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Hypothesis

Sewage Irrigation Fields—From Relict Landscape to Blue-Green Urban Infrastructure

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Abstract: In this study, we examined the fate and future of sewage irrigation fields; historic urban wetlands that served as sewer drainage before modern sewage treatment plants were built. Our aim in this study was to reappraise sewage irrigation fields in the urban fabric of modern cities and to analyse the possibility of re-integrating them into the ecosystem services system, as well as into green and blue infrastructure, providing leisure and recreational opportunities, stabilising the city's biodiversity and microclimate, and increasing water retention in these areas. The research was based on the identification of the location of sewage irrigation fields in green and blue infrastructure systems, determination of the scale and extent of their connections to the urban fabric and an analysis of their multi-functionality including: ecological, climatic, hydrological, landscape, spatial, environmental, cultural and social, educational, and tourist and recreational functions.

Keywords: green and blue infrastructure; relict landscapes; wetland restoration; urban ecosystem services

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1. Introduction

Globalisation and climate change are reflected in problems related to the transformation of the urban fabric and the quality of life of city dwellers. Urban development is largely based on economic stimuli, which entail spatial, environmental, and demographic transformations. Progressive change within the urban fabric includes changes in the vision for cities and the paradigms for cities of the future. In the 21st century, the looks of cities of many high- and medium-income countries are changing quite dynamically, moving from grey, concreted surfaces to green, functional areas, and the urban fabric is increasingly multi-functional, socially friendly, and ecologically sustainable [1,2]. It seems that bio-management, taking into account the multi-faceted design of contemporary green spaces, is a route to genuinely sustainable urban communities. This large transformation allows for and is supported by the application of new solutions regarding city management and the creation of new types of ecosystem services [1,3–5].

The reconstruction of the urban fabric toward green sustainable urban systems is carried out with varying results and at varying speeds, depending on the awareness of designers and financial resources. So far, the problem of modern cities has involved the massive taking over of areas for development, which were previously the green lungs of the city. Precious wet landscapes are disappearing from urban spaces at an alarming rate; thus, relict landscapes are disappearing and natural resources are significantly depleted.

In this way, for decades, ecological corridors have been destroyed on a micro scale, e.g., a street quarter or a district, as well as on a macro scale, where new planned cities

have emerged. Green spaces in the city were fragmented and did not achieve the required stability, which has had and still has an impact on the quality of the entire urban ecosystem. Another major problem is the lack of large, open, biologically active spaces that support the city's venting system and indirectly prevent the formation of oppressive urban heat islands [6,7]. Relict landscapes, which constitute a reservoir of natural landscape elements of the city, have also been lost in this system. Such areas include, among others, undervalued areas of sewage irrigation fields, which are now rare in the spatial arrangement of the urban fabric and, in the past, were an important link in the infrastructure responsible for sewage treatment in the city, and were thus an important element in the chain of ecosystem services. Currently, these areas are being successively developed and rebuilt. Residential buildings are introduced here and roads are concreted, which automatically reduces the acreage of green areas and affects the degradation of the urban fabric in terms of nature. Over the years, sewage irrigation fields have been hailed as a miracle of technology, and, in recent decades, they have aroused considerable controversy regarding sanitation and the level of safety for the population. However, they were areas with a very large biologically active area, which supported biodiversity: they were oases for the existence of birds and many other organisms, and reservoirs of green, undeveloped large-scale space supporting the city's ventilation. In the face of changes in the spatial structure of cities and the entry into the era of green renewal of urban fabric, these areas may be an excellent ecological complement in the sustainable development of cities. A return to forgotten old ecosystem services would strengthen their ecological potential [8–12]. Pursuant to Directive 2000/60/EC [13], it is important to take all measures to protect water, in terms of both quality and quantity. Such activities include the optimisation of irrigation management in sewage irrigation fields and the creation of retention systems, including landscape retention.

2. Materials and Methods

2.1. Motivation

Our aim in this study was to reassess the location of sewage irrigation fields in the urban fabric of modern cities and their green-blue infrastructure system, emphasising the possibility of intensive or extensive reuse and the protection of relict landscapes. Areas of sewage irrigation fields are inherent in wetlands, and the disappearance of these areas introduces a kind of disharmony, which as a function of time leads to irreversible processes of the loss of these areas and transformation of the natural environment in quantitative and qualitative senses (functional, material, visual, social, educational, etc.). An important aspect of the analyses was to present an alternative interface to sewage irrigation fields in the urban fabric of modern cities and to reintegrate them into a new package supporting ecosystem services and as an integral element of green and blue infrastructure. This state of affairs is reflected in real support for the city's natural system and the stabilisation of biodiversity and microclimate by increasing water retention in these areas. An important element of this study was an analysis of the need to strengthen the continuity of biologically active functional areas in the urban fabric from an interdisciplinary and multidimensional perspective. This theoretical research was based on the identification of the location of sewage irrigation fields in green and blue infrastructure systems, determination of their scale and extent of their connections to the urban landscape, and an analysis of multi-functionality in urban areas. The article presents the main problems related to their use in urban areas as a function of time and an analysis of their needs and the possibility of intensive or extensive reintegration into the urban infrastructure. In our analysis, we took into account the literature on the subject related to the problem of their use in urbanised areas. This review and analysis of the current research perspective on sewage irrigation fields mainly focused on the impact of this method of land use in historical and contemporary terms and its impact on the urban fabric due to the functions performed: ecological, climatic, hydrological, landscape, spatial, environmental, cultural and social, educational, and tourist and recreational. This analysis was a synthesis of literature review and our own know-how, covering several scientific disciplines, including environmental

protection, planning and spatial management, geology, hydrogeology, environmental engineering, and architecture and construction. Previous studies have mainly concerned the economic benefits of sewage irrigation fields, but also their impact on the quality of the environment, including human health and the pollution of soil and water [13–44]. The restoration of relict landscapes associated with wetlands is an added value.

To conduct this study, a library investigation of the resources of the databases of international journals was carried out. The databases Web of Science, Scopus, and others were analysed using criteria that allowed the assumption of data filtering in order to obtain a package of articles to be analysed in terms of content. The articles were selected using the following screening criteria:

1. The article should contain information on ecosystem services based on the creation or restoration of wetlands.
2. The article should provide information on how sewage irrigation fields are created; the history of their creation; and economic, social, ecological, cultural, environmental, climatic, landscape, spatial, ecological, educational, and tourist and recreational aspects.
3. The article should refer to the determination of the location of sewage irrigation fields in a system of green and blue infrastructure and their importance in the urban fabric.
4. The article should contain information on examples of the use of sewage irrigation fields in areas of various world cities and their impact on the environment and landscape.
5. Analyses and studies on green and blue infrastructure in the urban fabric.

A total of 275 articles were found that were cross-analysed to exclude repetition, and 131 basic articles were obtained for further analysis of the topic. On the basis of the performed analyses and know-how, we constructed hypothetical assumptions leading to the reintroduction of sewage irrigation fields and their likely impact on the environment, landscape, and ecosystem services.

2.2. Sewage Irrigation Fields in Cities—History and Significance

Problems with wastewater treatment in the urban fabric have accompanied humankind for millennia. In ancient Babylon, humans used a system of specialised brick-lined wells to filter faeces. In Mohenjo-Daro 3000–2000 BC (on the present territory of Pakistan), special rooms were located in homes (toilets), and the sewage was discharged into rivers through special gutters. In ancient Greece, archaeologists found many drainage systems, namely pipe systems, in Crete. However, in ancient Rome, the first sewage system was built, the operation of which was based on the system known to us and used until today. The Cloaca Maxima sewage system was constructed in approximately 735 BC [45]. Wastewater was processed and used for various purposes. In the Middle Ages, e.g., in Paris, sewage was discharged from a special sewage system into the moats.

Sludge was used for fertilisation of farmland, and the water was used to water the gardens. Historical materials regarding the deliberate use of wastewater for irrigation of crops combined with conscious disposal of wastewater date back to the 16th century from Bolesławiec [46]. During the Renaissance and Baroque periods, the sanitary conditions in cities and the way in which sewage was removed were disastrous, both for people and the environment. Sewage was directly poured into rivers, which caused not only environmental pollution but also various epidemics. The industrial revolution, initiated in England and Scotland in the 18th century, brought with it the need for changes in the city's water and sewage system due to the large migration of people to cities where they could find jobs. Workers' districts rapidly developed in cities, which, to a large extent, generated sanitary problems. The solution was to transform how sewage was disposed; instead of gutters, closed channels appeared, into which domestic and industrial sewage was introduced [47].

The industrial revolution in the nineteenth century brought the intensive development of plumbing and sanitary engineering. Starting in England, the "Sanitary Idea" laid the foundation for the development of public health and resulted in the implementation of sanitary rules in cities [48]. The problem, however, was the methods of sewage disposal

and storage. The solution was sewage irrigation fields, where sewage was distributed on special plots, and the principle of operation was based on a natural system that occurs in the soil environment with the use of microorganisms and appropriately selected vegetation. Therefore, they were the first soil and root treatment plants of their kind [46,49]. The first sewage irrigation fields in the urban fabric were established in England, but the practice was soon adopted across Europe, e.g., in Hamburg (1868), Gdańsk (1871), Berlin (1878), Wrocław (1881), Legnica (1895), and Królewiec in 1898. In France, the first treatment plant of this type was established in 1872 and collected wastewater from the whole of Paris and its environs [50,51]. During this period, sewage irrigation fields played a sanitary role, and the role of supporting green infrastructure was not appreciated. From the design and technical points of view, these areas were not associated with the need for natural ventilation in the city. This kind of ecosystem service naturally appeared. However, the development and expansion of sewage irrigation fields stopped at the turn of the 19th and 20th centuries, when new technologies of sewage treatment started to be used in artificial conditions, which had many advantages, especially those related to odours, as well as occupying less urban space [52–54]. There were doubts related to faecal bacteria, but the research of many scientists has shown that they are not a problem with the proper loading of sewage irrigation fields [52,55–60]. However, not all types of wastewater can be treated in the fields, especially those with a large amount of mercury and cadmium [52]. Due to the fact that a large amount of biomass is produced in these areas, it is possible to accumulate and bind metals and other pollutants here [32,61–64]. As indicated in their publications, inter alia, Chakrabarti [65] and Paliwal, Karunaichamy, Ananthalli [66], due to the high content of nitrogen, phosphorus, and potassium (NPK), irrigation with sewage has a very good effect on plant yield. It is also worth adding here that sewage irrigation fields needed soils to properly function, and by pouring sewage onto the plots, the humus layer significantly increases [67,68], and organic carbon content increases [69].

Sewage irrigation fields were gravity-fed and therefore naturally located downstream from city centres. In most cases, they were located close to the edge of the city. Due to urbanisation and the growth of cities, after some time, these wetlands became surrounded by urban development. Over time, these areas slowly were replaced to modern types of sewage treatment plants. Like other wetlands, they were often drained, landfilled, and built on, and thus disappeared from the city's landscape [70–73]. Currently, the surviving sewage irrigation fields are a kind of relict landscape, supporting green infrastructure and increasing the biodiversity of the area (Figure 1).

Figure 1. *Cont.*

Figure 1. Irrigation fields Wrocław, Poland, present condition. (**A**) Plant communities with *Carex Buekii Wimm*, (**B**,**C**) remains of the hydrotechnical infrastructure (**D**,**F**) reed rush, and (**E**) willow bushes (photos: A. Krzemińska and A. Zaręba).

3. Results

3.1. Location of Sewage Irrigation Fields in Blue-Green Infrastructure Systems

The rapid development of cities introduced gradual changes to the urban fabric, having a direct or indirect impact on the city biome. Wet and green areas gradually began to disappear from the landscape. Interestingly, it was urbanisation that was one of the reasons for introducing sewage irrigation fields and adapting these areas to the urban fabric, and it was through urbanisation that these areas were lost in exchange for commercial housing and road infrastructure [52,74–79]. For many years, sewage irrigation fields fulfilled important roles for the city's ecosystem. The first of these was wastewater treatment, while the remainder, which were underestimated over the years, were primarily supporting green and blue infrastructure networks, creating natural biocentres (areas with the highest biodiversity) and supporting ecological corridors and a significant share in the city's ventilation [80–84]. By weaving the elements of green and blue infrastructure into the urban fabric, a specific patchwork structure is created, characterised by varying degrees of stability and durability of the city's natural system [85,86]. The quality and durability of this structure depend on the variety of components within the green infrastructure and whether there are appropriate supporting elements in this system. Thus, it is a complex system, subject to many synergistic dependencies (Figure 2). Therefore, we here understand green infrastructure as a purposefully and strategically planned area cross-linked with natural and semi-natural areas, together with technical devices that provide many ecosystem services in urbanised areas. Individual elements are selected in the system of a given area due to the purpose they serve, as well as local conditions and the spatial and environmental policy of the city [77–79,87–96]. The functions that green infrastructure performs in the urban fabric are above all structural, environmental, social, economic, production, and technical. Blue infrastructure is understood as water management in urban areas through capturing, retaining, and using rainwater to improve the habitat conditions of urban green areas [76,77,97–99]. Moreover, this network should be included in the functional and spatial structure of all urbanised areas. The quality of ecological corridors, islands, and natural biocentres, and thus biodiversity and genetic drift, which determine the stability of the city's biome, depend on a coherent, well-designed, and self-regulating green-blue infrastructure [100]. The composition of green and blue infrastructure allows the urban fabric to comprehensively operate as part of ecosystem services, which significantly support a city's natural system [101–107].

Figure 2. The place of sewage irrigation fields in blue-green infrastructure in the urban fabric (own elaboration).

These areas may constitute a kind of "safety valve" in urban areas, supporting preventive and remedial actions related to counteracting climate change as well as the "overheating" and "airing" of cities. Wetlands are one of the most endangered ecosystems on a global scale, and in the urban fabric, they can be treated as relict [107–109]. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [110] estimated that as much as 85% of wetlands worldwide are at risk of complete degradation and disappearance, and approximately 90% of the already lost wetlands are located in Europe [108,109,111–113]. The situation is even worse in cities, where wet areas (natural and anthropogenic, including, for example, infiltration fields) have been systematically destroyed for decades, and they are not only a component of the city's natural system, but also an important link in landscape retention supporting blue infrastructure and the habitats for many organisms, including birds, the existence of which is supported by the Ramsar Convention [109].

3.2. The Multifunctionality of Sewage Irrigation Fields in an Urban System

The ecological solutions used in the new, green methods of designing cities will determine the quality of space and the comfort of life of their inhabitants in the future. Moving away from solutions that only promote the profit of developers and the transition to an ecological system of evaluating urban space seem to be the correct and only solution. Large- and micro-scale sewage irrigation fields disappearing from the city landscape should return to the city and fit into the pattern of biorevitalisation of the urban fabric due to the package of services and functions they perform, including: ecological, climatic, hydrological, landscape, spatial, environmental, cultural and social, educational, and tourist and recreational (Figure 3). The most extensive of these areas provide ecological, hydrological, and climatic functions, where their complexity is clearly visible [113–117]. Social interest and the need for environmental responsibility require the use of models based on the best ecological practices and proper environmental management of these areas in the urban fabric by including them in an open system of blue and green infrastructure, thus creating good solutions for the city, which is reflected in the spatial functions and landscape provided by sewage irrigation fields. Another important function is the economic function, which determines the profitability of investments and provides the possibility of balancing costs. The world's drinking water resources are declining, and there is great pressure to reuse treated water. It is already predicted that in the coming decades, over 100 countries will face water shortages [74,118]. Hence, irrigation field systems are primarily appreciated in arid regions and areas with little water. Sewage irrigation has significantly inhibited of destruction processes in food production related to water shortages. Sewage irrigation fields are mainly used by agriculture and are located outside cities. One example is northern Mexico, especially the state of Sonora [119,120], and part of Israel, Australia, India, China, Japan, and Singapore [74].

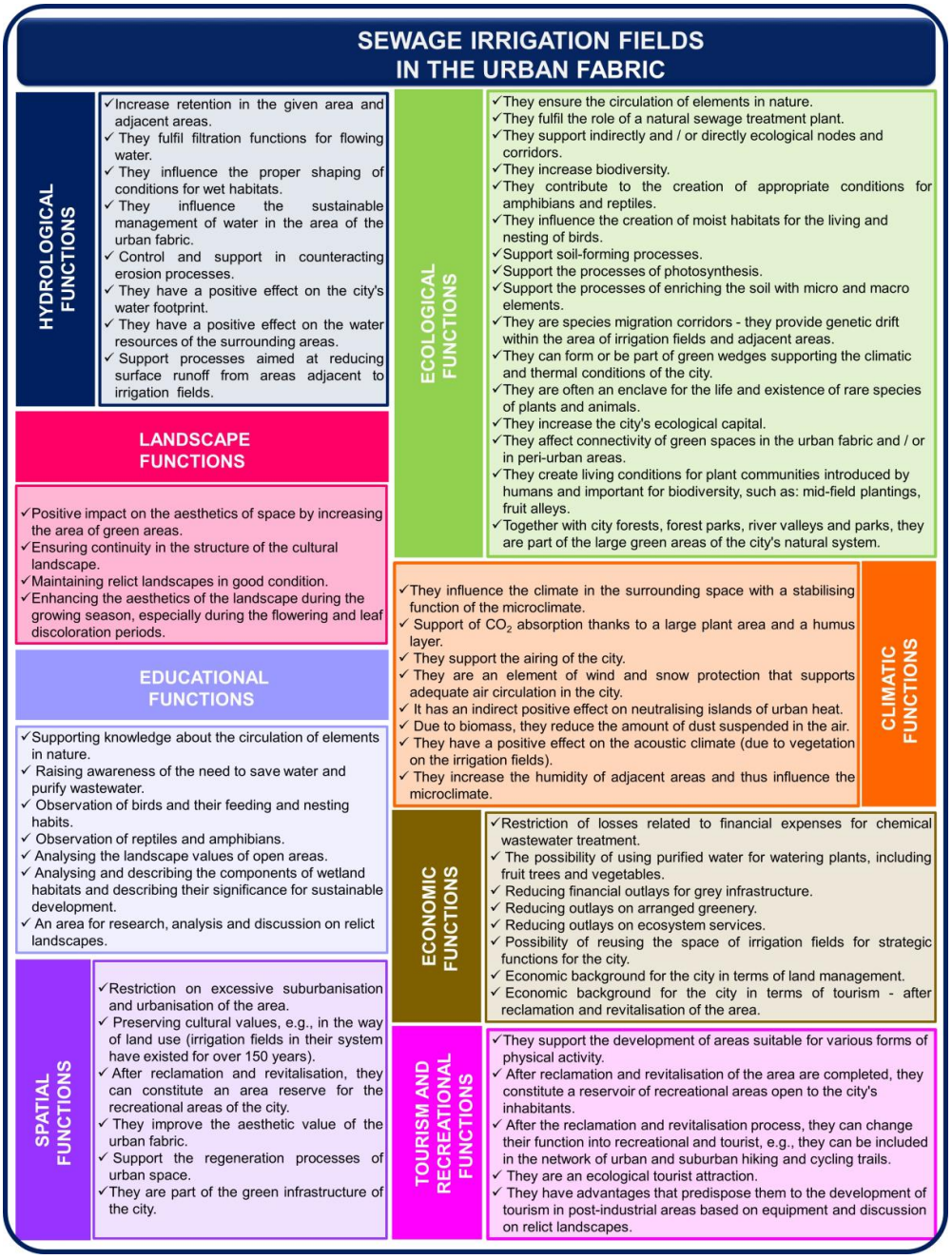

Figure 3. Functions of sewage irrigation fields in the urban tissue—multi-faceted analysis (own elaboration).

However, sewage irrigation fields are unappreciated from the point of view of their human ancillary nature. The removal of open and wet green areas from urban spaces has become the norm, which has contributed to reducing the direct contact of city dwellers with nature. This situation is also reflected in the increases in the general level of stress, depression, heart disease, cardiovascular disease, or even diabetes in people living in the urban fabric, which cause a de facto reduction in the standard of living [121,122]. Sewage irrigation fields can also be an important place to help children and youth in environmental education. They can also play important tourist and recreational functions, especially after the reclamation and revitalisation of the area.

The multi-functionality of sewage irrigation fields in the urban fabric is based on a patchwork system, where functions support one another to finally create a common element

supporting the city's natural system, contributing to varying degrees to the construction of the city's ecological system (Figure 3).

4. Discussion

Sewage irrigation fields have spatial and ecological potential in the urban fabric by supporting the processes of building and maintaining a good-quality environment. They have also aroused much controversy in connection with the irrigation of domestic sewage, nuisance related to odours, heavy metal pollution, parasites, etc. They have many disadvantages, but even more advantages that interact in both synergistic and antagonistic ways (Figure 4). Therefore, it is most advisable to use sewage irrigation fields in cities, where rainwater with a low pollutant load and no hydrogen can be treated. A natural method of wastewater treatment, where no chemicals are used and that supports agricultural cultivation, would be an ecological alternative to the chemical methods so widely used now [123]. The use of wastewater for irrigation of crops can, in many cases, solve a number of problems, including those related to the supply of plants with the necessary organic substances and nutrients in available forms, as well as the utilisation of waste disposal, which protects the environment against pollution [124–131].

Figure 4. Irrigation fields—SWOT analysis (own elaboration).

5. Conclusions

Sewage irrigation fields have been a great technological achievement in the field of wastewater treatment, while their participation in supporting the natural potential of the city, inter alia due to the area it occupies, is a completely underestimated aspect. Therefore, these areas can be classified as urban wetlands that are built landscapes based on ecosystems that maintain the high ecological quality of the area. They strengthen the urban ecological potential by increasing the acreage of biologically active areas, supporting the city's water footprint, and may also eliminate discontinuities of green areas in urbanised areas. Through their micro-regulatory impact on the city's climate and the ecosystems of wetlands, sewage irrigation fields favour biodiversity, especially the development of habitats for birds. They can also play a big role in many aspects of society, from education to tourism and recreation. Re-weaving them into the urban fabric and treating rainwater and wastewater from grey infrastructure (roads, paved areas, and buildings) would not only strengthen green and blue infrastructure, but would also be a response to the need for urban bio-revitalisation and the transition to closed-loop environmental management systems, which would have a positive impact on the development of bio-management in urban space.

In connection with the crisis of global water shortages, one of the most important activities in planning the urban fabric should be the introduction of areas with high retention potential, preferably large ones, which, at the same time, support the landscape, and such conditions are met by sewage irrigation fields, which in the future and, in accordance with the spirit of ecology, can experience their repeated, new resurgence in use, provided that irrigation is well-managed and environmental risks are minimised.

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