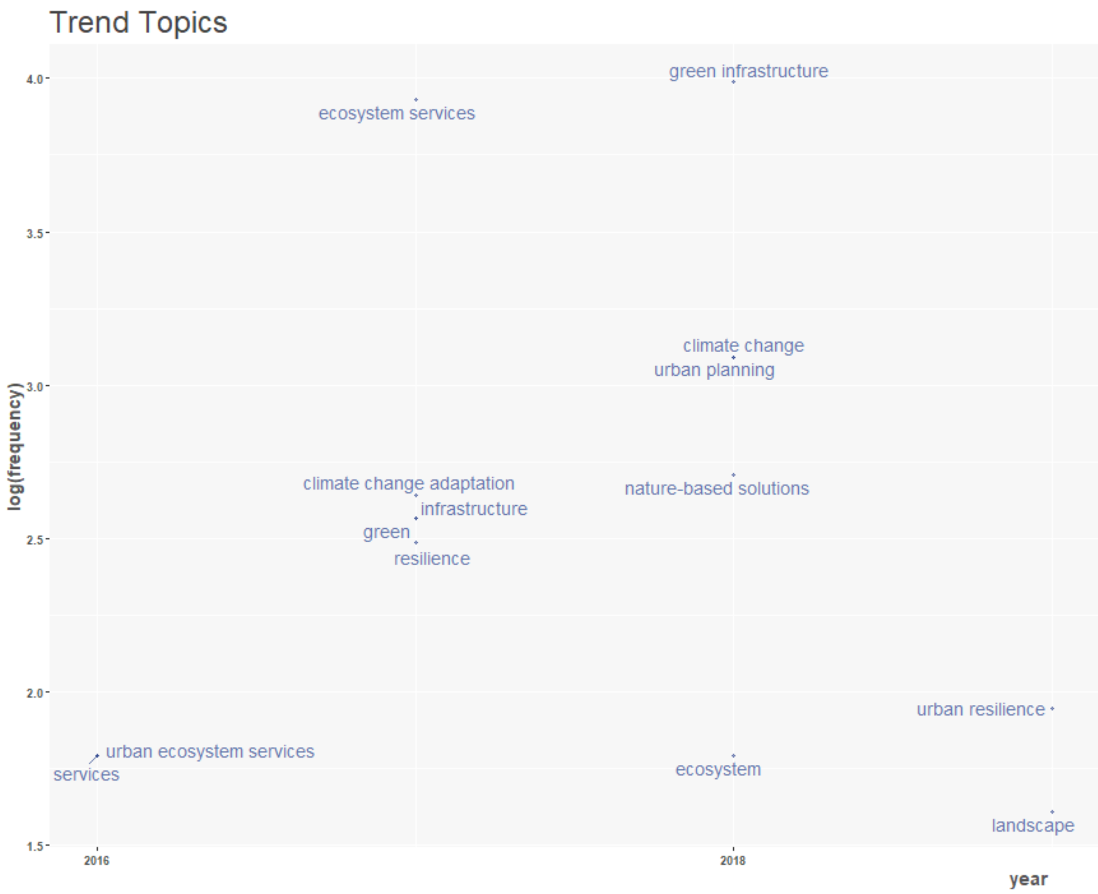

Figure 11. Trend topics by Author Keywords. Source: Biblioshiny. Own compilation.

In contrast, the Keywords Plus analysis (Figure 12) reveals that air-quality and physical-activity are the most recent terms in this research area, revealing two of the primary environmental services provided by green infrastructures: their contribution to improving air quality and reducing pollution [59–61] and its contribution to indirectly improving human health by promoting physical activity [62,63].

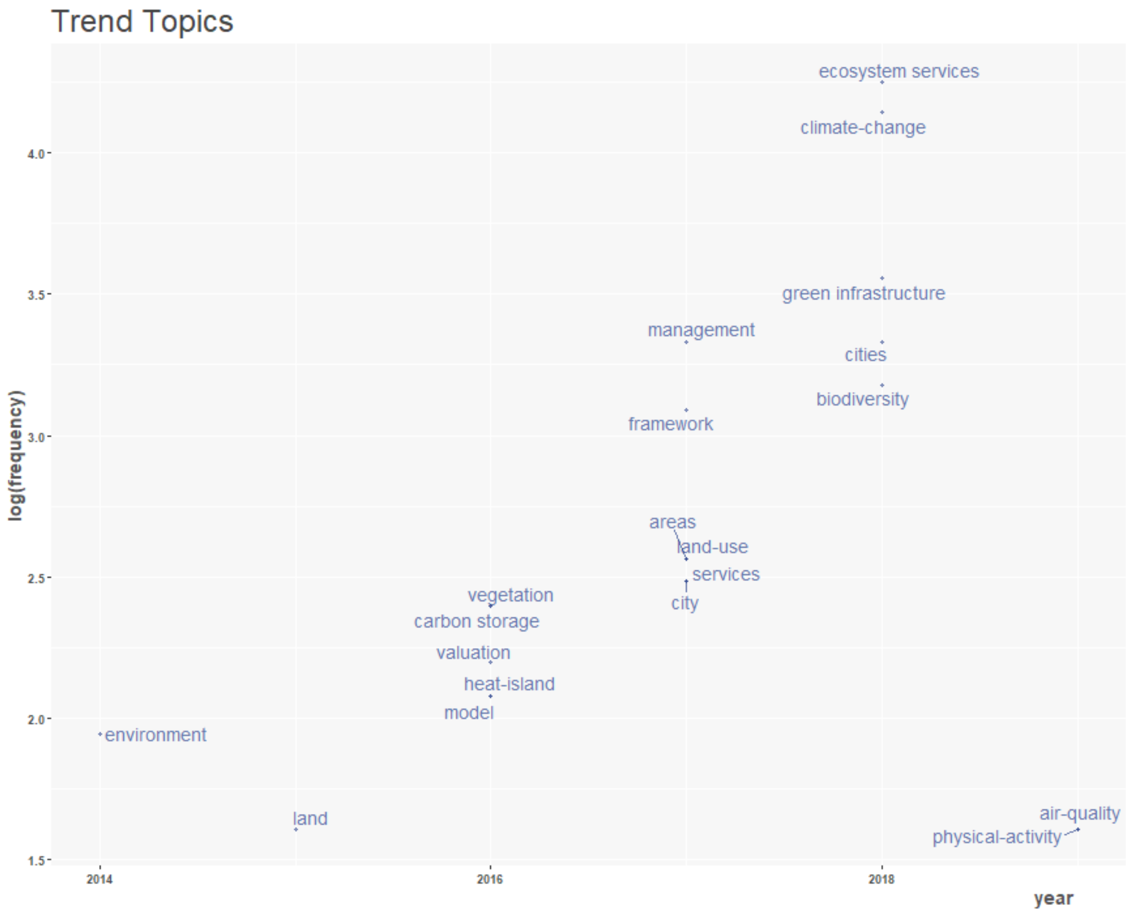

Figure 12. Trending Topics by Keywords Plus. Source: Biblioshiny. Own compilation.

A Multiple Correspondence Analysis (MCA), a matrix of Document × Word A co-word analysis, was applied with the words drawn on a two-dimensional map [64]. It categorizes the keywords in the documents into groups according to two dimensions: the frequency of use of each term and the joint use of the terms in each document. The results are interpreted based on the relative positions of the points and their distribution along the dimensions; the more similar the words are in their distribution, the closer they are represented on the map [24]. The parameters used in the analysis were automatic clustering and setting 50 as the maximum number of terms [54,65]. Both figures show the structure of the concept map representing the relationships between terms in a set of publications

In the analysis of the Keywords Plus (Figure 13), two differentiated groups are observed. In the blue cluster, there are terms related to the role that green infrastructures play in improving air quality, reducing pollution and increasing atmospheric carbon fixation and thus reducing the effects of climate change and pollution [66–68]. The red cluster groups together a large number of hard to categorize keywords ranging from those related to policy planning and green infrastructure strategies (e.g., governance, policy, design, management, framework, land use, restoration, adaptation, conservation, model), with urban green infrastructures (e.g., urban, cities, city, urbanization, heat islands) and with environmental services provided by green infrastructures (e.g., ecosystem services, resilience, climate change adaptation, health, benefits, human health).

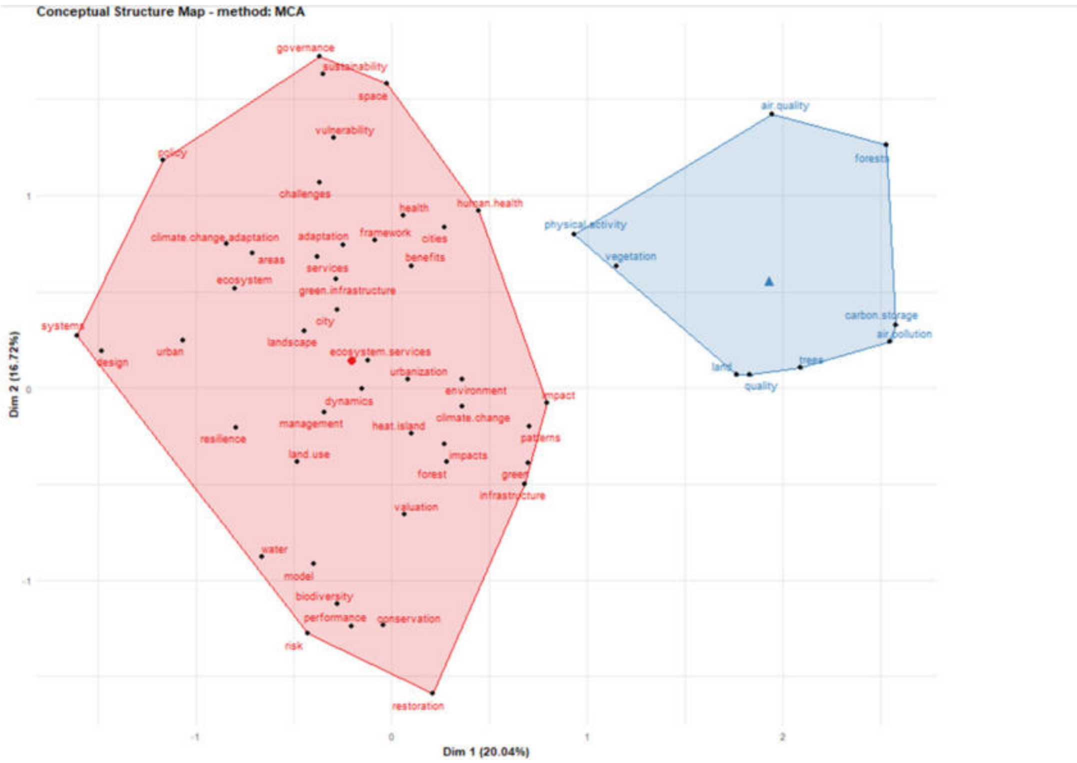

Figure 13. Conceptual Structure Map by Keywords Plus. Source: Biblioshiny. Own compilation.

Concerning the Author Keywords (Figure 14), the blue cluster comprises terms related to environmental services provided by green infrastructures linked to the adaptability of these systems to climate change.

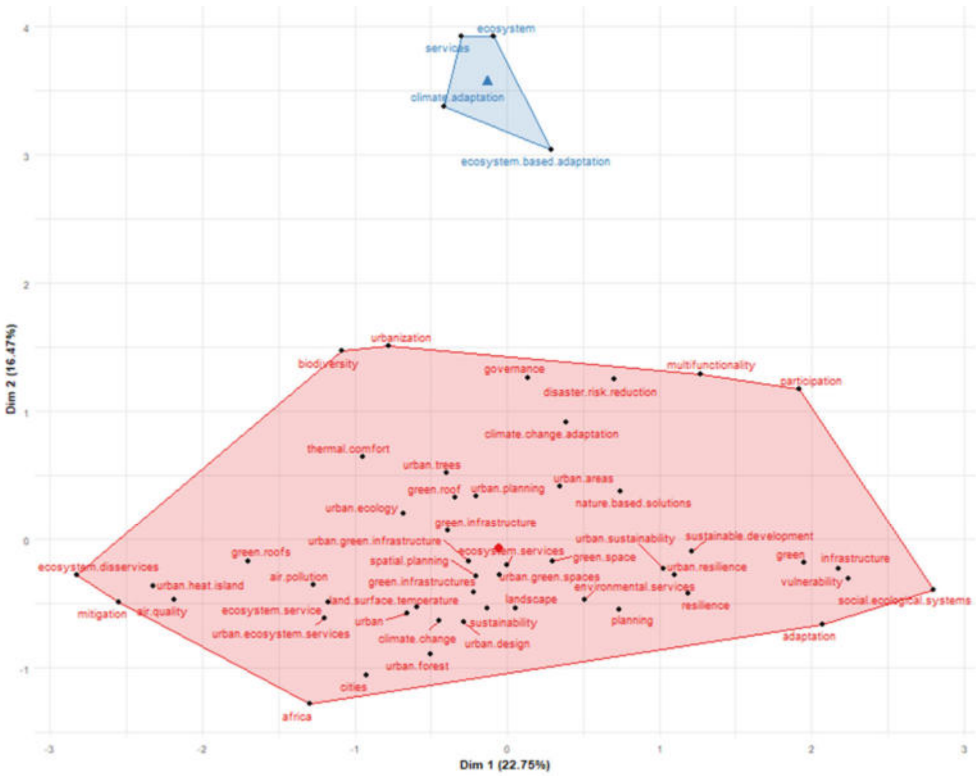

Figure 14. Conceptual Structure Map by Author Keywords. Source: Biblioshiny. Own compilation.

The red cluster encompasses many keywords related to the characteristics, functions, and services provided by green infrastructures, which are difficult to categorize given their high number. However, its larger size indicates that it is a more scientifically influential cluster in terms of the role of IGs in environmental challenges.

4. Conclusions

The results of this study contribute a series of general ideas (trends, areas, innovative terms) on current lines of research related to green infrastructures and the environmental services they provide.

Through the analysis of the Keywords and Keyword Plus we have highlighted the lines of research related to green infrastructures, environmental services and climate change. To this end, a cluster analysis and a study of research trends were developed. In the first case, five clusters were obtained that focus on the resilience and multifunctionality of green infrastructures in urban areas, their contribution to providing environmental services to society, their relationship with biodiversity conservation, their applicability in climate change policies and improving human health and, finally, their applicability in specific urban design and planning solutions.

One of the study's findings is the wide diversity of knowledge areas to which research on environmental services of green infrastructures is linked, covering fields as diverse as environmental sciences, ecology, or social sciences, among others. This aspect could also point to the multifunctionality and capacity to act at different scales and provide different environmental services at the same time as green infrastructures in urban areas.

However, despite the diversity of study topics, there has been a prominence of research related to environmental services provided by green infrastructures in urban areas and cities.

Likewise, there is scientific consensus on the suitability of applying nature-based solutions and green infrastructures to address the challenges of climate change and loss of biodiversity. Indeed, the scientific community has demonstrated the close link between protecting biodiversity and safeguarding environmental services provided by green infrastructures.

This line of research highlights the innovative nature of a new term related to urban green infrastructures, which is none other than "urban resilience", understood as the ability to take advantage of environmental services provided by green infrastructures to build cities adapted to addressing current environmental issues and problems.

In this sense, this study has highlighted the growing interest of the research community in planning GI solutions to ensure sustainability in the global context of climate change. In fact, from a look at the distribution based on Keywords Plus, climate change is clearly among the most recurrent terms. Therefore, from this perspective it is understood that the scientific community positions the use of GI as a tool for adaptation and/or mitigation of the adverse effects of climate change.

The results of this study suggest that GI could become a major strategic factor in addressing the global environmental and social challenges facing cities. Therefore, we believe it is necessary to advance in the study and proposal of new methodologies aimed at facilitating the valuation of the benefits provided by GI, both from an economic and public health point of view.

Given this study's results, we believe that it would be very interesting to address specific lines of research focused on assessing the extent to which administrations and managers apply scientific advances and results in green infrastructures when establishing and addressing environmental policies.

Regarding the limitations of this research, it should be noted that, first, this study was restricted to WoS, and, secondly, only articles were analyzed. Therefore, it would be interesting to consider a broader line of research that includes other databases such as Scopus or Google Scholar and other types of publications such as books or conference proceedings.

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2.3. Public policies for sustainability and water security: The case of Almeria (Spain).

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Review Paper

Public policies for sustainability and water security: The case of Almeria (Spain)

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ABSTRACT

Currently, there are 31,614 ha of greenhouses in the province of Almeria, being the largest concentration of this type of facilities in the world. In fact, this one is visible from space and is usually mistaken with a sea of plastics. This sector faces important challenges in terms of sustainability derived, on the one hand, from the new environmental demands of clients and markets and, on the other hand, from the fragility of some of the natural resources on which the model is based, especially water resources. In view of this situation, the aim of this article is to make a diagnosis of the water security and sustainability of the horticultural model of Almería (Spain), by studying the main factors that condition the availability of water for agricultural use. It analyses the current state of the groundwater bodies, the vulnerability of the factors to climate change and assesses the impact of public policies and actions carried out in this territory in this area. It also analyses the role that non-conventional resources such as desalination and water reuse can play in the agricultural areas of arid and semi-arid regions of the planet in the near future. Finally, based on the results of this analysis and within the framework of the new culture of water management and circular economy established by European regulations, general lines of public and private management are proposed, aimed at prioritizing the environmental services provided by the green infrastructures of this territory.

1. Introduction

According to the forecasts of the United Nations, by 2030, freshwater resources will decrease by 40%. This fact, together with the increase in world population, could generate a global water crisis (WWAP, 2015).

Given this situation, it is imperative that different countries and regions around the world urgently promote the implementation of measures that will help transform the way in which water is managed.

Almeria, located in a temperate zone in the northern hemisphere and at a geographical crossroads between two large continents, Europe and Africa and between two large bodies of water, the Mediterranean Sea and the Atlantic Ocean, has been endowed with a unique set of climatic, environmental and social characteristics which have been the cause of spectacular socio-economic growth in the province in recent decades.

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This socio-economic phenomenon, which has given rise to what is known as the *"Milagro Almeriense"* (Miracle of Almeria) (González Olivares and González Rodríguez, 1983; Wolosin, 2008), has been based on the paradox that, in the most arid region of Europe, a modern and intensive agricultural industry based on greenhouses has been developed. It has evolved from being an economic model based on small family farming to one that is much more industrial in nature. The model is based on an initial input, that is, the planting of seeds and is followed by a production process which transforms the seeds into products (output).

Thus, over several years, Almeria has developed the most specialized and profitable horticultural sector in Spain, capable of generating high yields per hectare, a greater number of crops per year and the capacity to export to European markets when there is a lack of available produce. This has been due to the concurrence of both social and environmental factors. Among the social factors that stand out are: the development of modern production techniques; the arrival of national and foreign immigrant labor, the entrepreneurial capacity of the population, and financing based on the establishment of a financial cooperative. Included among the environmental factors is the existence of a privileged climate, characterized by high levels of sunlight as well as optimum levels of temperature and humidity as well as the intensive use of local natural resources, mainly soil, groundwater and coastal sands.

To find the origin of the development of this agricultural industry, we must go back to the Decree of September 25, 1953, which approved the General Plan for the Colonization of the Area of National Interest in the Campo de Dalías Region, and later, in the Campo de Níjar with its additional 8,000 ha (Castaño, 1953).

Fig. 1 displays the geographical scope of the present study and includes practically all the municipalities in Almeria where intensive greenhouse agriculture is taking place.

The former National Colonization Institute (later called the Institute for Agrarian Reform and Development and currently, National Parks) is the body responsible for carrying out the aforementioned General Colonization Plan that included the outcrop of groundwater, the creation of infrastructure necessary for the irrigation and colonization of these lands by people from the province of Almeria or from neighboring provinces.

Starting from an initial 20 ha in 1957 (Rueda, 1987), the area devoted to greenhouses has grown to the current 31,614 ha, with a growth of 580 ha in 2018 alone (CAPDR, 2018), a figure that represents more than half of the greenhouses in Spain and about 80% of the total greenhouse acreage in Andalusia (Figs. 2 and 3).

Production, billing and employment data are also relevant. According to 2018 statistical data, the greenhouses of Almeria produce more than 3 million tons of fruit and vegetables per year, with an annual turnover of more than 2,500 million euros, generate more than 40,000 direct jobs and maintain a complex and diversified cluster of industries and auxiliary services that comprises 14,000 companies and 50,000 workers.

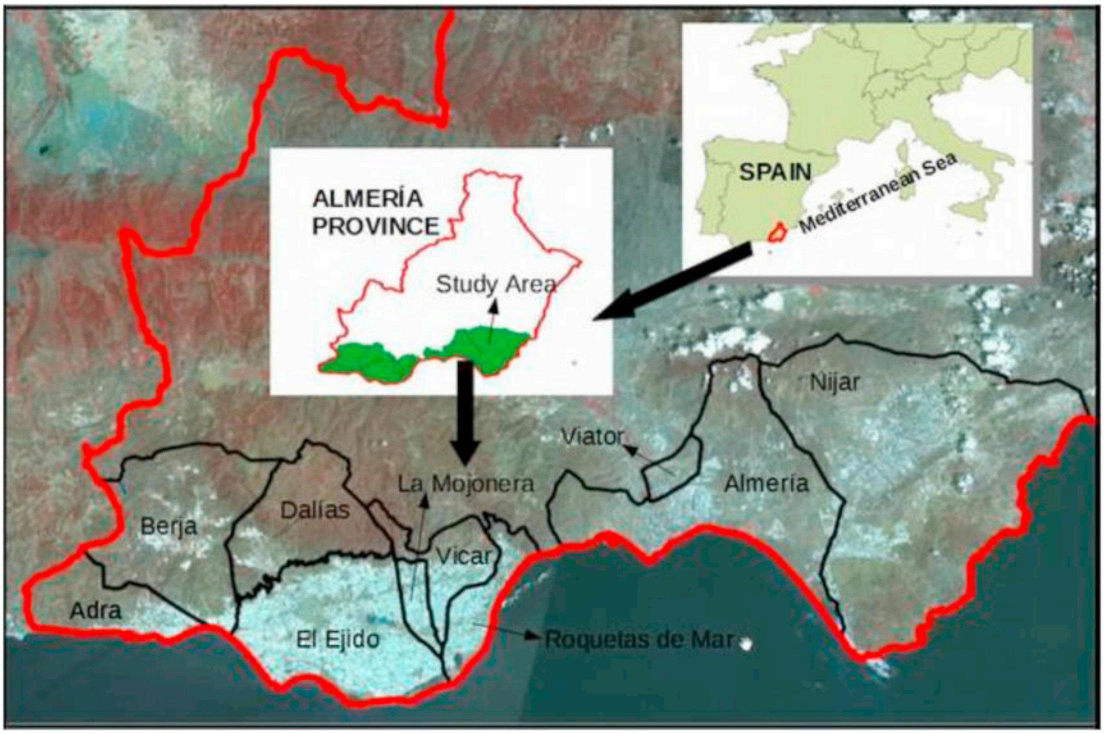

Fig. 1. Scope of geographical area being studied including the ten municipalities in Almeria where intensive agriculture is developed under greenhouses. (Source: Own compilation and Environmental Information Network of Andalucía - REDIAM).

Fig. 2. Greenhouses area in Almeria as seen from space. (Source: Google Earth).

Fig. 3. Interior of a **greenhouse**. (Source: Own ellaboration).

The greenhouses of Almeria are the principal engine of the socioeconomic and demographic growth in the province of Almeria. In recent decades, this sector of intensive agriculture under plastic in the province has established itself as a leader in international fruit and vegetable markets due to its high levels of quality, productivity, biological control and food security (Valera et al., 2016a).

In the near future, however, the sector faces significant challenges in terms of sustainability as a result of the new environmental demands of customers and markets, but mainly due to the fragility of some of the natural resources on which the model is based, water being the resource that most stands out. The following facts are a case in point. Firstly, the principal agent in the agricultural sector in Almeria, the Water Board, has estimated a deficit of 191 Hm3 in the province's water resources. Secondly, in the last few years, scientific studies on the impact of climate change on water resources point to a reduction of the Demarcation of the Andalusian Mediterranean Basin of −3% for the period 2010-2040, of −8% for 2040-2070 and −20% for 2070-2100 (CEDEX, 2017).

In this context, the present work aims to present an overview of the current state of water security and sustainability of the horticultural model in Almeria, assess the impact of the extant policies and, finally, propose general management guidelines focused on the future role of green infrastructure in this region as well as unconventional resources such as water desalination and reuse.

2. General state of sustainability and water security of the areas of intensive agriculture

2.1. Water resources

In Almeria, unlike in the rest of the Spanish peninsula, the bulk of the water resources allocated for different types of usage (supply, irrigation and industrial uses) does not come from water reservoirs. Around 80% of the resources come from underground aquifers (Custodio et al., 2016) and the remaining 20% from transfers, seawater desalination plants, reservoirs and regeneration plants for purified water. This scenario is repeated in other arid and semi-arid areas of the world (Foster, 1993; Foster and Loucks, 2011; Custodio, 2012;Wada et al., 2012; Ternes, 2019) and even in other Spanish provinces, some of which are near or bordering the province of Almeria (Custodio et al., 2016; Baños et al., 2019; Jodar-Abellan et al., 2019; Mendoza-Grimón et al., 2019), where surface water resources are also scarce and seasonal.

According to the study by Dalin et al. (2017), around the world, approximately 43% of the water used for agricultural irrigation comes from underground water sources. These same authors warn that this excessive dependence on groundwater will result in resource depletion, which will foreseeably trigger an increase in food prices and threaten their supply.

The use of water from aquifers vis-a-vis surface water has a number of advantages for farmers including its availability even in times of drought, an initial lesser investment and its easy and immediate accessibility. All these advantages provide infinite possibilities of extraction at multiple water points and lower water costs compared to other forms of supply (De Stefano and López-Guun, 2012 y Aznar et al., 2019).

The accelerated and extensive agricultural and urban transformation of a large part of the Almeria desert coastal plains (fundamentally in the regions of Dalías, Bahía de Almería and Níjar), in the absence, until recently, of any hydrological planning, had as its first and most serious environmental consequence the over-exploitation of almost all of its groundwater since the 1980s (thus, the *Royal Decree 2618/1986, of December 24, 1986, which approved measures relating to underground aquifers under Article 56 of the Water Law*, provisionally declared that the Campo de Dalías aquifer was overexploited).

This situation has been the cause that over the last 30 or 40 years, depending on the area, more water has been extracted from the aquifers than is recharged naturally, in breach of the two main objectives of *Directive 2000*/60/EC *of the European Parliament and of the Council of October 23, 2000, which established a framework for Community action in the field of water policy (WFD − Water Framework Directive)*, that is, protect and maintain the bodies of water in a good state and promote a sustainable use of water for the years 2015 or 2027, at the latest (Custodio et al., 2016). Thus, according to the Hydrological Plan of the Hydrographic Demarcation of the Andalusian Mediterranean Basin 2015/2021 (de Andalucia, 2016), the water bodies of the “Campo de Dalías - Sierra de Gádor” have suffered an over-exploitation of 180%; for the bodies of water in "Middle - Lower Andarax" the over-exploitation is of 130%; for the “Campo de Níjar” it is 145%; for the "Campo de Tabernas”, 118%; for the water body of "Aguas" it is 421%; for the "Cubeta of the Ballabona - Río Antas" it is 167%; and, finally, for the "Bajo Almanzora" it is100%. It should be noted that if annual exploitation exceeds 100% the implication is that the water that replenished the aquifers over many decades in the past, is now being inexorably emptied and consumed.

Water extractions above and beyond the capacity of these aquifers have not only caused a decrease in water resources in terms of quantity, but also a progressive deterioration in their quality, due to the appearance of salinization and contamination caused by the filtration of substances such as fertilizers and phytosanitary products (de Andalucía, 2009; Custodio et al., 2016; Aznar-Sánchez et al., 2019). This situation is especially serious in the *Poniente Almeriense* (western region of Almeria) where 80% of water wells have had to be abandoned (de Andalucía, 2009).

Fig. 4 has been prepared based on the data provided by the regional government of the Junta de Andalucia (2016) and shows that almost all of the groundwater bodies in the province of Almeria are in a poor condition.

According to the Hydrological Plan of the Hydrographic Demarcation of the Andalusian Mediterranean Basins 2015/2021 (de Andalucia, 2016), among the historical causes that have led to this situation, the following stand out: the lack of management plans in the past; excessive authorized extraction volumes; over-extraction of water; irregular or illegal use of aquifers; poor control of extractions; and the insufficient use of unconventional resources such as desalination or reuse.

In addition to the aforementioned, it must be noted that in the future these problems will be exacerbated by the effects of climate change.

The Spanish Office of Climate Change has updated in the last few years their impact assessment of climate change on water resources in Spain (CEDEX, 2017). To this end, twelve climate forecasts have been developed, combining different climate models with scenarios related to the effects of greenhouse gas emissions.

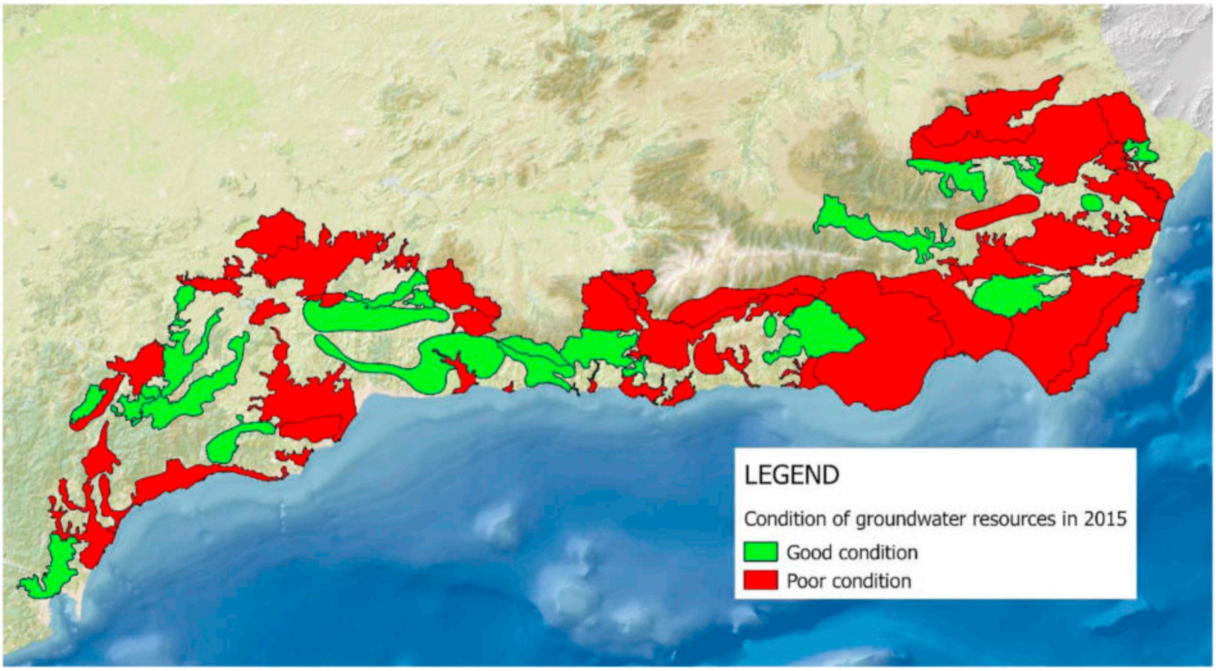

Fig. 4. Overview of the condition of groundwater resources in Almeria in 2015. Source: de Andalucía (2016).

The results from the aforementioned study (CEDEX, 2017), as well from others (Estrela et al., 2012; Mancosu et al., 2015) predict that, in the southern and southeast peninsular, where the province of Almeria is located, drought cycles will become more frequent as the 21st century progresses, with an ensuing increase in water scarcity due to the depletion of water resources.

This decrease in rainfall will cause adverse effects on aquifer recharge and on the availability of surface water reservoirs. These effects could also be exacerbated by the fact that higher temperatures will increase the atmospheric evaporative demand, meaning that lower water inflows into the ground will be added to greater exits in the form of evapotranspiration .(Estrela et al., 2012; Mancosu et al., 2015; CEDEX, 2017).

Finally, the increase in torrentiality predicted by the models will also negatively impact aquifer recharge (Estrela et al., 2012; Mancosu et al., 2015; CEDEX, 2017).

There is broad scientific-technical consensus that this phenomenon will take place in the semi-arid areas of the Mediterranean, such as the coast of Almeria and will be characterized by increasingly prolonged drought cycles, an increase in evapotranspiration and a general decrease in rainfall; all of which will result in reduced availability of surface water in reservoirs and a reduction in the recharge of aquifers by infiltration .(Estrela et al., 2012; Mancosu et al., 2015; CEDEX, 2017).

A future decrease in water resources may be the principal limiting factor of greenhouse crops as the remaining factors such as adequate soil, financing and favorable climate are well established. As noted in the manual by the classic economist David Ricardo (Fernández, 1993),

202 NB: David Ricardo has died in 1823. I see some difficulties with 1993. In addition, I doubt about his relevance on “hydroponic crop”, an issue he never addressed.

Answer: Quote and reference have been changed. We were referring to the relevance of the land for agriculture activities, as David Ricardo wrote back in 1817. We have changed the text to clarify it.

while land is essential for agriculture, it is not is important in the case of intensive crops because of the emergence of hydroponic crops. Water, however, remains essential. Consequently, historically, most of the solutions proposed by both public administrations and users have been based solely on improving water supply in order to guarantee irrigation with very few initiatives aimed at reversing the trend in groundwater degradation (De Stefano et al., 2015).

Some of the measures carried out in different world regions aimed at achieving the sustainability of groundwater management include the limitation and regulation of extractions through hydrological planning; the closure of illegal extractions; the shared use of surface and groundwater; the use of transfers and of alternative resources (mainly, desalinated and regenerated water); an increase in the price of groundwater to discourage consumption; or the improvement and modernization of irrigation (Aznar-Sánchez et al., 2019).

2.2. Water regulation and planning

Until the mid-1980s, water management in Spain was anarchic and irrational, without legal planning instruments. There was an exclusive system governing the use of water, wherein the landowner also owned the groundwater, a situation which, in many cases, led to over-exploitation.

The Water Law of 1985 radically changed this situation and established, as a general rule, the public nature of all water and the priority status of Hydrological Planning. However, users who extracted groundwater before 1986 were able to maintain their private water rights, a fact that has caused a large amount of water for irrigation to remain under private owners and companies and to be overexploited (Molinero et al., 2011; y Custodio et al., 2016).

Other milestones in the historical evolution of water management in Spain and Andalusia was the approval of the Andalusian Irrigation Plan of 1996; the 1998 Basin Plan; the WFD of 2000 and the corresponding Reform of the Water Law; the National Hydrological Plan of 2001; and the A.G.U.A. of 2005. These laws are outlined in Table 1.

The Hydrological Plan (2015-2012) of the Hydrographic Demarcation of the Andalusian Mediterranean Basins (DHCMA in Spanish), currently in force, is characterized by a process of continual updating, adaptation and review every six years, a practice which is common for all the member states of the European Union. The second cycle of the six-year review of the Hydrological Plan (2015-2021) is currently in force. Specifically, the Hydrological Plan (2015-2021), which oversees almost all of Almeria's intensive greenhouse agriculture, contains an ambitious package of measures aimed at achieving the good state and protection of public water; and a balance between consumer demands and the sustainable use of the resource.

In spite of the measures mentioned, the management of the water cycle in Spain, and specifically in the Mediterranean Basin, has not yet been adapted to the paradigm shift implied by the WFD which encompasses attaining a good ecological status of water bodies, integrating water cycle management, public participation and transparency in decision making.

3. Role of green and gray infrastructure in water cycle management in areas of intensive agriculture

3.1. General concepts and characteristics

According to the European Commision (2014b), green infrastructure is defined as a strategically planned network of natural and semi-natural spaces and other environmental elements designed and managed to offer a wide range of ecosystem services. This network consists of a valuable natural heritage which is a source of a wide variety of environmental goods and services that contributes to human development and well-being and plays a key role in the strategies used to meet the challenges of climate change.

This new term, green infrastructure, attempts to simplify complex ecological concepts related to the functioning of ecosystems and the environmental services they provide, making an analogy between the infrastructure of natural systems and the gray infrastructure of artificial man-made systems, such as roads, electrical networks and hydraulic infrastructures. Specifically, with regards to the object of this article and related to the identification of the infrastructures linked to the water cycle of the agricultural areas of Almeria, we identify gray infrastructure as the hydraulic works and conventional civil engineering installations, such as dams, reservoirs, transfers, desalination or treatment plants; and identify as green infrastructures all natural spaces and elements which play a fundamental role in the endowment and regulation of the water resources of the area, such as, forests, mountainous systems, aquifers, river channels (watercourses and floodplains), wetlands and coastal ecosystems.

By way of example, Table 2 proposes a mechanism for presenting how the various issues related to water resource management in agricultural areas in the province of Almeria could be addressed. It displays the solutions offered by both gray and green infrastructure.

The different possible options for the resolution of the problems related to water management, both from the perspective of green infrastructure and gray infrastructure, requires that water resource managers consider the different alternatives according to the following variables:

- The forecasted quantity and quality of environmental goods and services generated over time.
- Possible negative externalities, such as possible environmental or social impacts.
- The required investment and maintenance costs, as well as opportunity costs, i.e. cost of missed opportunities.

Table 1
Legislative milestones related to water management in Spain. (Source: own compilation).

Water Law (1985)	Established the public nature of all water sources and prioritizes Hydrologic Planning.
Basin Plan (1998)	The first Hydrological Plan in Spain is approved by public administrations and users.
Water Framework Directive (2000)	A unification of water management practices across the European Union which established environmental objectives for water resources.
National Hydrological Plan (2001)	Proposed large scale conventional hydrological projects (transfers, canals and reservoirs) to transport water from basins with excess water supply to those that in deficit.
A.G.U.A. Programme (2005)	A redirection of national water policy. Desalinization and the reuse of water from water purification plants are prioritized.

Table 2
Water management solutions offered by Gray and Green Infrastructure in the agricultural areas in Almeria (Source: Own compilation and UNEP, 2014).

PROBLEM OR SERVICE TO BE IMPROVED	SOLUTIONS OFFERED BY GRAY INFRASTRUCTURE	SOLUTIONS OFFERED BY GREEN INFRASTRUCTURE
Water Supply (including drought mitigation)	Dams/Wells/Transfers / Desalination Plants/ Reuse of Waste water / irrigation pipes and infrastructure	Mountain conservation and restoration of forested areas of the water basin
		Recovery of floodplains and restoration of riverbank vegetation
		Conservation and restoration of wetlands
		Construction of artificial wetlands
		Creation and restoration of green spaces
Control of water quality	Sewage treatment plants	Mountain conservation and restoration of forested areas of the water basin
		Recovery of floodplains and restoration of riverbank vegetation
		Conservation and restoration of wetlands
		Construction of artificial wetlands
		Creation and restoration of green spaces
Erosion Control	Reinforcement of embankments and other civil engineering works	Mountain conservation and restoration of forested areas of the water basin
		Recovery of floodplains and restoration of riverbank vegetation
Control of effects of river floods	Dams/ Levees/ Rainwater collectors	Mountain conservation and restoration of forested areas of the water basin
		Recovery of floodplains and restoration of riverbank vegetation
		Conservation and restoration of wetlands
Control of erosion and coastal flooding		Construction of artificial wetlands
	Breakwaters and sea walls	Conservation and restoration of wetlands
		Conservation and restoration of dunes and coastal ecosystems

- Alignment with existing regulatory requirements.

In the case of water-related services such as water quality, water supply, drought mitigation, flood control or coastal protection, the best solutions will not always be exclusively based on gray or green infrastructure solutions, but rather, as more and more studies have shown, on appropriate hybrid solutions, which can produce better synergistic positive results than the application of solutions based exclusively on gray or green infrastructures (Palmer et al., 2015; IEEP, 2014 y UNEP, 2014). A clear example of this is the recovery of the over-exploited aquifers of Almeria. From the green infrastructure approach, one option could be flood protection and increased natural recharge of groundwater bodies through restoration and conservation projects of natural ecosystems such as wetlands and forests in the upper part of the receiving basin; and from the gray infrastructure approach, the reduction of aquifer extractions by facilitating access to alternative resources from desalination plants and reclaimed waters.

As an example of this, Fig. 5 shows a schematic representation of the main gray and green infrastructures related to the water cycle in the *Poniente Almeriense*, the principal greenhouse agricultural area of Almeria.

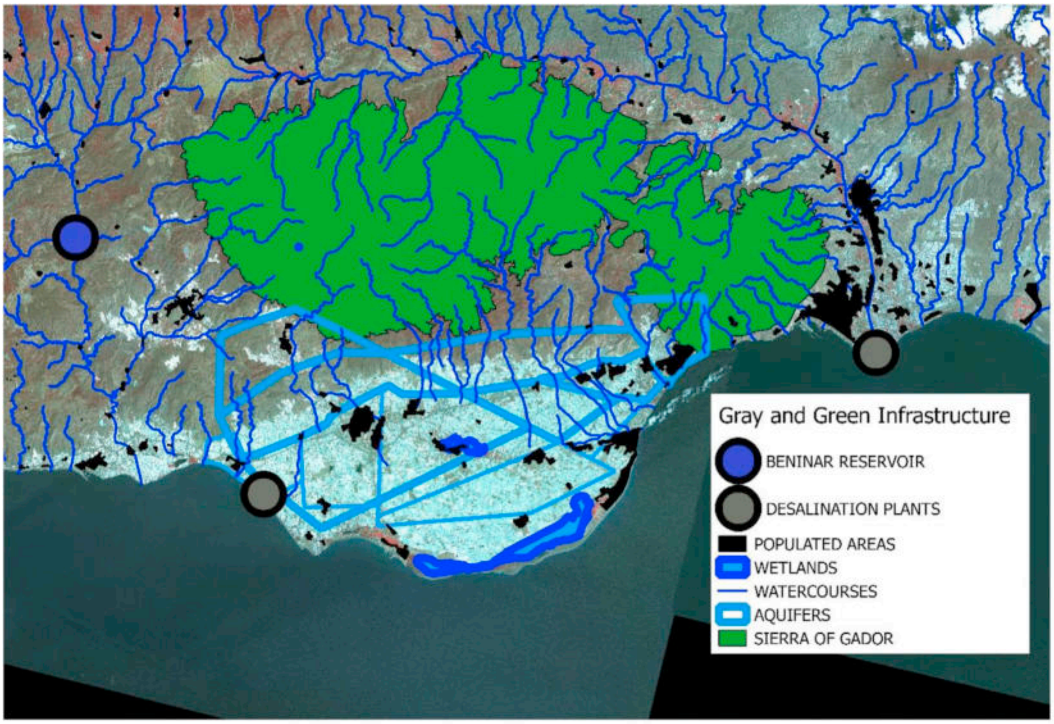

Fig. 5. Gray and Green Infrastructure related to water management in the *Poniente Almeriense* region (Source: own compilation and the Environmental Information Network of Andalucía - REDIAM). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2. Gray infrastructure

In this type of infrastructure, unlike green infrastructure, the relationship between investment and the environmental result can be perfectly quantified (UNEP, 2014). This has determined that, historically, the agricultural sector and denizens of Almeria have deemed that the most attractive and demanded type of action was to try to mitigate the effects the natural droughts in the province of Almeria. However, one of its most obvious drawbacks is that this option requires significant capital investments that need to be built, operated and maintained. For example, it is estimated that, globally, three out of four reservoir projects exceed their estimated projected cost by 96% (Palmer et al., 2015).

For decades, the different public administrations (local, regional and national) have invested significantly in gray infrastructure in order to obtain sufficient water resources in terms of quantity and quality which correspond to different demands and uses. Today, the province of Almeria has a series of fundamental legacy hydraulic infrastructures for flood control and that regulate the availability of water resources in the province. This notwithstanding, there is potential room for improvement. Proof of this is that around 80% of the water resources in the province still come from underground aquifers and only the remaining 20% come from the aforementioned gray infrastructures such as transfers, seawater desalination plants, reservoirs and water purification plants.

3.2.1. Reservoirs

In the province of Almeria there are two large reservoirs, both built in the mid-1980s, Beninar and Cuevas del Almanzora, whose main function is the protection against flood for the urban centers of Adra and Cuevas del Almanzora. These reservoirs also provide water for urban water supply and irrigation in the Campo de Dalías and Almanzora regions. However, due to the sharp decrease in rainfall in recent years and losses due to leaks and evapotranspiration, these water resources are becoming increasingly limited.

As can be seen in Fig. 6, of the extant reservoirs in Almeria, Granada and Málaga, the reservoirs in Almeria have stored less water in the last ten years.

The different forecast scenarios of the effects related to climate change: increases in average temperatures, abrupt decrease in rainfall and a sharp increase in evaporation (CEDEX, 2017; Mancosu et al., 2015; Estrela et al., 2012), indicate that, in the foreseeable future, we will be faced with reservoirs with record lows or even devoid of water. In addition, if the forecasts regarding the higher frequency of extreme weather events are realized, it is expected that an increase in torrential

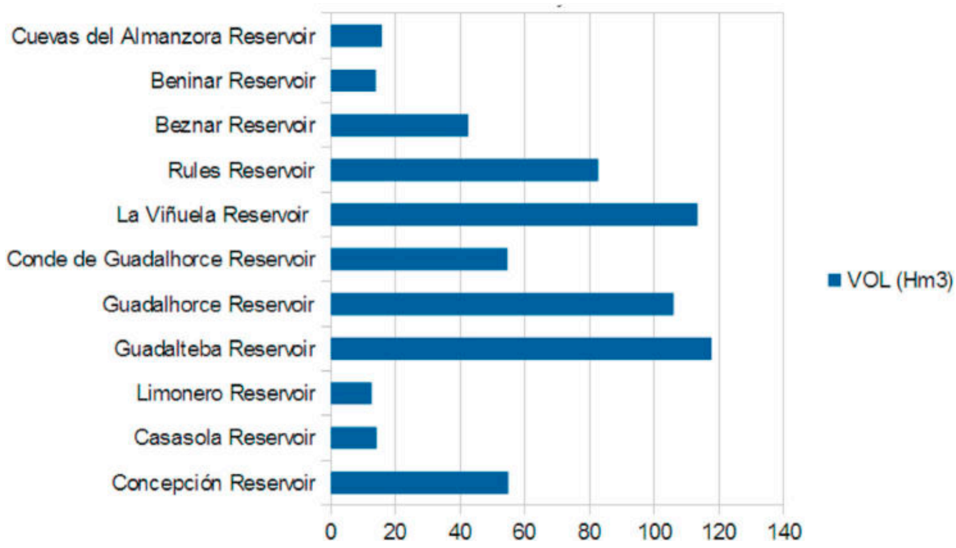

Fig. 6. Average volume of water (Hm3) over the last 10 years in water reservoirs in Almeria, Granada and Málaga. (Source: Junta de Andalucía, 2019).

rainfall will exacerbate erosion, and therefore the clogging and obstruction of reservoirs, thus reducing their efficiency. In fact, the province of Almeria is already suffering these consequences in both the Cuevas del Almanzora and Beninar reservoirs.

3.2.2. Irrigation infrastructure

Concurrent with the appearance of the first symptoms of the over-exploitation of the aquifers of Almeria, farmers began to introduce improvements in water channeling, drip irrigation and hydroponic crops, which have been perfected to achieve high efficiency, digitalization and technology of irrigation systems. In this sense, 99.6% of the farmers use localised irrigation systems (drip irrigation and hydroponic crops) and 81% of them have automatic irrigation controllers to manage fertigation (Valera et al., 2016b)

As a result of this efficiency in the use of irrigation water and the high levels of productivity, the greenhouses in Almeria consume half the volume of water used in the rest of Spanish agriculture and their water footprint per capita is 20 times lower than the national average (Giagnocavo et al., 2018; Piedra et al., 2018).

This efficiency in the use of water is due to four factors: the innovative use of local irrigation systems, the use of sand mulch, the use of greenhouses, and the extensive use of ponds that allow farmers to program irrigation according to a schedule adapted to the needs of the crops (Salazar et al., 1998).

A recent and notable example of this is the progress made in the "Fertinnowa" project, a European project involving various private and public institutions related to agriculture in Almeria and which is aimed at identifying and exchanging, throughout Europe, innovative technologies that optimize the use of water and fertilizers (Fertinnowa, 2018).

However, despite the fact that this modernization in irrigation techniques has led to an obvious saving of water on farms and a decrease in diffuse pollution in aquifers, it has not been enough to solve the problem of over-exploitation, since these techniques have not been used to reduce the levels of extractions, but rather to expand the area of irrigation.

3.2.3. Water transfer canals

Traditional Spanish hydraulic policies, for most of the 20th century, have been dedicated almost exclusively to the construction of hydraulic works, with the result that Spain is one of the countries with the highest number of large dams and reservoirs, both in relative and absolute terms (Funes et al., 2018). For the most part, these works were built with the presumption that they would be financially profitable, but without taking into account their environmental impact or the socio-territorial conflicts that they could engender (San Martín, 2011).

As a rule, all transfers polarize society, resulting in both detractors and defenders, depending on whether they are giving or receiving the transfer of water. In addition, they have generally not served to correct the so-called water deficit of the receiving basins; on the contrary, the results have generally aggravated the problem as they did not fulfil expectations (San Martín, 2011).

In the province of Almeria there are two water transfer canals: the Tajo-Segura and the Negratín-Almanzora. Although both have a maximum annual transfer capacity between 27 and 50 Hm3 respectively, these has not been fully satisfied historically, since the amount of water that can be transferred from one hydrographic demarcation to another is regulated.

Hence, for example, Law 21/2015, of July 20, 2015 which modifies Forestry Law 43/2003, of November 21, 2003, in relation to the Tajo-Segura Transfer, states in its penultimate provision: *"Surplus waters shall be considered all those reserves that are contained in the Entrepeñas-Buendía complex which exceed 400 cubic hectometers. Below this figure no transfers may be made* *under any circumstances. This minimum volume may be revised in the future according to the effective variations experienced by the demands of the Tajo basin, in accordance with the principles of efficiency and sustainability, in a way that guarantees its preferential nature, and ensures that the transfers from headwaters can never limit or impede the natural development of said basin."*

Given the aforementioned regulatory and socio-territorial circumstances as well the changing scenarios predicted by climate change which foresee a decrease in rainfall and longer drought cycles for the Mediterranean area, transfers are expected to be less and less useful, since it is very likely that in the future there will not be any surplus resources in the yielding basins.

3.2.4. Desalination plants

The current overexploitation of aquifers in many arid and semi-arid coastal regions of the world, the absence of other viable forms of water supply in these areas, as well as the continuous technological improvement and reduction of production costs has led to the fact that, today, desalination techniques are a viable option for irrigated agriculture (Martínez-Alvarez et al., 2019).

This form of water supply is already widely used in some countries such as Spain, Israel and Saudi Arabia and its development is also being considered in other countries and regions such as Egypt, Australia, California and China (Chao Chen et al., 2019 & Martínez-Alvarez et al., 2019).

Almeria currently has four desalination plants in operation (Carboneras, Almeria, Campo de Dalías and Desalobradora de Palomares), two plants which are out of commission (Rambla Morales and Bajo Almanzora) and three are being planned and whose construction is the responsibility of the National Government (Carboneras, Phase II, the Desalting Plant in Adra and the Balsa del Sapo).

Fig. 7 shows the location of these desalination plants, as well as their current status.

The reality is that Almeria has not reached its full potential in terms of desalination. The reasons for this include the lack of desalination infrastructure and service distribution; and, fundamentally, the higher cost of desalinated water for farmers compared to pumped water. Only in those cases where the water in the aquifers is of poor quality, does desalinated water have a good level of acceptance among farmers, since in some cases it is the only viable alternative and, in others, its higher quality permits a greater diversity in the types of crops that can be cultivated (Aznar-Sánchez et al., 2019). In this sense, the irrigation boards of Almeria demand that a maximum price of € 0.3/m3 be established as a matter of urgency for desalinated water used for irrigation, as has already been established in other regions such as Murcia and the Canary Islands as a result of

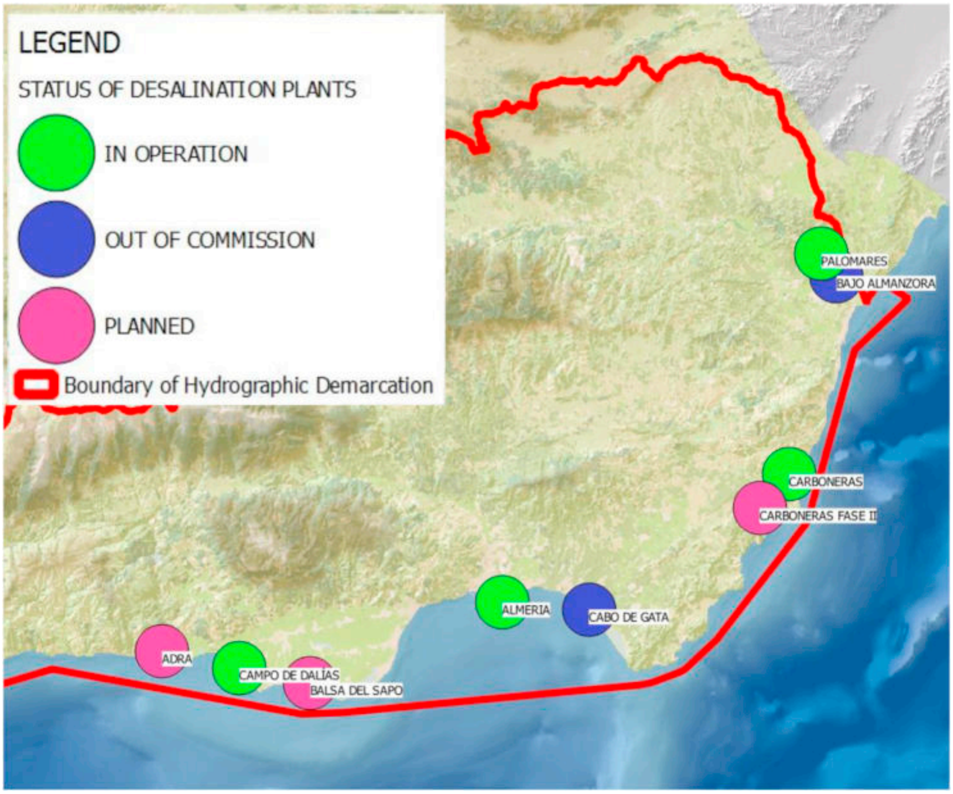

Fig. 7. Location and Status of Desalination and Desalting Plants in the province of Almeria within the Hydrographic Demarcation of the Andalusian Mediterranean Basin. (Source: Own compilation).

the application of the decrees which regulate drought. For example, *Royal Decree 1210/2018, of September 28, 2018, extends the drought situation declared for the territorial scope of the Segura Hydrographic Confederation by Royal Decree 356/2015, of May 8, 2015, which itself declares the drought situation in the territorial scope of the Segura Hydrographic Confederation and the exceptional measures to be taken for the management of water resources; and the Draft of a Royal Decree regulating the direct* award *of a subsidy to the Autonomous Community of the Canary Islands to reduce the cost of desalination and water extraction from wells and tunnels for agricultural irrigation in the Canary Islands*.

However, it should be noted that there are studies (Albaladejo-García et al., 2018) that show that for farmers, the higher cost of desalinated water (€ 0.6/m^3) when compared to the cost of well water (0.25 €/m^3) does not pose a threat to the economic viability of the sector, given the relatively low weight or impact of the cost of water compared to the overall total variable costs for these types of farms.

In addition, several studies show that it is profitable to use desalinated water for irrigation of fruits and vegetables grown in greenhouses in the province of Almeria. Tomato production can be increased by 3.73 kg/m^2 (Valera et al., 2016a), and even improve product quality parameters in certain situations (Vera et al., 2020)

The advantages of desalination are that this resource provides fresh water where the supply is scarce or nil; does not depend on weather conditions or the variable availability of conventional resources (reservoirs and transfers); constitutes a guarantee in emergency situations (droughts); avoids the risks associated with climate change; does not generate socio-territorial conflicts between transferring and receiving basins; is an alternative to other infrastructures of greater economic or environmental cost; allows the recovery of over-exploited aquifers; and allows the use of renewable energy (wind or solar) (Baños et al., 2019; Aznar-Sánchez et al., 2019 y Morote Seguido, 2018).

As a result of the aforementioned advantages of this unconventional water resource, the world population that depends on desalinated sea water is expected to increase from 5.5 $\times$ 108 in 2015 to 1.7 $\times$ 109 in 2050, that is to say, from 7.5% of the world population in 2015 to 18% in 2050 (Gao et al., 2017). Other similar projections forecast that the global production capacity of desalinated seawater will double between 2011 and 2040 (Hanasaki et al., 2016).

Today, the most utilized and efficient desalination technique is that of reverse osmosis. However, this method is still characterized by high energy requirements, significantly exceeding the energy consumption of other conventional forms of water supply such as surface or groundwater (García-Caparros, 2017). This high energy consumption is its main limiting factor, since it implies an increase in the price of water and greenhouse gas emissions associated with agricultural activity.

Given this situation, the desalination techniques associated with renewable energy sources are presented as an alternative to reduce the carbon footprint and provide greater sustainability to irrigated agriculture. Among the different renewable energy alternatives, solar energy is the most promising alternative to fossil fuels because it is more predictable and accessible than other resources (Alkaisi et al., 2017), especially in arid and semi-arid regions which usually have a high number of hours of sunlight.

Almeria is a clear example of this type of area, since in addition to having a high number of hours of sunlight throughout the year, the periods of greatest solar radiation coincide with those of greatest irrigation needs (Zarza, 1997).

In this sense, the approval of RDL 15/2018 on urgent measures for the energy transition, from which the incomprehensible regulatory barriers that existed in Spain for renewable energies (popularly known as the "sun tax"), are repealed, opening the door for both public and private promoters to start considering desalination with renewable energies as a more economically and technically viable option.

3.2.5. Water reuse

Another, so called, unconventional means of increasing the availability of water resources for irrigation, is the use of reclaimed water, which is purified wastewater that has undergone an additional or complementary treatment process that allows its quality to be adjusted to their required use. The reuse of purified water for irrigation is becoming increasingly widespread in Spain, being one of the countries that most utilizes this technique. In spite of this, there is still significant potential for growth, since at present, less than 5% of the total wastewater collected is reused (De Bustamante et al., 2010).

The principal advantages of the reuse of reclaimed or purified water in agriculture are: the reduction of pollution problems by eutrophication of natural ecosystems, the guaranteed availability of water flow regardless of the seasonality of the resource or droughts, aquifer recharge through the infiltration of surplus irrigation, reduction of fertilizer expenditure, and increased profitability of investments made in water purification (Segura and Baeza, 2012). At present, the greenhouses of Almeria use only a portion of the reclaimed waters of the WWTP (wastewater treatment plant) of El Ejido, Roquetas de Mar and Almeria for irrigation purposes.

The possibilities of direct reuse are closely related to the volume of treated effluents, which in turn depends on the number and capacity of existing wastewater treatment plants. In this sense, the Junta de Andalucía has constructed several large water treatment works in the province of Almeria (WWTP of Níjar, Huércal-Overa and Antas) with several others currently being planned (WWTPs Cuevas del Almanzora and Mójacar).

3.3. Green infrastructure

The European Commision (2014b) considers green infrastructure to be a proven tool that provides ecological, economic and social benefits through natural solutions and helps us understand the value of the benefits that nature provides to the population and mobilizes investments to sustain and reinforce them.

In addition, solutions mentioned in Table 2 are more effective than exclusively gray infrastructure solutions in terms of cost-benefit and resilience (European Commission, 2014a; IEEP, 2014; UNEP, 2014; Magdaleno et al., 2018).

This evidence leads to the progressive incorporation of ecosystem conservation or restoration measures in territorial, hydrological, economic or natural risk prevention planning strategies.

Investment in green infrastructure is based on the logic that it will always be more profitable to invest in nature-based solutions than to replace environmental services with man-made technological solutions (Valladares et al., 2017). The development and conservation of the green infrastructure of a region is based on a suitable strategy with a number of advantages for the environment, the economy and employment. These advantages include:

Cost Savings. If green infrastructures are properly managed and conserved, there can be considerable cost savings, since, over time, they tend to improve the environmental services they provide healthy ecosystems, the recovery of damaged habitats and the reconnection of fragmented natural and semi-natural areas. In contrast, gray infrastructures require continual investments to keep pace with population growth and repair damages that are a result of wear and tear (European Commission, 2014). A clear example would be the control of coastal erosion through the restoration of dunes vis-à-vis the alternative of levees and coastal breakwaters which tend to degrade over time.

In addition, green infrastructures can alleviate the need to invest in gray infrastructures or, where appropriate, can alleviate the cost of maintaining them. Thus, for example, the conservation and improvement of forest land in the higher regions of river basins reduces erosion and the introduction of sediments to reservoirs and dams, reducing the costs of possible dredging.

Its multifunctional character and lower environmental cost. Unlike gray infrastructures, which usually have a single purpose, investments in water-related green infrastructure usually produce other positive externalities. For example, among other advantages, investments in forest conservation and improvement of receiving basins, in addition to improving the filtration and natural recharge of aquifers, also help to control erosion, generate greater carbon sequestration, improve habitats and create new recreational areas for the population. However, for this to happen, the ecosystem must be healthy (Palmer et al., 2015; European Commission, 2014a y UNEP, 2014).

Adaption to different territorial scales.

Unlike gray infrastructures, which are normally operated locally, green infrastructure resembles a fractal structure, with elements ranging from the continental scale (for example, a large transnational mountain range that functions as an ecological corridor), to smaller valuable elements that provide environmental services at a local level (for example a wetland, which is responsible for purifying water and protecting against possible floods). Green infrastructure is considered to be a very effective management tool, since this approach offers alternatives at different territorial levels.

Despite the advantages listed above, these types of actions are frequently neglected when it comes to the decision-making or investment planning processes of managers. This is largely due to the fact that, unlike with gray infrastructure, evidence of the benefits of green infrastructure is more difficult to quantify than the costs associated with its implementation (Naumann et al., 2011). In general, this type of action requires longer periods of time for the results to be visible and it is difficult to assess their contribution in terms of market value, given the gaps of historical data in most of the territories and lack of tools for the economic evaluation of environmental services (Palmer et al., 2015). Despite this, studies carried out to date in different areas of the planet demonstrate a greater profitability of the alternatives proposed by green infrastructures than those derived from gray infrastructures (UNEP, 2014).

With regards to the water cycle of the agricultural areas of Almeria, green infrastructure fundamentally refers to the contribution of mountains, aquifers, river systems (floodwaters and floodplains) and wetlands for the regulation of water flows; the capacity of aquifers, soils and ecosystems to retain water; the improvement of water quality; the reduction of flood risks; and the adaption and mitigation of the effects of climate change (see Fig. 8).

3.3.1. Mountain ranges and aquifers

Forest ecosystems play a fundamental role in the protection against soil erosion and water resources by capturing and slowing down rainwater, thus facilitating aquifer recharge and dampening the effects of both floods and droughts (Nagabhatla et al., 2018; Palmer et al., 2015).

Although the environmental services provided by forest ecosystems are rarely quantified and studied at the local level, globally, an estimated 1.7 billion people live in large cities (more than half of the world's urban population). The water supply for these cities depends on the conservation of forests and the agricultural woodland in its geographical basins often located hundreds, if not thousands, of kilometers away. By 2050, these urban watersheds will feed up to two-thirds of the world's population, even though they cover only one third of the land area (Abel, 2017).

A third of the one hundred largest cities in the world depend on protected forested areas for their drinking water. In fact, well-managed forests often provide clean water at lower costs than treatment plants (TEEB, 2009).

For example, there are studies linking deforestation in the Amazon with droughts suffered in recent years in the Sao Paulo region in Brazil, affecting 21.3 million inhabitants (Nagabhatla et al., 2018).

In the territorial scope of the present work, the Sierra of Gádor stands out as the principal green infrastructure, a natural space in which the socioeconomic activity of the entire southwestern region of Almeria depends on since it is the source of water supply for the all the intensive agriculture and tourism industries of the *Poniente Almeriense*, as well supplying half of the population of Almeria (the inhabitants of Almeria capital, Poniente and Berja) (Oyonarte et al., 2016). The Sierra of Gádor and its associated aquifers make a very productive hydrogeological system, which relevance lies fundamentally in the

Fig. 8. Environmental services related to the water cycle provided by green infrastructure in agricultural areas of Almeria. (Source: Own elaboration). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

carbonated character of its water, which favors the recharge of underground water bodies through the infiltration of precipitation, in the form of rain and snow, attaining high values in the upper regions of this mountainous massif.

Currently, as described in previous sections, these groundwater bodies are heavily over-exploited and contaminated (marine intrusion on the coast or chemical contamination).

On the other hand, the environmental services provided by this green infrastructure to the agricultural activity of Almeria have never been quantified in terms of market value and, for this reason, to date, both their protection and conservation have had little weight in the political or business decisions of the sector.

Consequently, the promotion of actions related to forest conservation and the restoration of this mountain massif, as well as limiting changes in land use of surrounding mountain areas would favor the natural recharge of the over-exploited aquifers of the *Poniente Almeriense* region, reduce the collapse and grounding of the Beninar reservoir and reduce the impact associated with erosion and floods (Oyonarte et al., 2016).

3.3.2. Watercourses, flood plains and wetlands

The rivers and watercourses of Almeria, as well as its floodplains and associated deltas, provide a wide range of environmental services to the population, which are often undervalued. These green infrastructures facilitate storm water runoff from urban and agricultural sources; mitigate flood problems through flood abatement; favor aquifer recharge; and contribute to the natural deposit of sand on our beaches through coastal protection measures.

For their part, wetlands favor aquifer recharge; they cushion the effect of floods through their ability to store water and reduce the energy of rivers and waterways after storms; and purify water, acting as green filters that reduce and eliminate nutrients and pollutants of agricultural and urban origin.

At present, in the areas of intensive agriculture in Almeria, these environmental services are quite limited, due in large part to the fact that the space historically occupied by watercourses, wetlands and floodplains, is almost entirely occupied by other elements. They are often covered by crops, infrastructures and constructions, as well as degraded by the disposal of waste (agricultural and construction), which in the event of torrential rains are an obvious flood risk for the population. Instead of opting for the recovery of these occupied lands, historically, attempts have been made to correct these flood risks through unfortunate actions aimed at trying to “domesticate” the operation of these river systems through costly engineering works, such as channeling, dredging of aggregates, desiccation of wetlands, construction of concrete and breakwater defenses; all of which usually aggravate the problem or move it to another location.

In fact, it has recently become evident that the consequences of the no proper application of the river planning and management criteria contained in European regulations (Framework Directives on Floods, Water and Habitat), due to the DANA (isolated high level depression), which occurred from 9 to 16 September 2019, have caused significant flooding and material damage to infrastructure and private properties in the area, mostly greenhouses.

Fig. 8 summarizes and shows the main benefits that green infrastructures bring to the water cycle of the agricultural areas of Almeria.

4. Discussion

The implementation in Spain of the European Water Framework Directive (WFD) has meant a change of paradigm for the country's agricultural sector, and more specifically for an eminently agricultural province such as Almeria.

The application of this European standard means for the agricultural sector of Almeria a change from a traditional water management model, where only the demands of economic uses were taken into account, to a model where environmental considerations now prevail, such as the need to approve basin plans, policies for saving and efficient use of water, cost recovery of water use, improvement of water quality and the protection of ecosystems, already included in other European Directives, such as the Habitats Directive or the Birds Directive.

For decades, until the establishment of the European WFD, the intensive and unsustainable use of groundwater has resulted in significant benefits for the Almeria agricultural sector, although this has been at considerable cost to the environment, which since they were not quantified as production costs, have been socialized and the problem passed down to future generations.

This lack of market valuation of environmental services provided by the green infrastructure of the agricultural regions of Almeria has resulted in a continuous availability of groundwater at affordable prices for farmers (Custodio et al., 2016), which has triggered and culminated in a deterioration of almost all of the aquifers in these areas.

On the other hand, there is broad scientific-technical consensus that climate change will cause longer drought cycles in the Mediterranean coast, an increase in evapotranspiration and a general decrease in rainfall (CEDEX, 2017; Mancosu et al., 2015; y Estrela et al., 2012). All this, inevitably, will result in a decreased availability of surface water in reservoirs and a reduction in the recharge of aquifers by infiltration. As a consequence of climate change, the forecasts point to a reduction in water availability for the Demarcation of the Andalusian Mediterranean Basin of −3% for the 2010-2040 period, of −8% for the period between 2040 and 2070, and −20% for the period 2070-2100 (CEDEX, 2017). Given this situation, adequate planning of water infrastructure and hydrological-environmental management, negotiated between the different public administrations (local, regional and national), farmers and civil society, is proposed as the principal road map.

In the context of Spain, a similar experience of integral and participatory water cycle management has begun in recent years in Alicante, a Spanish province with environmental characteristics and water deficit problems similar to those of Almeria (Jodar-Abellan et al., 2019).

With regards to other global regions, the literature also confirms that the involvement of consumers of water has played a key role in the success or failure of public policies related to groundwater (De Stefano et al., 2015). In order for farmers and water sector entrepreneurs to be actively involved with this model, the creation of Central User Boards in the water bodies of the province should be encouraged, as a means of promoting transparency, strengthening the concessional system in order to reverse the process of commodification, involving the users themselves in the control of illegal extractions, and promoting the recovery of water bodies in poor condition.

A good example of the way forward is the pioneering initiative undertaken by administrations and some of the farmers of the *Poniente Almeriense* in the Program of Support Activities for the Regeneration of the Aquifers of the Southern Sierra de Gádor-Campo de Dalías. This is an ambitious initiative that facilitates the recovery of aquifers in poor condition by reducing extractions and replacing them with water saving and efficiency measures as well as unconventional resources such as desalinated and regenerated water.

On the other hand, the recovery of aquifers has been demonstrated to be an essential measure in climate change adaptation policies since they can act as strategic reserves to manage drought cycles, predicted to be increasingly frequent (Custodio et al., 2016).

However, for the recovery of aquifers, it is a vital to prioritize the recovery and conservation of the valuable green infrastructure that is made up of the mountains and the network of watercourses and wetlands of the province of Almeria, which are responsible for collecting water derived from rainfall, making it possible to recharge aquifers and reduce flood risks. Actions aimed at conserving, restoring and recovering the natural heritage of the agricultural areas of Almeria should be a priority in the future.

In this sense, the environmental requirements and the most sustainable production processes currently demanded by international agricultural markets is an opportunity to convince farmers and administrations about the need to carry out this type of restoration and conservation of green infrastructure through corporate social responsibility initiatives (Castro et al., 2019).

Regarding the policies for works and hydraulic infrastructures (gray infrastructure) there are several issues that should be taken into account. The proposal for new conventional hydraulic infrastructures (reservoirs and transfers), in addition to requiring large construction budgets and having a significant impact on the environment, can be inefficient and even ineffective, especially during periods of drought that are a result of climate change (BOCG, 2018).

However, whenever conditions permit, the use of the maximum volumes of water authorized for the two existing transfers in the province should be sought.

Priorities regarding gray infrastructure should focus on water reuse and desalination models from the perspective of energy use and be based on renewable resources (Baños et al., 2019). It is necessary to regenerate and reuse 100% of purified water and reach zero discharge in both the public water domain and coastal areas. New desalination plants must be promoted and full use made of existing ones.

An adequate and sufficient implementation of these unconventional hydraulic infrastructures is considered to be the most flexible and effective strategy to ensure the self-sufficiency of water resources during periods of drought. To this end, it is essential that the distribution networks and irrigation pipes be improved in some areas (Aznar-Sánchez et al., 2019). However, this is a pending task because until now political rather than economic or social issues have prevailed.

While the higher cost of desalinated water should not pose a threat to farmers, in order to reduce this, fiscal measures similar to those proposed in other autonomous communities[1], (Aznar-Sánchez et al., 2019), as well as lines of research aimed at improving desalination technologies through renewable energy, increasingly more efficient to reduce the per cubic meter cost of water produced.

Two world-leading research centers in solar energy, located in Almeria, CIEMAT (Center for Energy, Environmental and Technological Research of the Tabernas Solar Platform) and CIESOL (Center for Research in Solar Energy of the University of Almeria), are currently working to develop and evaluate solar energy de-energization technologies that imply a reduction in costs for use in greenhouse intensive agriculture.

In addition, the private operators of the current desalination plants in operation in Almeria are also working on innovating ways to reduce energy costs. An example of this is the case of the Campo de Dalías Desalination Plant, where the use of state-of-the-art membranes and other improvements have reduced the energy consumption of the reverse osmosis process by 45%, from 3.5 to 2.7 kW h per cubic meter (Fertinnowa, 2018).

It is essential that, unlike what has happened historically, new water resources that are generated from desalination or reuse techniques, or those that arise as a result of reduced consumption through irrigation improvement and modernization programs, are not used to expand the area of cultivation, but rather used to reduce the aquifer extractions. It is also important to avoid speculation about forest lands that could be susceptible to possible changes to agricultural use. To this end, the public environmental administration should develop and approve a Provincial Management Plan for Forest Resources aimed at the effective protection of natural resources and provide legal security for land transformations that are environmentally compatible.

It is also necessary to carry out, within the framework of *Directive 2007/60 for the Evaluation and Management of Flood Hazards*, an effective agro-hydrological management, which prioritizes measures such as the limiting the use of flood prone areas; the release of river lands currently occupied by waste, construction and other infrastructure; as well as the collection of rainwater recovered from greenhouses and other waterproofed surfaces for the purpose of irrigation.

5. Conclusions

The development of intensive agriculture and the acceleration of urban growth that has occurred in a large number of arid and semi-arid areas of the world have, in many cases, caused the over-exploitation and degradation of natural ecosystems, especially those related to the water cycle, such as aquifers or wetlands. If we add to this fact the effects that climate change is expected to cause, we can affirm that in these regions, in the near future, the security and water sustainability of local populations is at risk.

This state of environmental vulnerability is currently taking place in the intensive greenhouse agriculture areas of the province of Almeria. The accelerated and extensive agricultural and urban transformation that has taken place in recent decades in these areas has caused the over-exploitation of almost all of its groundwater and the degradation of its natural ecosystems.

In this sense, the degradation and over-exploitation of mountain ranges, aquifers, river channels, wetlands and coastal ecosystems in this region, determines the ability of these natural infrastructures to provide essential environmental services for human development and well-being such as the provision and regulation of water resources; the protection against natural disasters, such as torrential rains and floods; or adaptation to the effects of climate change.

Faced with this threat, the present paper proposes the development of adaptation and integral management strategies for these semi-arid and arid areas aimed at promoting Social Contracts for Water, in which public administration, entrepreneurships and society take part in.

The objective of public administrations should be the long-term development of a program of measures aimed at redirecting the policies implemented to date towards policies based on mixed green/gray infrastructure solutions designed to restore the environmental services provided by the green infrastructures of these regions and to guarantee the sustainability

[1] Territories such as Canary Islands, Murcia and the Community of Valencia have proposed, through the formulation of Drought Decrees, allocations of public expenditure for the reduction of the cost of water from desalination plants.

of the water cycle in a scenario where climate change is a factor and under a circular economy strategy, which favors unconventional water resources, such as desalination and water reuse.

In order to achieve this objective, the participation of the agricultural business sector is key, which should devote part of its economic benefits to improve extraction and consumption control systems, modernise irrigation systems to encourage savings and implement corporate social responsibility actions aimed at conserving "Green Infrastructures" (mountains, rivers and streams), which recharges the groundwater bodies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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2.4. Mapping green infrastructure and socioeconomic indicators as a public management tool: the case of the municipalities of Andalusia (Spain).

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Mapping green infrastructure and socioeconomic indicators as a public management tool: the case of the municipalities of Andalusia (Spain)

José Luis Caparrós Martínez, Juan Milán García*, Nuria Rueda López and Jaime de Pablo Valenciano

Abstract

Background: Green Infrastructure (GI) is defined as a strategically planned network of natural and semi-natural spaces that provide society, in both rural and urban areas, with a large number of goods and services of great value and economic importance such as clean air and water, carbon storage, pollination or protection against the effects of climate change. Traditionally, municipalities, like other territorial units, are characterized by a series of social and economic indicators that determine their degree of local development. The objective of this article is to identify and assess, through a system of indicators, what role urban and rural municipalities in Andalusia (Spain) play in the provision and reception of ecosystem services. To this end, Geographical Information System (GIS) techniques are used and a cluster analysis is carried out to contrast the results.

Results: Rural municipalities show the largest portion of GI area in the whole region. However, they show a low socioeconomic level, with high unemployment rates.

Conclusions: It can be said that the municipalities in rural areas are "ecologically" financing the entire Andalusian population. Faced with this situation, the decisions, and actions of policymakers in this region should aim at promoting measures that can restore and conserve GIs, addressing the demographic and/or socioeconomic imbalances of the region.

Keywords: Green infrastructure, Ecosystem services, Municipalities, Socioeconomic indicators, Geographic information systems, Cluster analysis

Background

Andalusia, a southern region in Spain, is located in a temperate zone in the northern hemisphere, at a biological crossroads between two great continents, *Europe and Africa*, and between two great bodies of water, the *Mediterranean Sea and the Atlantic Ocean* (Fig. 1). This location gives it a unique biological, geological and landscape diversity, and a wide variety of rich ecosystems, ranging from arid spaces, high mountains, marshes, dunes and coastal sands, forests and countryside, among others. This privileged situation has determined that, since time immemorial, this region has been occupied by various cultures that have left their mark through a model use of natural resources [62, 63], perfectly adapted to the environmental conditions and which has favored this unique and rich biodiversity [36, 37, 57, 61]. It is hard to find in Europe a territory as populated (8,414,240 inhabitants) and extensive (87,599 km^2 in area and 910 km of coastline) that is also so rich in natural resources or that is better conserved [26, 31, 32]. In addition, it is a territory where rural spaces have an important presence.

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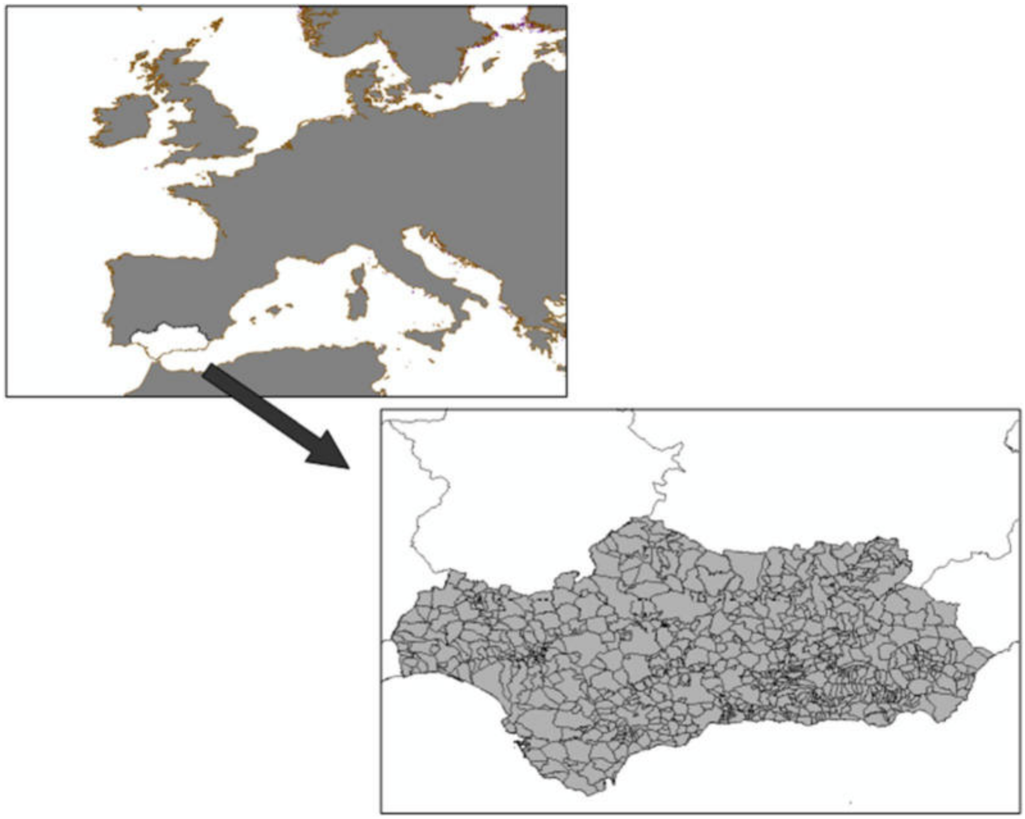

Fig. 1 Study Area. Source: *Red de Información ambiental de Andalucía – REDIAM* (Environmental Information Network of Andalusia) (2010)

The region of Andalusia is part of one of the 20 most relevant biodiversity points on the planet with 28.7% of its surface listed as a natural space protected by regional, national and international regulations [37] and is key for the provision of ecosystem services. However, the sustainable interaction that has existed for centuries between nature and the human population is at risk. This is made manifest in the problems of depopulation and abandonment of traditional land uses, which in many cases, are causing a significant degradation of the ecosystems that make up the GI [5, 37];. The data are compelling. Half of the municipalities in Andalusia have lost population so far this century. Depopulation affects 389 municipalities, which represent 48.41% of Andalusia. Of these, 89.2% are rural municipalities (347/389), some of which, although small in size, suffer the greatest relative loss of population [22, 23, 25, 27].

There are exceptions to this scenario, such as the municipalities that are located in the Guadalquivir Valley and along the coast, which in recent years have seen a palpable growth in their population. At present, there are municipalities with fewer than 5,000 inhabitants that occupy 51.08% of the territory with 11.01% of the population, while large cities occupy 7.95% of the territory, concentrating 50.75% of the population [21].

Situations, such as the current COVID-19 health crisis and its spread from animals to humans can be linked to the alterations and impacts suffered by the planet's natural ecosystems [42, 67]. There is empirical evidence of the protective effect of nature and biodiversity against pathogens and infections. This capacity lies in the fact that healthy ecosystems harbor a great diversity of species that can act as hosts for pathogens, limiting the transmission of diseases, either by dilution or damping of the existing viral load. [20, 41, 44].

Although the existence of healthy ecosystems which are rich in biodiversity is important, functional ecosystems are also needed for the provision of key ecosystem services for human well being and for adaptation to the phenomenon of climate change. Various reports prepared by the Intergovernmental Group of Experts on Climate Change (IPCC) of UNEP [33–35] indicate that global warming of the planet is also a factor that accelerates the arrival and spread of infectious diseases. This situation is aggravated by increasing urbanization and the accelerated change in land uses that are taking place around the world, in which natural resources are being overexploited and natural ecosystems are being contaminated. This scenario facilitates the spread of infectious diseases, the consequences of which are accentuated, as is the case of the recently detected link between the high mortality rates from the coronavirus in Madrid and some cities in Northern Italy which have alarming rates of air pollution [56].

Faced with degraded and polluted territories, well structured and functional ecosystems provide society with a large number of environmental goods and services of great value and economic importance, such as clean air and water, carbon storage, pollination, etc. They also play a fundamental role in the fight against climate change, protecting us from epidemics, floods, and other environmental catastrophes.

To respond to these important environmental challenges, policymakers can adopt, on the one hand, engineering or technological strategies; and/or, on the other hand, alternative approaches based on the comprehensively managing natural and social systems in order to increase the benefits that nature provides for human well being, health, and development [46]. GI is defined as a strategically planned network of natural and semi-natural spaces and other environmental elements designed and managed to offer a wide range of ecosystem services [14, 58]. This term is intended to simplify complex ecological concepts related to the functioning of ecosystems and the ecosystem services they provide, making an analogy between the infrastructure of natural systems and the gray infrastructure of human artificial systems, such as road networks or the hydraulic infrastructures themselves. Investing in GI is based on the logic that it will always be more profitable to invest in nature-based solutions than to replace these ecosystem services with human technological solutions [75]. Table 1 shows the main benefits of GI grouped according to main ecosystem service types.

In the context of Europe, the concept of GI is a fundamental element of the strategies aimed at achieving a climate neutral Europe and protecting natural habitats for the benefit of people, the economy and the planet [14]. This is in line with the formulation of the Green Deal of the European Commission, a new growth strategy based on a green and fair transition which plans to mobilize at least 100,000 million euros during the period 2021–2027 [16]. These types of European policies point to the fact that GI could become a primary strategic factor for European cities and municipalities when facing not only global environmental challenges, but also the economic and social reconstruction that will be necessary after the coronavirus epidemic.

An analysis of GI initiatives in European countries revealed seven major areas where GI approaches have been adopted; namely: ecological networks for

Table 1 Potential ecosystem services and benefits of GI

Habitat services	Regulating services
1. Biodiversity/species protection:	1. Climate change adaptation:
a) Habitats for species	a) Mitigating urban heat island effect
b) Permeability for migrating species	b) Strengthening ecosystems' resilience to climate change
c) Connecting habitats	c) Storing floodwater and ameliorating surface water run-off to reduce the risk of flooding
Cultural services	2. Climate change mitigation:
1. Recreation, well being, and health:	a) Carbon sequestration
a) Recreation	b) Encouraging sustainable travel
b) Sense of space and nature	c) Reducing energy use for heating and cooling buildings
c) Cleaner air	d) Providing space for renewable energy
d) Tourism/Ecotourism	Provisioning services
2. Land values:	1. Water management:
a) Positive impact on land and property	a) Sustainable drainage systems, attenuating surface water run-off
3. Culture and communities:	b) Fostering groundwater infiltration
a) Local distinctiveness	c) Removal of pollutants from water
b) Opportunities for education, training and social interactions	2. Food production and security:
c) Tourism opportunities	a) Direct food and fiber production on agricultural land, gardens, and allotments
	b) Keeping potential for agricultural land
	c) Soil development and nutrient cycling
	d) Preventing soil erosion

Source: European Environment Agency (2011) biodiversity, connectivity and ecological coherence; multifunctional use of farmland and forests; multifunctional use of coastal areas; freshwater and wetlands management and restoration; urban GI; gray infrastructure mitigation; and GI mapping for planning [50]. The present work specifically addresses this last initiative, GI mapping for planning, and its main contribution is to offer a methodology that identifies and evaluates GI at the municipal level, taking the region of Andalusia (Spain) as a reference. Based on this methodology, the following objectives are pursued in this work. First, to identify and characterize the elements of GI at the municipal level, both in urban and rural settings, through the use of GIS technology. Secondly, to analyze the possible clusters that group the municipalities of Andalusia based not only on the state of their GI but also based on the socioeconomic indicators of the municipalities where the GI is located. And, finally, in light of the the results obtained, propose approaches to public management aimed at prioritizing the ecosystem services of the GI and addressing possible demographic and/or socioeconomic problems in the municipalities.

Methodology

GIS (geographic information system) technology is widely used in environmental studies. Along these lines, Rüdisser et al. [70] analyze the parameters of the linear regression model together with exhaustive spatial data from GIS to spatially predict the values of the soil biological quality index. Wang et al. [79] investigate the solar, wind, biomass, geothermal, and hydroelectric potential within Fukushima Prefecture (Japan). Zolin et al. [81], focus on the spatialization and production of different information plans. Xiao et al. [80] estimate and map the biological diversity and ecosystem services in the municipality of Chongqing (China). Nagy et al. [54] combine the analysis of quantitative data with a computer mapping technique. More recently, several works have been published that relate GIS technology with environmental indicators [2, 52, 71].

Our study commenced with a selection of indicators related to GI and the socioeconomic sustainability of the municipalities of Andalusia. Studies related to the establishment of GI indicators in the international arena have been reviewed in order to minimize the subjectivity associated with the methodological process for selecting indicators and establishing assessment thresholds for each one [1, 15, 60, 69]. Various reports from national and international institutions have also been consulted, establishing thresholds for some of the indicators used European Commission 2016 [10, 22, 55]. Finally, consultations have been carried out with a panel of experts, from both the academic field and from public management, the Ministry of Agriculture, Livestock, Fisheries and Sustainable Development, the Andalusian Environment and Water Agency as well as technicians and heads of City Councils.

The final set of indicators has been selected by applying representativeness and availability criteria in the following regional and national statistical and cartographic information sources: Environmental Information Network of Andalusia (REDIAM), the Andalusian Multiterritorial Statistical Information System (SIMA), Atlas of Andalusia, National Statistics Institute (INE), and Spatial Data Infrastructure of Spain (IDEE).

Once the statistical information and cartography have been selected, spatial analysis operations have been carried out through GIS technology (ArcGis 10.4.1) that have allowed the GI to be scaled in each of the municipalities of Andalusia, in addition to applying a socioeconomic characterization of each of them. The geoprocessing method used is the intersection method, in which the input elements are cut from another layer superimposed on the first. The result is a new layer that collects the spatial combination of the different elements that make up both layers (Fig. 2).

Fig. 2 Example of Intersection between two layers of polygons (geometries and table of attributes). Source: Own Compilation

The joint geoprocessing of the different types of geographic databases selected through GIS technology has allowed us to establish a novel system of useful indicators to delimit and characterize GI at the municipal level, both from an environmental and socioeconomic point of view.

In order to contrast the validity of the results obtained in the selection of the indicators through the implementation of GIS, a cluster analysis was carried out using the indicators in Tables 2 and 3. This is a method that allows individuals within a specific municipality to be grouped based on a series of variables, whose versatility is made manifest in the variety of areas in which it has been used, such as medicine [6, 53], economics [3, 64] or even local development [9, 51],among others. This methodology presents several types of clusters, such as the hierarchical cluster, in which the division by groups follows the shape of a tree [40], spatial clustering, based on the density of noise applications [30], or the K-means method, which is used in a multitude of research areas [47]. This latter clustering method has been chosen due to the nature of the data and its availability [49].

The procedure follows a simple process. First, the user decides the number of clusters into which they want to divide the sample. Each element of the data sample that is assigned to a centroid is considered to be a cluster. The centroid of each cluster is updated based on the objects assigned to the cluster. The allocation and update steps

Table 2 GI indicators

	Indicator	Variable	Criteria	Type	Source	Year
Indentification indicators	Core area	Protected Natural Area	> 50% of Municipal area is a Natura 2000 site	Vector Polygon	REDIAM	2018
		Habitats of Community Interest	> 50% of Municipal area is considered a Habitat of Community Interest	Vector Polygon	REDIAM	2018
	Buffer zones / ecological corridors	Buffer zones/ecological corridors	> 50% of Municipal area is considered an Important Area for Ecological Connectivity	Vector Polygon	REDIAM	2013
Characterization indicators	Biodiversity	Areas of rich biodiversity	> 10% of Municipal Area is in the Biodiversity Atlas	Vector Polygon	ATLAS OF ANDALUSIA	2005
	Fragmentation	Artificial surface	> 10% of Municipal Area is artificial surface	Table	SIMA	2017
			> 10% of Municipal Area is Industrial Agriculture under plastic	Table	*SIMA*	2019

Source: Own Compilation

Table 3 Socioeconomic sustainability indicators

	Indicator	Criteria	Type	Source	Year
Demographic indicators	Evolution in population 1996–2019	Variation in population (±) during this period	Table	INE	2019
	Municipalities with small populations	Municipalities with population of < 1000 in 2019	Table	INE	2019
		Municipalities with population of > 1000 in 1996	Table	INE	2019
	Population density	Municipalities with population density < 12.5 inhabitants /km^2	Table	SIMA	2019
		Municipalities with population density > 500 inhabitants /km^2	Table	SIMA	2017
Economic indicators	Annual declared income	Municipalities with average declared income < regional average	Table	SIMA	2017
		Municipalities with average declared income > regional average	Table	SIMA	2017
		Municipalities with average incomes well below regional average (< €7000 p.a.)	Table	SIMA	2017
		Municipalities above average income (> €18,000 p.a.)	Table	SIMA	2017
	Municipal rate of unemployment	Municipalities with unemployment rates < regional average	Table	SIMA	2019
		Municipalities with unemployment rates > regional average	Table	SIMA	2019

Source: Own compilation

are repeated until no data point modifies the groups or until the centroids remain the same [43]. Specifically, eleven indicators have been used to carry out this analysis: five related to GI and six related to the socioeconomic sustainability of the municipalities of Andalusia.

GI Indicators

The indicators related to GI are divided into two categories: identification and characterization indicators Table 2.

Indicators for the identification of the GI

For a proper identification of the GI in the municipalities of Andalusia, the classification guide of the European Commission [13] has been used, which differentiates:

Core Areas These are areas where conservation is a priority, even if that area is not legally protected. These areas have included not only all the areas located in Protected Natural Spaces of Andalusia, but also those well-preserved ecosystems and areas of high ecological value [75]. For the identification of these core areas, in our work we have used the information layer of the Network of Protected Natural Spaces of Andalusia; and to delimit well-preserved ecosystems, the Habitats of Community Interest layer of the European Directive 92/43/EEC has been used (Fig. 3). Both sources of information are available on REDIAM.

This study has used the, *the Core Area Indicator to identify those municipalities that have more than 50% of their territory included in the network of Protected Natural Areas of the European Union (established by Directive 92/43/EEC and known as Natura 2000) and/or as Habitats of Community Interest.*

Buffer zones and/or ecological corridors One of the main purposes of GI is to guarantee the ecological connectivity of a territory, since this is essential to maintain the ecological flows of energy and materials and, more particularly, natural heritage and biodiversity [65, 68, 78].

For the identification of important areas for ecological connectivity has been used the mapping of the Master Plan for the Improvement of Ecological Connectivity in Andalusia, developed by the regional government of Andalusia [39].

By means of the *Indicator for buffer zones/ecological corridors, those municipalities with more than 50% of their territory are included in areas that are important for ecological connectivity, applying the criteria as established in the Master Plan for the improvement of the Ecological Connectivity of Andalusia. Landscapes of interest for connectivity (LIC) and Reinforcement Areas (RA).*

Indicators for the characterization of GI

In order to assess the conservation status and integrity of GI in the Andalusian municipalities, based on

Fig. 3 Network Natural Protected Areas of Andalusia (Natura 2000). *SCI: Site of community importance, SAC: Special area of conservation, SPAB: Special protected areas under Bird Directive.* Source: [67]

information available at the municipal level (REDIAM, SIMA, Atlas de Andalucía, and IDEE), three criteria have been selected: biodiversity, fragmentation and state of conservation of aquifers.

Biodiversity For the elaboration of the biodiversity indicator, it has been used the biodiversity map included in the Atlas of Andalusia, volume II, which reflects the variation and relative abundance of habitats and species in the region has been used to develop a GI biodiversity indicator for this region [66]. This biodiversity map was prepared from a series of normalized and standardized variables in the context of REDIAM. Some of the variables of note used for its development are the typology and distribution of plant associations, the different uses of the soil, the distribution and endemicity of the main taxa of flora and fauna and the degree of threat of natural and semi-natural habitats. From this information, the level of plant diversity is represented and natural ecosystems are classified (high, medium, and low), and in cultivated areas, structural diversity is also classified (high, medium, and low) (Fig. 4).

An indicator has been developed to select those municipalities that contribute most to the conservation of biodiversity. Specifically, *the Biodiversity Indicator has been selected to represent all those municipalities in which more than 10% of their territory in classified High Biodiversity areas according to the Atlas of Andalusia (2005).*

Fragmentation To assess the degree of fragmentation of the region's GI, two indicators were used, based on the information available from SIMA. First, the percentage of artificial soil of each of the Andalusian municipalities in 2017 has been taken into consideration, according to the criteria established by Eurostat [19] and, secondly, the area occupied by intensive agriculture under plastic has been considered for the year 2018.

The Fragmentation Indicator used in this work includes those municipalities that have more than 10% of their territory occupied by artificial surfaces or industrial agriculture under plastic.

Socioeconomic sustainability indicators.

In relation to socioeconomic sustainability indicators, it must be pointed out that the GI of Andalusia has its origin in a unique geology and climate, although its structure and operation is highly conditioned by the human activities that have taken place over millennia in the region [37, 38, 74].

Demographic indicators

The following indicators have been used to analyze the population variable in the study:

Changes in population in the period 1996–2019 Measured as a percentage of variation between the two periods.

Municipalities with a small population Measured as a percentage of the total of municipalities with less than 1,000 inhabitants in both 1996 and 2019.

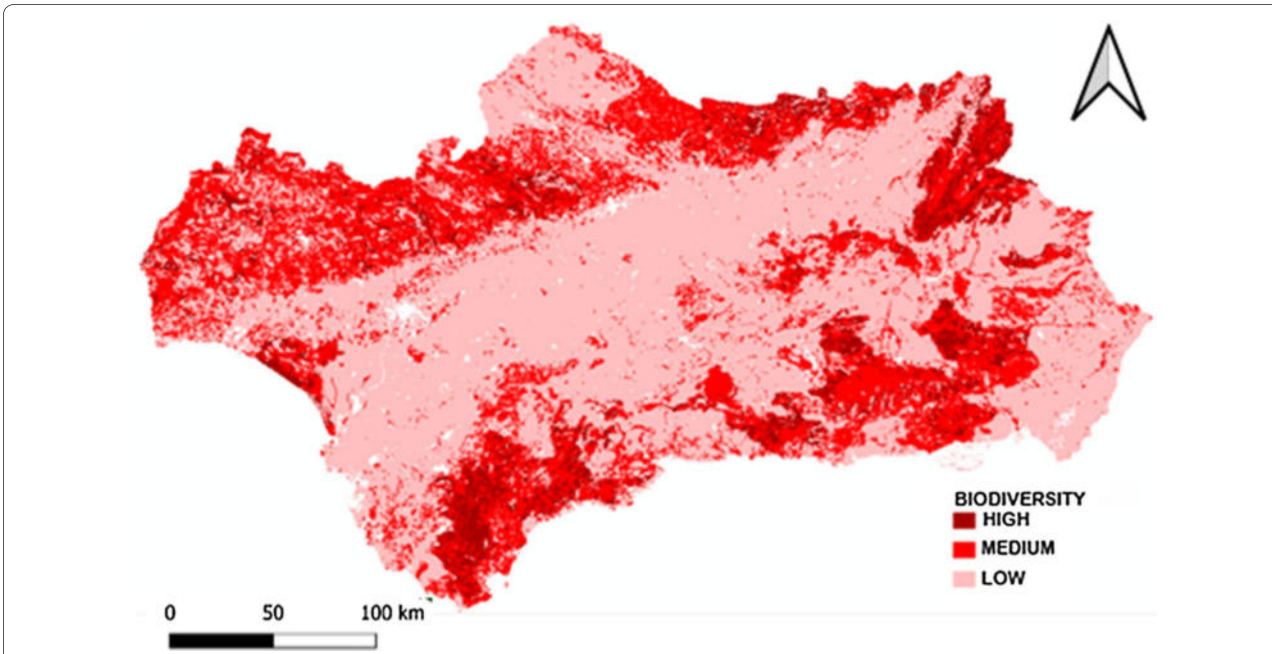

Fig. 4 Biodiversity Map of Andalusia. Source: Atlas of Andalusia and REDIAM (2005)

Population density Measured as the number of municipalities with a population density of less than 12.5 inhabitants/km^2 (municipalities at risk of depopulation) or greater than 500 inhabitants/km^2 (municipalities at risk of overcrowding).

The reason for including these three indicators is to not only understand population levels (represented by the population density of each municipality) but also the depopulation trends of recent years (represented both by the proportion of municipalities with fewer than 1000 inhabitants and the evolution of the population between 1996 and 2019).

Economic indicators

The economic status of the municipalities of Andalusia has been measured using the following indicators:

Average declared income Represented by the number of municipalities with higher and lower declared income than the regional average, as well as the number of municipalities with average incomes of less than € 7,000 of per annum and municipalities with average incomes of more than € 18,000 per annum.

Municipal unemployment rate Measured as the number of municipalities with an unemployment rate higher or lower than the regional average.

Using these two indicators allows us to gain a broader perspective of the economy both in terms of income and employment Table 3.

Results

After using the selected indicators, the results obtained are presented below. Firstly, a classification of the municipalities of Andalusia has been developed in relation to the conservation status of their GIs, these have subsequently been linked to the socioeconomic situation of each of these localities in order to identify possible trends and general processes regarding environmental management, land use, and demographic and economic evolution in the region.

GI, biodiversity and fragmentation

The cartographic representation of the location indicators shows an extensive and well-configured GI network in Andalusia in the mountainous areas of the region (Sierra Morena and the Subbética and Penibética mountain ranges) and more fragmented network in the coastal strip and the Guadalquivir valley.

On the other hand, the GI buffer zones encompass a series of diverse landscapes ranging from low and medium mountain areas to extensive patchwork of agricultural crops, which stand out for their natural value and their ability to adapt to ecological flows.

The Core Areas, in their entirety, are attached to the network of Protected Natural Spaces and specifically to a large number of municipalities that include Habitats of Community Interest. Buffer Zones, in contrast, are widely distributed throughout the region and act as ecological corridors, fulfilling the ecological connectivity function of the Core Areas (Fig. 5).

The inland Core Areas are made up mostly of forest and high mountain ecosystems, most of which are public property, in which there is rich and unique biological diversity as a result of variable environmental conditions and minimal traditional ecological human management.

The Core Areas of the coastal and semi-arid spaces in the extreme southeast of the region are characterized by ecosystems of great uniqueness and rarity in the context of the European Union, but of a smaller area, more fragmented and with less biodiversity compared to the ecosystems of the inland Core Areas (Fig. 6).

In this regard, as shown in Fig. 6, many of the Andalusian coastal municipalities have more than 10% of their surface occupied by urbanized and artificial soil (mainly the Costa de Sol and Cádiz) and by intensive agriculture under plastic (coast of Almería, western Granada and the coast of Huelva). In some coastal municipalities, more than 60% of their first coastal kilometer is urbanized: Torremolinos (73.8%), Fuengirola (73.4%), Malaga (72.3%), Benalmádena (69.3%), Mijas (61.7%). There are also cases where more than 50% of the municipal surface is occupied by greenhouses, namely El Ejido (56.94%) and La Mojonera (60%).

In addition to the fragmentation of the coastline, there are large pockets of artificial soil around the urban peripheries of some provincial capitals of the region (Seville, Granada, Malaga, and Almería).

GI and demography

Since the mid-twentieth century, rural Andalusian municipalities have suffered continuous demographic losses as a result of the heavy emigration of the population to the coast and the large metropolitan areas of the region (Fig. 7).

The municipalities in the Core Areas of the GI are not oblivious to this general dynamic since the hinterland and most peripheral areas lose population while the coasts and areas closest to large metropolitan areas gain population. However, there are some inland municipalities that evince a trend away from this general dynamic of population regression during the period 1996–2019 (Guejar Sierra, Monachil, Huétor-Santillán, Aracena, El Bosque, Paterna del Rio, and Fondón). The common characteristic of all these municipalities is their inclusion in the Andalusian Network of Natural Parks and the weight of rural tourism in their local economy.

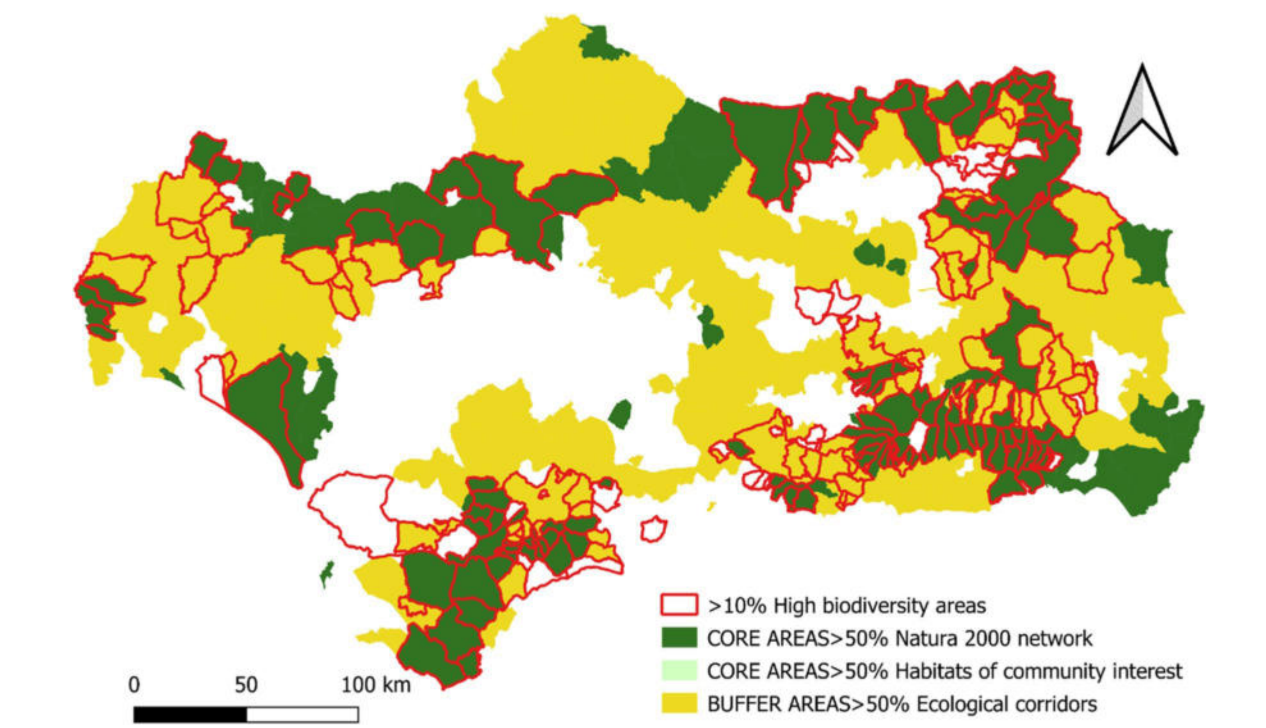

Fig. 5 GI and municipalities with high biodiversity. Source: Own Compilation

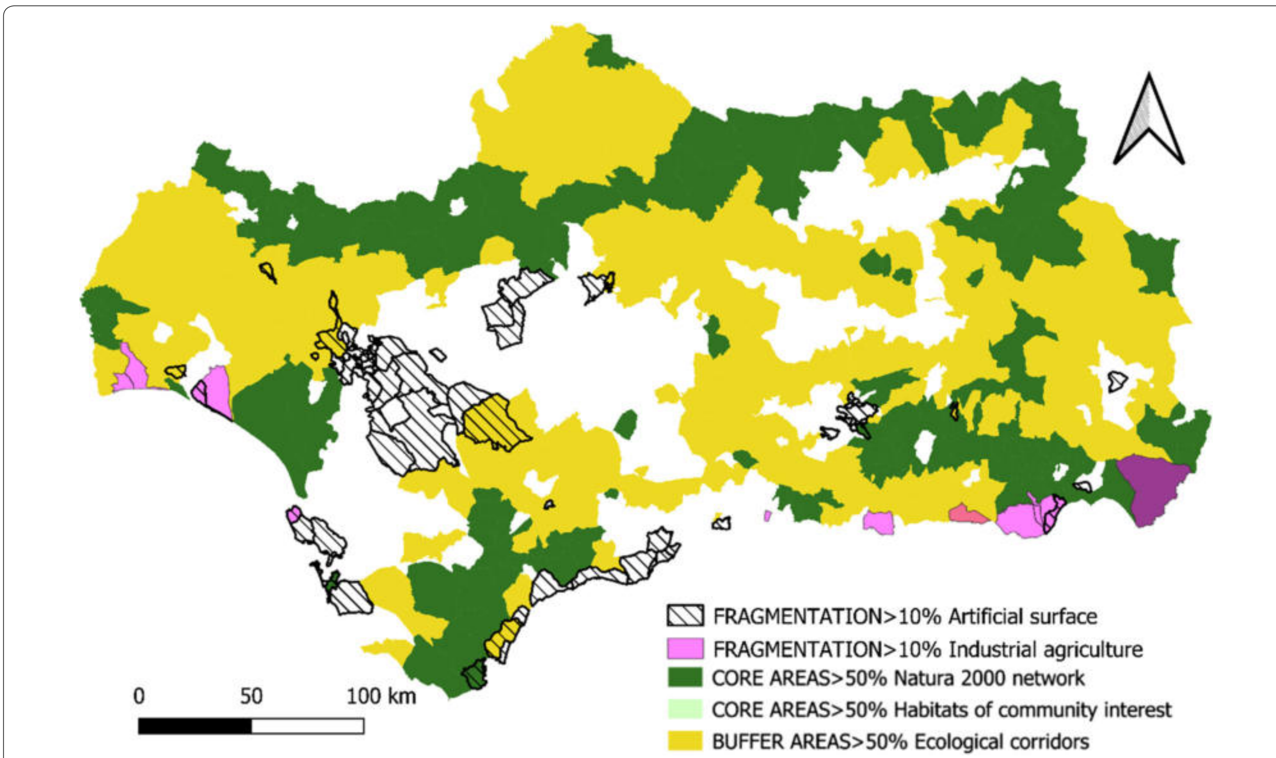

Fig. 6 Fragmentation. Source: Own Compilation

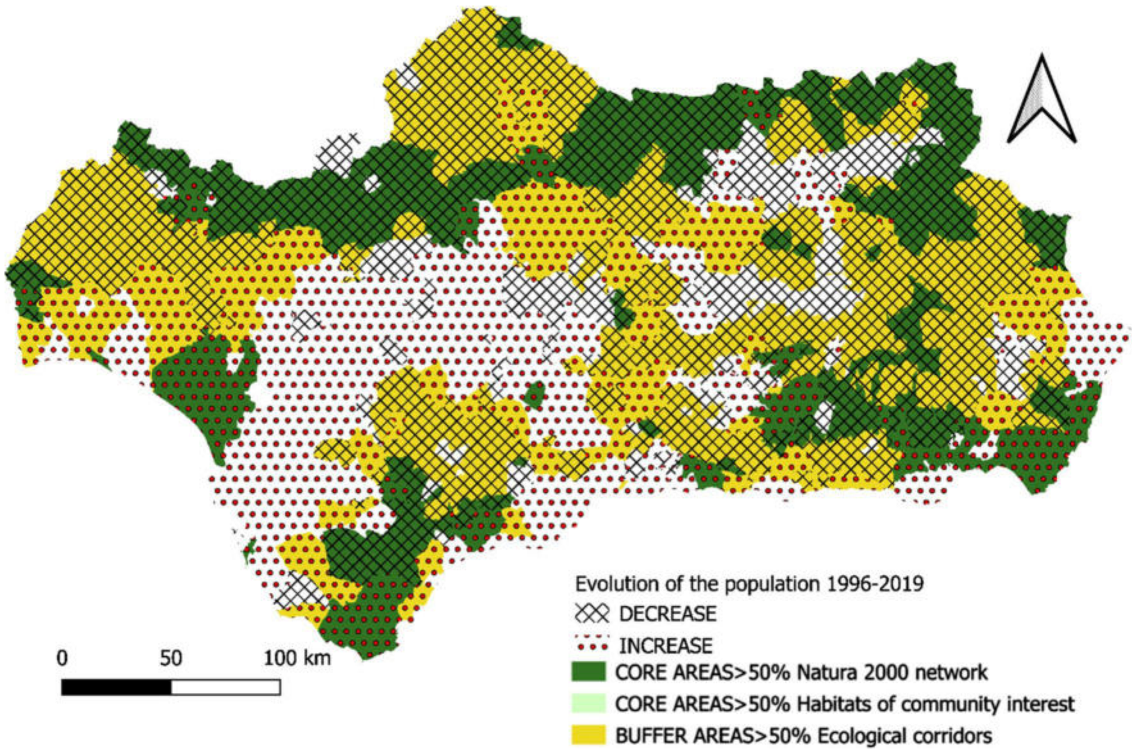

Fig. 7 Evolution of the population between 1996 and 2019. Source: Own Compilation

Regarding the indicator referring to municipalities with a population of fewer than 1,000 inhabitants during the period 1996–2019, there is no difference in dynamics observed between municipalities located inside and outside the GI areas (Fig. 8). In general, the number of municipalities in the region with fewer than 1,000 inhabitants have remained stable during this period.

With regards to the population density of the municipalities of Andalusia, the previously mentioned phenomenon of migration to coastal areas is very obvious (Fig. 9). Almost all of the municipalities with serious risk of depopulation (< 12 inhabitants/km^2) are located further inland from the GI Core Areas and Buffer Zones. Those areas with high population density (> 500 inhabitants/km^2) are located, for the most part, outside the GI Core Areas, in coastal areas and, occasionally, in the metropolitan areas of the provincial capitals.

GI and socioeconomic indicators

Many of the municipalities with unemployment rates above the regional average are located in coastal and urban areas (Cuevas del Almanzora, Almería, Roquetas de Mar, Almuñecar, Mijas, Marbella Tarifa, Conil de la Frontera, Cádiz, Punta Umbría, Sevilla, Córdoba, etc.). This can be explained by the strong impact caused by the financial crisis on the construction sector and the bursting of the housing bubble (Fig. 10). As a counterpoint to the above, it is interesting to note that a good many of these urban municipalities, whose employment has hitherto been less affected by the financial crisis, have an agrarian-based economy (Níjar, El Ejido, Adra, Almonte), although in some of these, tourism also plays an important role in the economy (Mójacar, Carboneras, Nerja, Málaga). Thus, it becomes clear that these two sectors of activity, agriculture and tourism, are helping to boost the employment rate in Andalusia.

Part of the results and trends obtained in this section regarding the unemployment rate are similar to those obtained in previous studies [29].

Regarding per capita income (Fig. 11), as with demographic indicators, those municipalities with incomes above the regional average are located principally in coastal towns and around the large metropolitan areas. These are the areas where the largest companies in the region are located and there is greater economic dynamism. A positive aspect to highlight is the good rate of employment and income data offered by some rural populations located in GI areas and within the scope of the network of Protected Natural Areas in the region. A good number of municipalities in the natural parks of Sierra María-Los Vélez, Sierra de Cazorla, Segura and Las Villas, Sierra Norte, Aracena and Picos de Aroche,

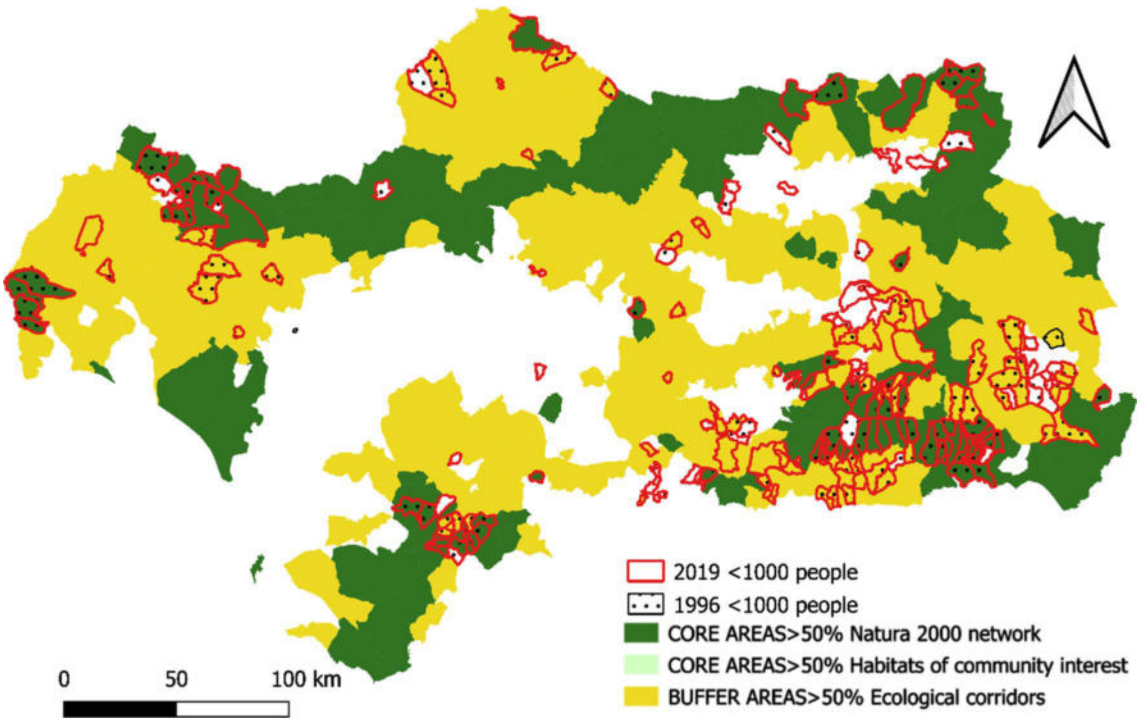

Fig. 8 Municipalities with population < 1000 inhabitants in 2019 and in 1996. Source: Own Compilation

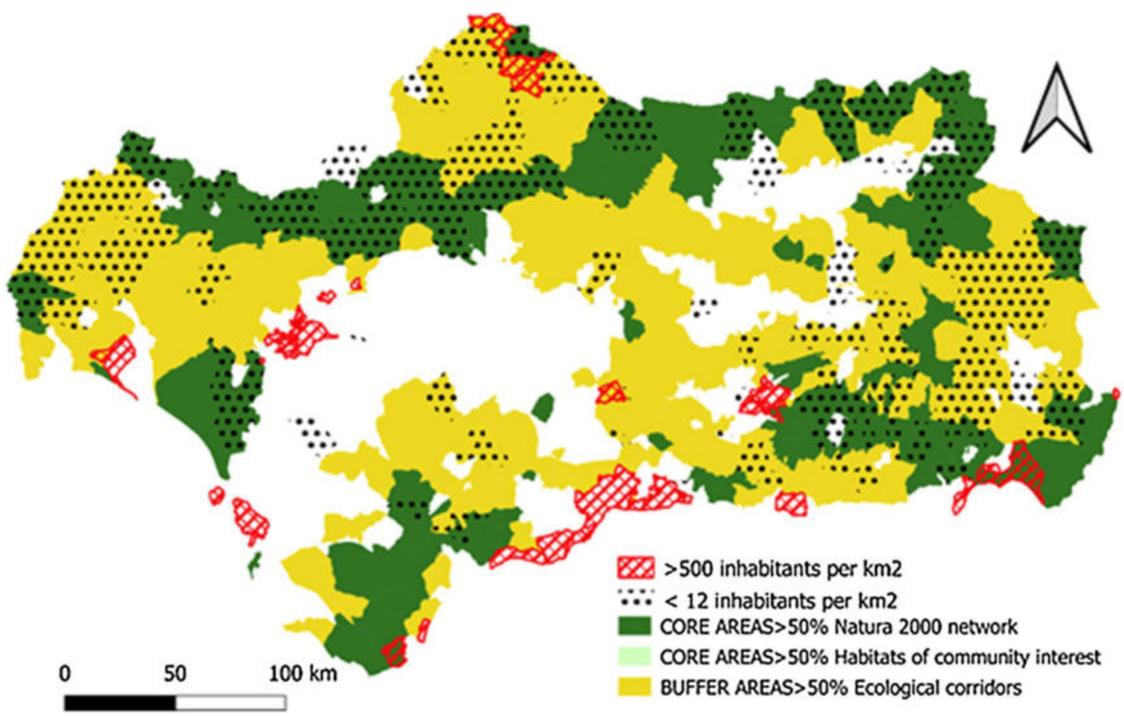

Fig. 9 Municipalities with low and high population density. Source: Own Compilation

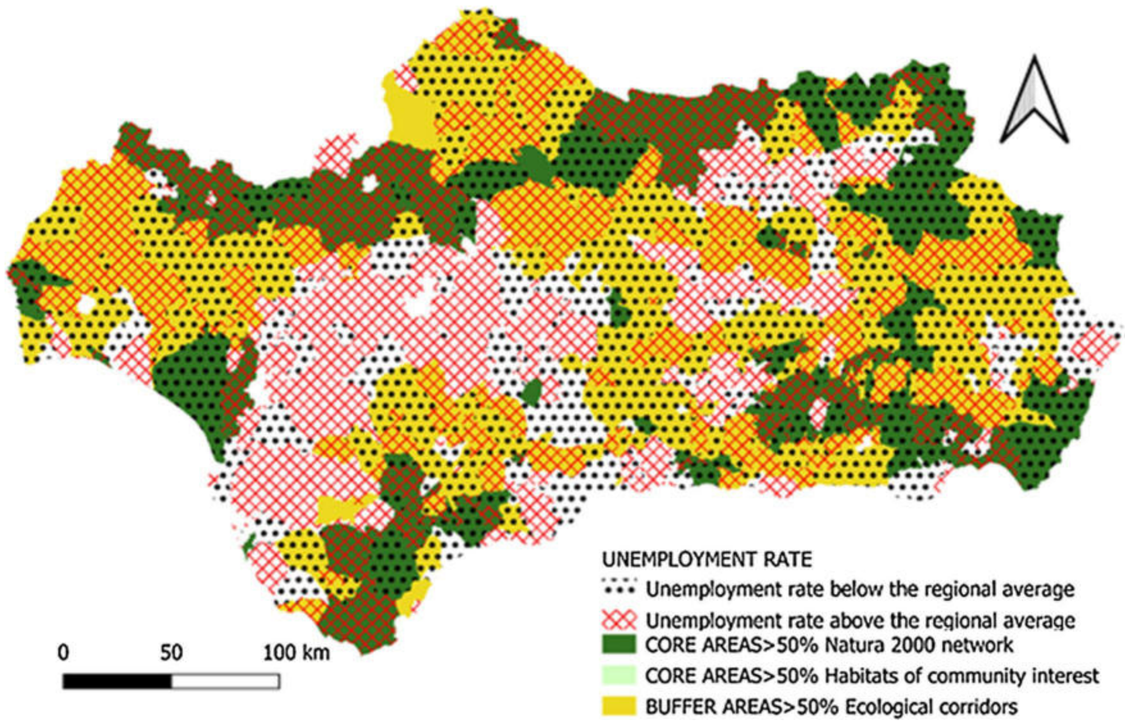

Fig. 10 Unemployment rate. Source: Own Compilation

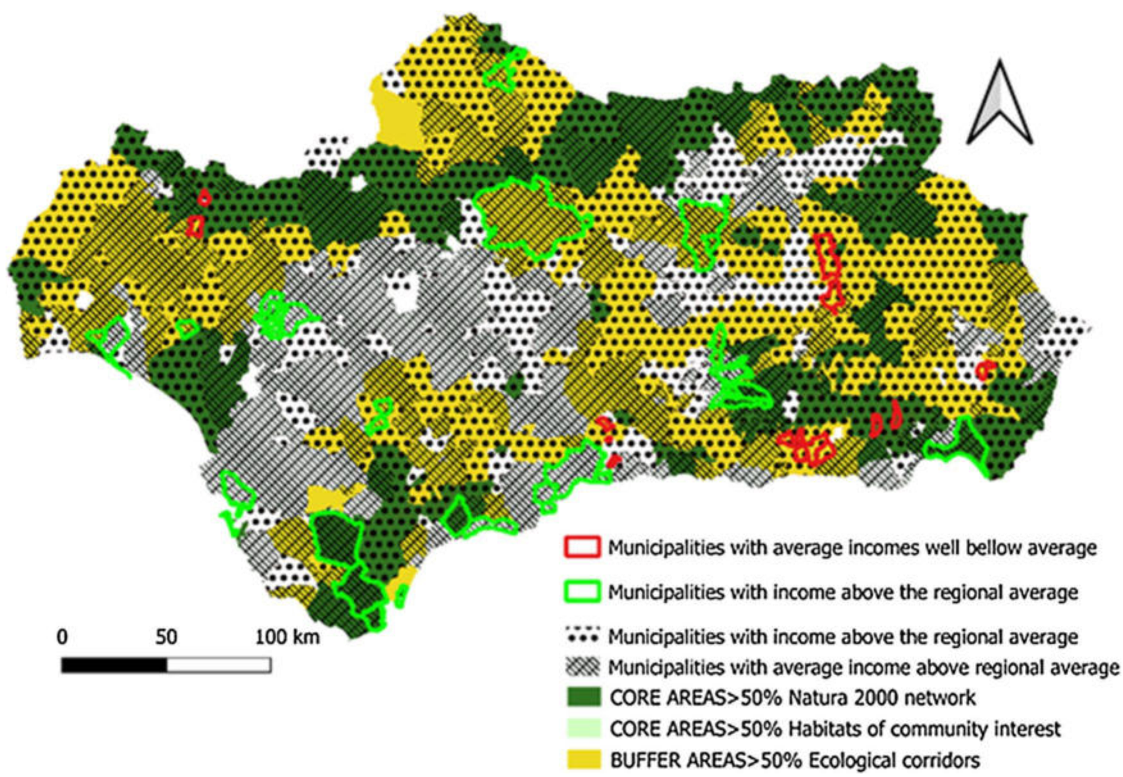

Fig. 11 Per capita income distribution. Source: Own Compilation

Alcornocales, Sierra de las Nieves, Sierra Nevada, or Sierra de Baza show more positive data as compared to the regional average, both in terms of unemployment rates and income.

Cluster analysis of indicators used

By means of a cluster analysis of the indicators used, a comparison will be made to those results obtained through GIS technology. The indicator data have been standardized and the R NbClust package has been used to decide the relevant number of groups based on various indicators [7]. In this instance, it was deemed that three was the ideal number of groups. Next, a clustering of Andalusian municipalities has been carried out using the K-means method. The results are reflected in Fig. 12.

The results obtained through the cluster analysis of the indicators offer a similar trend to those obtained through the analysis by means of geographical information systems.

The territories of the municipalities in inland and mountainous areas (green areas) are those which most closely configure the Core Areas of the IGs in Andalusia, as they have the largest surface area of Natural Areas, Habitats of Community Interest and areas of high-quality biodiversity.

On the other hand, if we exclude certain coastal areas and large metropolitan areas (red areas) where the fragmentation of ecosystems is greater, the cluster analysis confirms once again the adequate ecological connectivity between the IGs of the region (yellow areas).

From the socioeconomic point of view, it also reconfirms the trend that municipalities with lower population, higher unemployment and lower socioeconomic level are more concentrated in the core areas and zones of ecological connectivity of the IGs (green and yellow areas), while those with higher population and socioeconomic level are located in the coastal areas and metropolitan areas (red areas).

Discussion

The crisis caused by the global pandemic of COVID-19 has revealed how fragile and vulnerable the human species is and how interconnected the planet is to global phenomena, both environmental and social. There is scientific evidence that biodiversity has positive impact on the productivity of ecosystems and the ecosystem services they provide, adapting to the adverse effects of climate change or offering protection against infectious diseases or pandemics [20, 24, 42, 44, 45, 48].

Likewise, it has also been shown that, in the face of degraded and polluted areas, the well-preserved ecosystems with GI provide society with a protection barrier against pathogens and infections. In particular, these ecosystems are a source of environmental goods and services of great value and economic importance, such as clean water and air, carbon storage or protection against the effects of climate change [72, 73, 77].

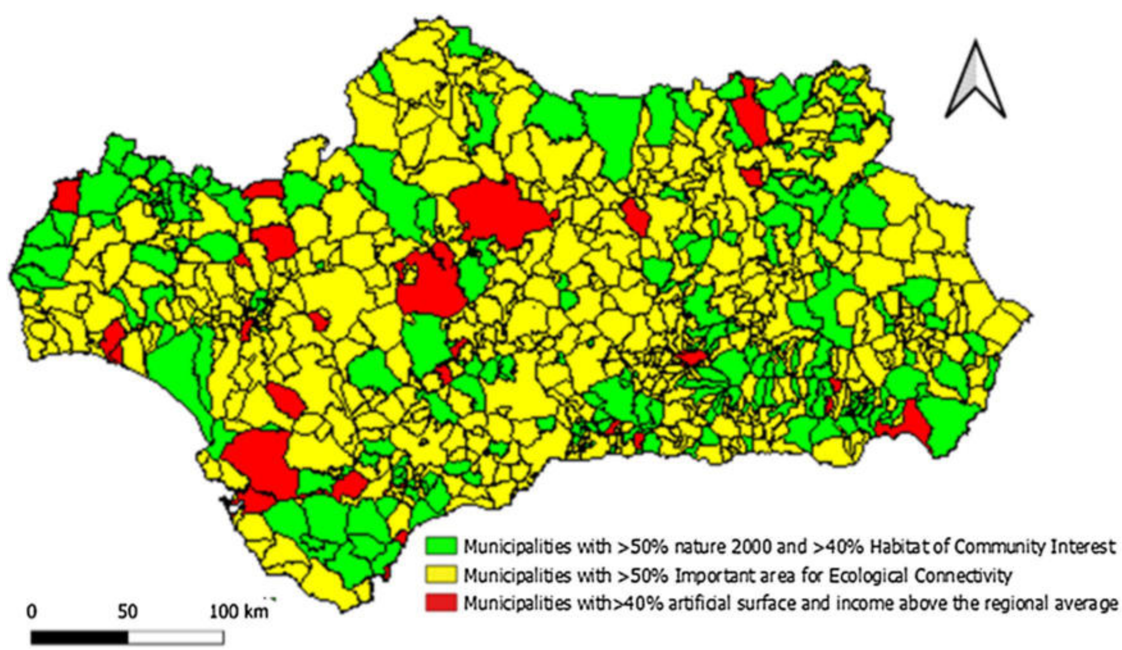

Fig. 12 Cluster of the municipalities of Almería Source: Own Compilation

This is recognized by the European Union, in the recent 2030 Biodiversity Strategy, where it is pointed out that the risk of the appearance and spread of infectious diseases increases as nature or the proper functioning of ecosystems is destroyed. This strategy identifies that investments in the protection and restoration of nature will be essential for the recovery of the European economy after the COVID-19 crisis, as well as that it will be crucial to avoid falling back into old harmful habits [17, 18]. According to the aforementioned strategy, the European Green Deal "*the EU's growth strategy will be the compass for our recovery, ensuring that the economy serves people and society and gives back to nature more than it takes away*".

Given this future scenario in which Europe is considering a green economic reconstruction, and based on the results obtained in this work, it is considered a priority that the different European regions carry out an adequate assessment and diagnosis of their different GIs as these are responsible for generating key ecosystem services for the quality of life and human well being.

Currently, almost 32.25% of the land area of Andalusia is protected. With 2,825,347.20 ha, this region comprises 21.19% of the entire Natura 2000 sites in Spain (Junta de Andalucía 2017). Andalusia possesses significantly above average number of species compared to other countries of Atlantic Europe and many Mediterranean countries, reaching 56% of the taxa of Community Interest in the Mediterranean region in its territory [36]. These figures are an indication of the key role that this network plays in the configuration of Andalusian GIs and, therefore, in the provision of ecosystem services to the region's population. However, as it is a very heterogeneous region in terms of environments and land use, this biodiversity is not distributed evenly throughout the territory.

The historical absence of market valuation of the ecosystem services provided by the GI in many regions of the planet has led to their overexploitation or deterioration as a consequence of the abandonment of practices compatible with their conservation. This is the case in Andalusia, (see Figs. 5, 6, 7, 8, 9, 10, 11, 12) where the area originally occupied by GI in the coastal strip and in large cities has decreased considerably in recent decades as a consequence of population growth, urbanization and the development of intensive agriculture. Furthermore, these phenomena have caused the fragmentation, decrease, and deterioration of the existing GI [12, 28, 37, 76].

In this sense, the work carried out within the framework of the United Nations Millennium Ecosystem Assessment Initiative (2012) determined that 77% of the evaluated Andalusian coastal ecosystem services were being degraded or being used unsustainably [8].

In contrast, the best preserved GIs have been identified in the rural inland areas of this region, today subjected to the phenomenon of depopulation (Figs. 5, 7, and 9). These infrastructures are responsible for providing, directly or indirectly, key ecosystem services for the quality of life of the entire Andalusian population, including those of the major cities in the region.

Perhaps the most paradigmatic case of this contribution is the Sierra de Gádor (Fig. 13), a mountainous massif located in the province of Almería, in charge of supplying the necessary water resources for one of the most productive agricultural zones in Europe and for supplying half of the population of the province of Almería,that is, the inhabitants of the capital Almería, El Poniente and Berja [4, 11, 59].

Conclusions

In order to address the lack of identification and valuation of the ecosystem services provided by GIs, this work proposes a model of territorial analysis that serves to make decisions in situations where there are different environmental, social, political and economic contexts. Specifically, a classification of the municipalities of Andalusia in relation to the conservation status of their GIs is addressed which is subsequently related to their socioeconomic situation based on the selection of a set of indicators.

Based on the results obtained, among the public management recommendations, it is essential, first of all, to adopt a more sustainable model for the coastal strip and metropolitan areas of Andalusia. To this end, the quality of life of the people must be prioritized over the occupation and urbanization of land. This means that it is essential to recover and restore the GIs and to have healthier urban and agricultural spaces, where sustainable mobility models prevail, less water and energy are consumed, more is recycled and local and local commerce is promoted.

Public Authorities must commit to a new water culture throughout the region. For this, reversing the processes of the commodification and speculation of water must be prioritized, involving the users themselves in the control of illegal extractions; and promoting the recovery of aquifers in poor condition through reuse and desalination with renewable energy. In this sense, it is necessary to regenerate and reuse 100% the purified water and reach zero discharge to the hydraulic, and other land or maritime infrastructures which are publicly managed.

The ecosystem services provided by the region's GI are closely related to the persistence of traditional ecologically based land uses, which are in sharp decline as a consequence of the loss of population in inland and mountainous areas. Consequently, public financing

Fig. 13 Intensive agriculture in the Poniente Almeriense and Sierra de Gádor regions. Source: Almería Free Tours. https://www.raizes.es/en/posteexperiencia/espanol-almeria-freetour/

mechanisms in the region must take into account these demographic imbalances, as well as possible compensations for the provision of ecosystem services, which must be aimed at guaranteeing equal opportunities and shielding essential public services in these rural zones. In this sense, the work already carried out by the regional government in recent decades in Protected Natural Areas aimed at promoting green employment, rural tourism, and ecology agriculture and livestock can serve as the foundation on which to base this new territorial model. Indeed, it is evident that these initiatives have provided a certain dynamism in the local economies of the Andalusian municipalities founded on sustainability criteria.

As a final conclusion, it can be affirmed that the municipalities in rural areas are "ecologically" financing the entire Andalusian population. Faced with this situation, the decisions and actions of policymakers in this region should promote measures aimed at restoring and conserving GI, addressing the demographic and/or socioeconomic imbalances of the region.

A limitation of this work consists in the exclusion of indicators related to specific resources (physical and monetary) and to the financial sustainability of public actions aimed at improving GI. In this sense, as a future line of research, it would be interesting to incorporate efficiency indicators of GI, which would report on those policies that allow the consumption of public resources to be minimized and have certain impact on environmental, social, and economic indicators.

Abbreviations
GI: Green Infrastructure; GIS: Geographical Information System; INE: National Statistics Institute; REDIAM: Environmental Information Network of Andalusia; SAC: Special area of conservation; SCI: Site of community importance; SPAB: Special protected areas under Bird Directive.

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Publisher's Note

3. RESÚMENES Y CONCLUSIONES DE LOS ARTÍCULOS

3.1. Green Infrastructure and Water: An Analysis of Global Research.

Resumen:

El escenario actual de cambio climático, crecimiento demográfico, urbanización, intensificación de la contaminación y degradación de los recursos hídricos va a obligar a los distintos países y regiones a que cambien su forma de gestionar el agua. Para responder a estos grandes desafíos, se pueden adoptar, por un lado, estrategias de ingeniería o tecnológicas; y/o, por otro lado, soluciones basadas en la naturaleza, que ponen su foco de atención en la gestión de IVs, conformadas por sistemas naturales y sociales que aumentan los beneficios que la naturaleza proporciona tanto para el bienestar, salud y desarrollo humano.

Respecto a los recursos hídricos, la IV se presenta como un importante instrumento para lograr y mantener la salud de los ecosistemas acuáticos y ofrecer múltiples beneficios relacionados con el incremento de la disponibilidad de agua para diferentes usos, la depuración de aguas, la conservación y protección de la biodiversidad acuática; así como, para la adaptación y mitigación de los efectos del cambio climático, como inundaciones, lluvias torrenciales o largos períodos de sequía.

En este contexto, el objetivo de este artículo ha sido analizar el estado actual y las tendencias en la investigación sobre las IVs relacionadas con el ciclo del agua.

Con tal fin se ha llevado a cabo un estudio bibliométrico tomando como referencia los artículos publicados en las dos bases científicas más importantes como son Web of Science (WoS) y Scopus en los que aparecen las palabras claves "green infrastructur*" y “water”.

Conclusiones:

La investigación acerca de GI y agua se inicia en el siglo XXI en ambas bases de datos, lo que viene a demostrar que este término es novedoso y que aún se encuentra en plena discusión en los círculos científicos.

Los resultados muestran que a partir de 2013 se produce un incremento exponencial del número de publicaciones, momento que coincide con la puesta en marcha de estrategias dirigidas a fomentar el uso de IVs, en importantes regiones del planeta, como Europa.

Los resultados muestran que las IVs conforman una de las principales herramientas para abordar las amenazas a la biodiversidad, así como para desarrollar e implementar soluciones basadas en la naturaleza útiles para políticas como la planificación urbanística, la gestión del agua, el control de inundaciones o la adaptación al cambio climático.

En este sentido, los resultados del estudio bibliométrico realizado vienen a confirmar que el término IV es un concepto amplio e interdisciplinar, que abarca distintas áreas de conocimiento, siendo las más habituales las investigaciones relacionadas con los recursos hídricos, las ciencias ambientales, las ciencias sociales y la ingeniería.

Asimismo, los artículos más citados se corresponden con estudios que valoran el potencial de las IVs a la hora de abordar la planificación y diseño de las zonas urbanas desde la óptica de la sostenibilidad ambiental.

Por otro lado, esta investigación nos muestra que el campo de la IV y su relación con el ciclo del agua, es un ámbito de investigación ampliamente distribuido por todos los continentes, a excepción de África, siendo Estados Unidos, China, Reino Unido y Australia los países que presentan mayor número de publicaciones.

Hay que subrayar que las revistas que publican un mayor número de artículos relacionados con IVs y el ciclo del agua están indexadas en los dos primeros cuartiles de ambas bases de datos (WoS y Scopus), lo que garantiza, por lo general, la calidad de la producción editorial de este tipo de investigaciones.

La distribución por revistas muestra que Sustainability es la que mayor número de artículos ha publicado (33 artículos) sobre IV y agua en WoS, mientras que Water lo es en Scopus (32 artículos).

El análisis cluster ha mostrado las siguientes tendencias de investigación principales:

- La relación de la IV con la recolección y el aumento de la disponibilidad de agua.
- La relación entre calidad ambiental de los espacios urbanos e IVs.
- La importancia de las IVs en las políticas de adaptación y mitigación del cambio climático relacionadas con el agua.
- La gestión de las aguas pluviales a partir de soluciones basadas en las IVs.
- La contribución de las IVs en la prestación de servicios ambientales

esenciales para el bienestar humano, tanto desde la óptica ambiental, la social o la económica.

Finalmente, a la vista de los resultados y teniendo en cuenta el actual contexto de crisis sanitaria, se proponen algunas líneas futuras de investigación, como el análisis del papel que juega las IVs en la salud pública y la valoración económica de los servicios ambientales que éstas prestan.

3.2. Green Infrastructures and Grand Environmental Challenges: A Review of Research Trends by Keyword.

Resumen:

Recientes estudios nos muestran la relación que existe entre la degradación y contaminación de los ecosistemas naturales y el incremento del riesgo de la población humana a sufrir enfermedades o pérdidas económicas como consecuencia de eventos ambientales extremos (Ogen *et al*, 2020; Gibb *et al*, 2020; Waldron *et al*, 2020)

Ello demuestra que los desafíos ambientales a los que nos enfrentamos como sociedad, tales como el cambio climático o la pérdida de biodiversidad, no son sólo un problema ecológico, si no también sanitario y económico.

Por ello, se hace imprescindible cambiar la mentalidad a la hora de abordar las políticas y estrategias económicas, sanitarias y de ordenación territorial, de manera que éstas contemplen medidas dirigidas a integrar los sistemas ecológicos y urbanos y a proteger la biodiversidad.

Estas políticas no deben considerar a los hábitats naturales no sólo como una fuente de recursos o energía para producir bienes y servicios, también es clave que tengan en cuenta que son los responsables de la prestación de otros servicios ambientales claves para el bienestar humano, tales como la protección frente al cambio climático, la seguridad alimentaria y la disminución del riesgo de desastres y enfermedades ambientales.

Bajo este enfoque adquiere un enorme protagonismo las conocidas como IVs, que son una red estratégicamente planificada de espacios naturales y seminaturales y otros elementos ambientales diseñados y gestionados para ofrecer una amplia gama de servicios ecosistémicos que contribuyen a aumentar y proteger el bienestar, la salud y el desarrollo humano (Kubiszweski *et al*, 2017; UICN, 2016; European Commission, 2014a).

El objetivo de este artículo fue analizar las tendencias de investigación en relación al papel que juegan las IVs como herramienta para hacer frente a los desafíos ambientales a los que enfrentamos como sociedad, tales como, el cambio climático. Para ello se ha utilizado un análisis bibliométrico mediante la explotación de las palabres claves incluídas en los documentos y artículos de la base de datos WoS.

Los registros de WoS proporcionan dos indicadores útiles para el análisis. El campo de palabras clave es el que proporciona el autor y expresan la esencia del documento de investigación y el campo keywords plus es un algoritmo que proporciona términos ampliados derivados de las referencias citadas o la bibliografía del registro (Zhang, et al., 2016). Además, las Keywords Plus proporcionaron términos de búsqueda adicionales, ya que se extraen de los títulos de los documentos citados en sus registros bibliográficos (Garfiel, 1990).

Para el período 2008-2020 se filtraron 175 artículos que tenían como palabras clave: *green infrastructure, ecosystem services y climate change*, con el objeto de estudiar la vinculación existente entre las IVs, los servicios ambientales que prestan y la contribución de éstos a los procesos de adaptación y mitigación de los efectos del cambio climático.

Para estos 175 artículos se analizaron las palabras extraídas de los títulos y resúmenes, así como las palabras clave de autor y keywords plus. En concreto entre las 1.087 palabras seleccionadas se encontraron 71 coincidencias, las cuales fueron agrupadas a través de 5 clústers.

Conclusiones:

Los resultados del estudio proporcionan una serie de ideas generales (tendencias, áreas, términos innovadores) sobre las líneas de investigación actuales relacionadas con las IVs y los servicios ambientales que éstas prestan.

Una de las conclusiones del estudio, es la amplia diversidad de áreas de conocimiento con las que guardan relación las investigaciones relacionadas con los servicios ambientales de las IVs, abarcando campos tan variados como las ciencias ambientales y la ecología, la ingeniería o las ciencias sociales entre otros.

No obstante, a pesar de la diversidad de temas de estudio, se ha podido observar un importante protagonismo de las investigaciones relacionadas con los servicios ambientales prestados por las IVs en zonas urbanas y ciudades.

En esta área destacan las investigaciones que versan sobre:

- La necesidad de considerar las IVs a la hora de diseñar políticas de planificación urbana, de ordenación de usos del suelo, así como, en las políticas de mitigación y adaptación al cambio climático y otros riesgos ambientales que sufren las ciudades.

- La estrecha relación existente entre los servicios ambientales que prestan las IVs y la salud y resiliencia de los sistemas socio-ecológicos.
- La estrecha relación existente entre protección de la biodiversidad y la salvaguarda de los servicios ambientales prestados por las IVs.
- El papel fundamental que juegan las IVs en el ámbito urbano tanto para la adaptación y mitigación de los efectos del Cambio Climático como para contribuir a la salud humana.
- Soluciones concretas en ambientes urbanos desde el punto de vista de las IVs para mitigar los efectos del cambio climático o para mitigar el efecto de isla de calor, tales como, arboles urbanos o tejados verdes.

Respecto a las tendencias de investigación emergentes, destaca el carácter innovador de un nuevo término relacionado con las IVs urbanas, que no es otro que el de "Resilencia urbana", entendida como la capacidad de aprovechar los servicios ambientales que prestan las IVs para construir ciudades adaptadas para hacer frente a los problemas ambientales actuales.

Los resultados muestran como áreas de investigación más recientes la contribución de las IVs a la mejora de la calidad del aire y reducción de la contaminación, así como, a la mejora de la salud humana ya que favorecen la actividad física.

Por otro lado, a la vista de los resultados de este estudio creemos que sería muy interesante abordar líneas de investigación específicas centradas en valorar en que medida los avances y resultados científicos en materia de IVs son aplicados a la hora de establecer y abordar las políticas ambientales por parte de las administraciones y gestores.

3.3. Public policies for sustainability and water security: The case of Almeria (Spain).

Resumen:

En la actualidad en la provincia de Almería hay 31,614 hectáreas de invernaderos lo que supone la mayor concentración de este tipo de instalaciones en el mundo, que incluso es visible desde el espacio.

En las últimas décadas, este tipo de agricultura intensiva ha sido la impulsora de la economía almeriense y ha construido el sector hortofrutícola más especializado y rentable de España, capaz de generar elevados rendimientos por hectárea, mayor número de cosechas al año y exportar a los mercados europeos cuando éstos están desabastecidos de género.

No obstante, en la actualidad, el sector se enfrenta a importantes retos en materia de sosteniblidad, derivados de las nuevas exigencias medioambientales de clientes y mercados, pero fundamentalmente debido a la fragilidad de algunos recursos naturales en los que se sustenta el modelo, entre los que destacan especialmente los recursos hídricos.

Ante esta situación, el presente trabajo tiene por objeto realizar un diagnóstico de la seguridad y sostenibilidad hídrica del modelo hortícola de Almería (España), mediante el estudio de los factores ambientales y sociales históricos y actuales que condicionan la disponibilidad y la gestión del agua en este territorio.

Para ello se aborda el estado actual de las masas de agua subterráneas, la vulnerabilidad del ámbito a los efectos del cambio climático y se valoran el impacto de las políticas y actuaciones públicas llevadas a cabo en este territorio en esta materia.

Finalmente, a partir de los resultados de este análisis y en el marco de la nueva cultura de gestión del agua y economia circular establecido por la normativa europea se proponen líneas generales de gestión pública y privada dirigidas a priorizar los servicios ambientales prestados por las IVs de este territorio y el papel futuro que los recursos no convencionales como la desalación y la reutilización de aguas pueden desempeñar en las zonas agrícolas de regiones áridas y semiáridas del planeta.

Conclusiones:

El desarrollo de formas de agricultura intensiva y el crecimiento urbanístico acelerado que se ha producido en una gran cantidad de zonas áridas y semiáridas del mundo, en muchos casos ha provocado la sobre-explotación y la degradación de sus ecosistemas naturales, especialmente aquellos relacionados con el ciclo del agua, como acuíferos o humedales.

Este es el caso de la provincia de Almería, donde durante décadas el aprovechamiento intensivo y no sostenible de las aguas subterráneas ha dado lugar a importantes beneficios para el sector agrícola local, pero a su vez también ha provocado importantes costes ambientales, tales como la sobre-explotación de la práctica totalidad de sus aguas subterráneas y la degradación de sus ecosistemas naturales.

Además, todo parece apuntar, a la vista del amplio consenso científico-técnico existente, que esta fragilidad ambiental del territorio en cuanto a la disponibilidad de los recursos hídricos se verá agravada como consecuencia del cambio climático, lo que provocará una menor disponibilidad de agua superficial en embalses y en una reducción en la alimentación de los acuíferos por infiltración.

Ante estas amenazas, el presente artículo propone para estas zonas semiáridas y áridas, el desarrollo de estrategias de adaptación y de gestión integral, dirigidas a impulsar Pactos Sociales por el Agua, en los que participen de una forma compartida tanto las administraciones públicas, los empresarios como la sociedad civil y cuya principal hoja de ruta sea la ordenación hidrológica-ambiental del ámbito.

Para lograr este consenso es fundamental impulsar de manera definitiva la creación de Juntas Centrales de Usuarios en las masas de agua de la provincia, como medio para favorecer la transparencia, fortalecer el sistema concesional para revertir el proceso de mercantilización, implicar a los propios usuarios en el control de extracciones ilegales y promover la recuperación de las masas de agua en mal estado.

Por otro lado, el papel de las administraciones debe ser el impulso y desarrollo a largo plazo de un programa de medidas dirigidas a reorientar las políticas llevadas a cabo hasta la fecha por políticas basadas en soluciones mixtas de infraestructuras verdes/grises dirigidas a restaurar los servicios ambientales que prestan las IVs de estas regiones, y a garantizar la sostenibilidad del ciclo del agua en un escenario de cambio climático y bajo una estrategia de Economía Circular, que favorezca los recursos hídricos no convencionales, como la desalación y la reutilización de aguas.

Algunas de las soluciones que proponemos pasarían por:

- La recuperación de los acuíferos, como medida esencial de adaptación frente al cambio climático, ya que estas IVs pueden actuar como reservas estratégicas para gestionar los ciclos de sequía, que cada vez serán más frecuentes.
- Planificar inversiones y actuaciones dirigidas a la excepcional IV que forman la extensa superficie de montes y la red de ramblas y humedales de la provincia de Almería, encargada de recoger las aguas derivadas de las precipitaciones, posibilitando la recarga de los acuíferos y la reducción de riesgos de inundación.
- Priorizar aquellas infraestructuras grises de gestión del agua basadas en modelos de reutilización y desalación eficientes desde el punto de vista energético y basados en recursos renovables.
- Para ello, se deberían impulsar medidas fiscales para la bonificación del agua desalada y para avanzar en la investigación y puesta en marcha de técnicas de desalinización, através de energías renovables.
- Regenerar y reutilizar al 100% las aguas depuradas y alcanzar el vertido tanto al dominio público hidráulico como al marítimo-terrestre. Se deben promover nuevas desaladoras y alcanzar la plena utilización de las existentes.
- Evitar la especulación sobre terrenos forestales susceptibles de posibles cambios de uso agrícola mediante la elaboración y aprobación, por parte de la administración pública ambiental, de un Plan de Ordenación provincial de los Recursos Forestales, destinado a la efectiva protección de los recursos naturales y a dotar de seguridad jurídica las transformaciones de terrenos que sean ambientalmente compatibles.
- Llevar a cabo una ordenación agrohidrológica, en la que se prioricen medidas como la limitación de usos en suelos inundables; la liberación de los terrenos fluviales ocupados por residuos, construcciones y otras infraestructuras; así como la recuperación para el riego de las aguas pluviales que reciban los invernaderos y otras superficies impermeabilizadas.

Para conseguir todos estos objetivos, es clave la participación del sector empresarial agrícola, el cual debería dedicar parte de sus beneficios económicos a la mejora de los sistemas de control de extracción y consumo, a la modernización de los sistemas de regadío para favorecer el ahorro y a la puesta en marcha de acciones de *Responsabilidad Social Corporativa* dirigidas a la conservación destinadas a la conservación de las IVs (montes, ríos y ramblas) que son las anualmente cosechan de manera gratuita las aguas que recargan las masas de agua subterráneas.

3.4. Mapping green infrastructure and socioeconomic indicators as a public management tool: the case of the municipalities of Andalusia (Spain).

Resumen:

En el contexto europeo, el concepto de IV es un elemento primordial de las estrategias dirigidas a conseguir una Europa climáticamente neutra y proteger el hábitat natural para el beneficio de las personas, el planeta y la economía (European Commission, 2014a). Esta línea es la seguida en la formulación del Pacto Verde por parte de la Comisión Europea, una nueva estrategia de crecimiento basada en una transición verde y justa, que tiene previsto movilizar 100.000 millones de euros, como mínimo, durante el período 2021-2027 (European Commission, 2019). Este tipo de políticas europeas apuntan a que la IV se podría convertir en un factor estratégico de primer orden para las ciudades y municipios europeos a la hora de hacer frente no solo a los retos globales ambientales, sino a la reconstrucción económica y social que será necesaria tras la epidemia del coronavirus.

Para abordar el déficit existente de trabajos dirigidos a identificar y valorar los servicios ambientales prestados por las IV a nivel municipal, el presente trabajo propone un modelo de análisis territorial que sirva para la toma de decisiones en situaciones en las que existan distintos contextos ambientales, sociales, políticos y económicos. En concreto, se aborda una clasificación de los municipios de Andalucía en relación al estado de conservación de sus IVs y, posteriormente, se relaciona éste con su situación socioeconómica a partir de la selección de un conjunto de indicadores.

Las fases llevadas a cabo en este proceso serían las siguientes:

- Identificación y caracterización de las IVs a escala municipal, tanto en ambientes urbanos como rurales, mediante el uso de Sistemas de Información Geográfica.
- Clasificación de los municipios de Andalucía en función de un conjunto de indicadores relacionados con el estado de sus IVs y su sostenibilidad socioeconómica y demográfica.
- Finalmente, a la luz de los resultados obtenidos, propuesta de líneas de gestión pública dirigidas a priorizar los servicios ambientales de la IV y

atender posibles problemas demográficos y/o socioeconómicos en los municipios andaluces.

Conclusiones:

Los indicadores relacionados con el estado de las IVs nos indican que las Áreas núcleo de estas infraestructuras coinciden en su práctica totalidad con la red de espacios naturales protegidos y puntualmente con zonas con una alta representación de hábitats catalogados como de interés comunitario por parte de la Unión Europea. Por otro lado, las Áreas de amortiguación se encuentran ampliamente distribuidas por toda la región y cumplen con la función de conectividad ecológica de las Áreas Núcleo.

En las zonas interiores de la región, las áreas núcleo de las IVs coinciden con ecosistemas forestales y de alta montaña, en su mayor parte de propiedad pública, en los que existe una elevada diversidad y singularidad biológica producto de unas condiciones ambientales variables y de un manejo humano tradicional de base ecológica que, hoy día, está en riesgo como consecuencia del problema de despoblación que sufren estos territorios. Si por algo son importantes este tipo de IVs interiores, sin lugar a dudas, es por su contribución al bienestar humano, ya que son las responsables de generar servicios ambientales claves para la calidad de vida de la totalidad de la población andaluza, tales como la protección frente a patógenos y epidemias, control de la erosión y avenidas, la regulación de la cantidad y calidad del agua, el reciclado de nutrientes, la regulación del clima o el suministro de espacios de ocio y de recreo.

Por otro lado, las Áreas núcleo de las IVs litorales y semiáridas de la región, en las últimas décadas, han reducido considerablemente su superficie como consecuencia del crecimiento de la población de estas zonas, la urbanización y el desarrollo de la agricultura intensiva. Esta situación, junto con los efectos del cambio climático, condicionan la capacidad de estas infraestructuras naturales para prestar servicios ambientales.

En lo que respecta a los indicadores demográficos de los municipios andaluces estos nos muestran que, desde mediados del siglo XX, los municipios rurales andaluces, incluidos los localizados en las áreas núcleo de las IVs, han sufrido continuas pérdidas demográficas como resultado de la fuerte emigración de la población hacia la costa y las grandes áreas metropolitanas de la región.

En este sentido, los resultados nos muestran que la práctica totalidad de municipios con grave riesgo de despoblación (<12 hab/km2) se encuentran ubicados en áreas interiores de las áreas núcleo y de amortiguación de las IVs y las zonas con gran densidad de población (>500 hab/km2) se ubican en su mayor parte fuera de las áreas núcleo de las IVs, en zonas litorales y, puntualmente, en las áreas metropolitanas de las capitales de provincia.

Respecto a los indicadores socioeconómicos éstos nos muestran que las tasas de desempleo superiores a la media regional se sitúan en zonas costeras y en aglomeraciones urbanas donde la crisis del sector de la construcción ha tenido incidencia en los últimos años y además adolecen de una fuerte economía de base agraria o turística.

El indicador de renta per cápita al igual que ocurre con los indicadores demográficos, se observa que los municipios con rentas por encima de la media regional se sitúan sobre todo en las localidades costeras y en torno a las grandes áreas metropolitanas de la región, que es donde se ubican las empresas más grandes de la región y existe un mayor dinamismo económico. Un aspecto positivo a destacar son los buenos datos de empleo y renta que ofrecen algunas poblaciones rurales ubicadas dentro del ámbito de la red de espacios naturales protegidos de la región. Este hecho parece demostrar que los Espacios Naturales aportan dinamismo a la economía de algunos municipios, lo que viene a confirmar la viabilidad económica de determinadas actividades reguladas bajos criterios de sostenibilidad y que apuestan por el empleo verde y por prácticas tradicionales agroecológicas.

Los resultados obtenidos indican la necesidad de adoptar un modelo más sostenible en la franja litoral y áreas metropolitanas de la región de Andalucía. En estas zonas se debe priorizar la calidad de vida de las personas frente a la ocupación y urbanización del suelo. Para ello, es fundamental, recuperar y restaurar las IVs y disponer de espacios urbanos y agrícolas más saludables, donde primen modelos de movilidad sostenible, se consuma menos agua y energía, se recicle más y se impulse el comercio local y de cercanía.

En este sentido, la Administración debe apostar por una nueva cultura del agua en toda la región. Para ello las prioridades se deben centrar en revertir los procesos de mercantilización y especulación del agua; implicar a los propios usuarios en el control de extracciones ilegales; y promover la recuperación de acuíferos en mal estado mediante la reutilización y la desalación con energías renovables. En este sentido, resulta necesario regenerar y reutilizar al 100% las aguas depuradas y alcanzar el vertido cero tanto al dominio público hidráulico como al marítimo-terrestre.

Los servicios ambientales que prestan las IVs de la región están íntimamente relacionados con la persistencia de usos tradicionales del suelo de base ecológica, los cuales están en franca regresión como consecuencia de la pérdida de población de sus áreas interiores y de montaña. En consecuencia, los mecanismos de financiación pública en la región deben tener en cuenta estos desequilibrios demográficos, así como, posibles compensaciones por prestación de servicios ambientales, las cuales debes estar dirigidas a garantizar la igualdad de oportunidades y el blindaje de servicios públicos esenciales en estas zonas rurales.

Como conclusión final se puede afirmar que los municipios de las zonas rurales están financiando "ecológicamente" a la totalidad de la población andaluza. Ante esta situación, las decisiones y actuaciones de los gestores en esta región deben impulsar medidas dirigidas a restaurar y conservar las IVs, atendiendo los desequilibrios demográficos y/o socioeconómicos que tiene la región.

4. CONCLUSIONES GENERALES Y FUTURAS LÍNEAS DE INVESTIGACIÓN

En esta tesis, utilizando como ámbito de trabajo la Comunidad Autónoma de Andalucía, se abordo la propuesta de una metodología dirigida a identificar y valorar los servicios ambientales prestados por la infraestructuras verdes a escala municipal por medio de un modelo de análisis espacial basado tanto en indicadores ambientales como socioeconómicos.

Posteriormente, a partir de los resultados obtenidos, se proponen posibles estrategias de gestión pública de promoción de las infraestructuras verdes útiles para la gestión territorial en situaciones en las que existan distintos contextos ambientales, demográficos y económicos, como es el caso andaluz.

En este sentido, tras abordar el estudio de las tendencias de investigación y a la luz de los resultados obtenidos en los dos casos de estudio incluidos en esta tesis, se desprenden las siguientes conclusiones generales.

- El término de Infraestructuras Verdes es un término novedoso que aún se encuentra en plena discusión en los círculos científicos, razón por la cual, todavía existe un amplio camino por recorrer para dar a conocer las potencialidades de esta herramienta en campos tan variados como las ciencias ambientales, las ciencias sociales o la ingeniería.

- Existe un importante protagonismo de las investigaciones relacionadas con el papel que juegan las infraestructuras verdes en relación a nuevas formas de planificación y gestión urbana sostenible, dirigidas a mejorar la calidad de vida y bienestar humano.

- Se ha puesto de manifiesto la existencia en Andalucía de dos realidades ambientales y sociales contrapuestas. Por un lado, una franja litoral y grandes zonas metropolitanas, donde se concentra la mayor parte de la población de la región y con unas infraestructuras verdes degradadas y contaminadas como consecuencia de los grandes cambios de uso del suelo producidos en las últimas décadas. Y, por otro lado, en contraposición, unas zonas rurales donde se ubican infraestructuras verdes claves para la sociedad andaluza, dado el papel que desempeñan para la protección frente a patógenos y epidemias, el control de la erosión y avenidas, la regulación de la cantidad y calidad del agua, el reciclado de nutrientes, la regulación del clima o el suministro de espacios de ocio y de recreo. Servicios ambientales que de cara a un futuro pueden verse comprometidos como consecuencia del fenómeno de la Despoblación.

- Ante esta situación, en la franja litoral y áreas metropolitanas es necesario adoptar políticas de recuperación de las funciones ambientales de las infraestructuras verdes urbanas y en las áreas rurales interiores los mecanismos de financiación pública deberían considerar la corrección de los desequilibrios demográficos existentes por medio del establecimiento de posibles compensaciones por prestación de servicios ambientales.

- El estudio de las políticas públicas llevadas a cabo en las zonas de agricultura intensiva de la provincia de Almería ha puesto de manifiesto la necesidad de apostar decididamente por una Nueva Cultura del Agua a escala regional y local. Para ello las prioridades se deben centrar en revertir los procesos de mercantilización y especulación del agua, implicar a los propios usuarios en el control de extracciones ilegales y promover la recuperación de las infraestructuras verdes relacionadas con la dotación y calidad de los recursos hídricos, así como, la reutilización y desalación con energías renovables. Hay que regenerar y reutilizar al 100% las aguas depuradas y alcanzar el Vertido 0 tanto al Dominio Público Hidráulico como al Marítimo-Terrestre. Se deben promover nuevas desaladoras y alcanzar la plena utilización de las existentes.

FUTURAS LÍNEAS DE INVESTIGACIÓN

En el momento del cierre de este documento (abril de 2011), se constata que el tema de la tesis es de plena actualidad, en gran medida debido al hecho de que a raíz de la crisis sanitaria y económica provocada por la epidemia SARS-CoV-2 (COVID-19) instituciones mundiales como la ONU, la Unión Europea y gobiernos como el de España, se estén planteando una reconstrucción económica que vele por nuestra salud y la de los ecosistemas del planeta, por medio del impulso de una economía limpia que sea de utilidad para plantar cara a los retos del cambio climático.

En este contexto, de cara a futuro, nos planteamos explorar futuras líneas de investigación, tales como: (i) Analizar y divulgar los beneficios y servicios ambientales prestados por algunos tipos de infraestructuras verdes marinas como las praderas de *Posidonia oceanica y* (ii) abordar el estudio de nuevas estrategias de desarrollo rural y de lucha contra la despoblación basadas en el mejora en de prestación de servicios públicos esenciales y la sostenibilidad ambiental. Todo ello para seguir en la senda de ir reforzando el carácter estratégico de las cuestiones relacionadas con la transición ecológica y la lucha contra la despoblación

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