Geographic Information System Applied to Sustainability Assessments

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The conceptual variations and divergences that permeate the debate on sustainability end up directly reflecting the choice of sustainability assessment (SA) processes, providing different methodological approaches. Among them, some researchers have pointed out challenges, but also opportunities to use geospatial data, techniques, and tools as resources to be explored in sustainability assessments.

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1. Introduction

The debate on sustainability is as broad as it is old, and the problem surrounding its conceptualization is one of its main challenges. The use of terms that translated this meaning was first introduced in the literature by German researchers in 1713, who were concerned with forestry activities, in particular that the forest was never harvested more than it was able to replenish [1]. However, this discussion expanded globally from 1972 onwards, when concerns related to environmental issues were addressed at the UN General Assembly meeting at the Stockholm Conference, gaining an international priority status [2]. Later, in 1987, the term sustainable development (SD) was popularized from the report “Our Common Future” (Brundtland Report) into the one adopted by current generations to satisfy their needs without making it impossible for future generations to do the same, decreeing an intergenerational character to this concept [3].

Although widely accepted, the definition of SD adopted by the United Nations has been the subject of discussions about what it actually represents, as it is presented as a broad, ambiguous, imprecise, and sometimes contradictory concept [4]. These examinations are justified because it is an ingrained concept of cultural values that can define different principles [5], depending on the different interpretations that are given [6], making the evaluation process even more complex.

Such complexity translates into a huge diversity of sustainability assessment (SA) mechanisms found in the literature and which differ in their objectives, methods, and tools [7]. However, even if they differ in spatial and temporal scales, the SA ends up aiming to guide decision-making that leads the object of research to the path of sustainability [8]. This definition of SA can be expanded if, in addition to integrating sustainability issues into decision-making, it also promotes the sustainability objectives themselves, that is, being able to influence decision-makers, and this also contributes to the contextual interpretation of sustainability [9].

Among the SA methodologies that enable this exchange of information between evaluators and decision-makers, the application of sustainability indicators (SI) is probably the most popular internationally [5]. However, despite being popular, there is still no methodological (or even conceptual) consensus on the use of SI, and this is due to the very complexity of assessing what really matters for monitoring society's progress towards sustainability [7].

Through a very constructive debate, Ramos [7] points out some possible future paths for SA with SI by identifying a set of challenges found in the literature. Among the challenges and opportunities raised, the author highlighted the use of geospatial technologies (for example, remote sensing) as new approaches to indicators, which can be an important solution to mitigate the limitations and availability of data, especially for certain scales of analysis. The use of satellite data, for example, is still relatively unexplored.

However, despite still being a challenge, the concern towards approaching sustainable development (SD) geospatially is not recent. Even in the 1990s, Manning [10] warned that the SD path involves understanding the relationship between biophysical and socioeconomic information and that this requires a better understanding of the spatial dimension of both the problems and the proposed solutions. In other words, decision-makers must be able to interrelate, even spatially, information from many different sectors. The author is categorical in stating that, in this sense, a vital tool to achieve these goals is the geographic information system (GIS).

Nevertheless, even after three decades, important studies continue to point to the GIS tool and techniques as trends in SD measurement [11]. This trend, to some extent, is perceived through preliminary research in scientific databases, and in studies from different areas of knowledge [12][13][14][15][16][17][18][19][20]. However, while there is a discussion about the different interpretations of sustainability, it is also necessary to consider that the geospatial approach in SA will also occur in different contexts.

In this way, the researchers understand that the role of GIS in SA is a scientific gap still to be explored. Thus, the researchers postulate that, for greater effectiveness of the GIS application, it is necessary to understand in a more holistic way the thematic fields in which these geospatial tools act in the evaluations that aim to measure sustainability. To reach this understanding, it is necessary to explore the historical paths of scientific research that approach this field of knowledge, to identify how research areas evolve over time, even showing future scientific ways to be considered.

2. Methods Applied to Sustainability Assessments

Assessing sustainability is not an easy task. The complexity of the evaluation process occurs insofar as there are several ways to interpret the concept of sustainability itself. In the studies by Patterson et al. [6] some SA tools were methodologically detailed to identify their common characteristics, and to exemplify the complexity of this evaluation process, the authors list four different interpretations of sustainability on which the different methods can be supported, namely: ecological, economic, thermodynamic, and ecological–economic interpretations, as well as interpretation by public policy and planning theory. Therefore, the researchers can infer that the use of geospatial data, techniques, and tools can also take place in different contexts depending on the sustainability approach on which the assessment is based.

The use of GIS in SA has been encouraged since the 1990s, mainly because it allows analyses that interrelate environmental and economic variables, providing a more holistic approach to the relationship between the natural and human environments [10]. Since then, several works have been developed in which the GIS supports assessments that aim to understand sustainability at different scales, whether macro (strategic) or micro (operational) [7].

However, when consulting different publications that stand out on the subject, and which have had great scientific visibility in the last 30 years, one can see a variety of approaches in which GIS can support SA processes. In general, there is a consensus that GIS is applied to works that involve the treatment of spatialized data and that it produces results in the form of mapping, and even tables or graphs.

Nevertheless, other scientific knowledge can be added to GIS to obtain even more accurate results. In studies by Forsyth [21], for example, some indigenous knowledge was incorporated into spatial analyzes to measure soil erosion to test the assumptions that land scarcity has increased cultivation on steeper slopes and that erosion is a problem for the degradation of the highlands. In this example, the debate on the concepts of sustainable knowledge and “hybridity” stands out; it uses local and indigenous knowledge, together with global scientific techniques, to achieve guidelines for sustainable development focused on environmental issues.

However, if on the one hand the GIS appears to support sustainability assessments based on the analysis of the damage caused by action, the opposite is also perceived. This is what Joerin et al. [22], who carried out mapping of land suitability for housing in a region of Switzerland, posited. This mapping incorporated a set of complex criteria that integrated the views of several stakeholders, and a GIS was used to assess the criteria requested in the definition and suitability of land for housing. Therefore, predictive mapping appears as an option to support assessments.

In addition, other sciences can enhance mapping capability when used in conjunction with GIS tools. This is the case of products derived from remote sensing (RS), such as images obtained via satellite. In the cases of Weng [23], Cheng and Masser [24], and Xiao et al. [25], remote sensing is integrated with geographic information systems to detect urban growth and assess its impact on urban sustainability, in which the detection of land use and cover change plays a key role. Therefore, evolution in the support of GIS to SA can be seen with the increase of new sciences of observation of the earth’s surface, however, this is still restricted to the use of biophysical data for the mapping of land uses. MacKerron and Mourato [26] differ in that they build a model that relates life satisfaction with a focus on air quality, in particular, using data from 400 London residents and GIS software to calculate pollutant concentrations in the vicinity of their homes. Despite this, GIS tools still appear to be applied in sustainability assessments that are directly related to environmental issues.

From the following decade, other examples of highly visible publications can be explored that show some sustainability approaches in which the evaluations applied, in different ways, use GIS tools in the methodological process.

Burkhard et al. [27] aimed to present and apply a concept of mapping, through GIS, the supply and demand of ecosystem services, which could be applicable at different scales and that allowed the comparison of different ecosystems, in addition to developing a tool in which landscape managers can rely on sustainability assessments. Jiang et al. [28] present a GIS-based approach to assessing the availability and distribution of agricultural waste in China, considering several conservation issues: resources (total amount, spatial and temporal distribution), economics (transport costs), environment, and technology, in order to assess the potential for conversion into bioenergy. In these studies, an ecological approach to sustainability is evident, where GIS presents itself as a support mechanism for decision-makers.

However, GIS allows, in essence, the application of variables from different categories, as long as they can be spatialized: not restricted to environmental/ecological data, but also to economic or social ones. In this sense, Bathrellos et al. [29] proposed an urban planning and sustainable development approach for Trikala City Hall (Western Thessaly, Central Greece). For this, several parameters were used and correlated by the method of the analytical hierarchical process (AHP) and incorporated in a GIS to produce the corresponding maps of suitability.

Therefore, the researchers cite above some examples that can help to understand what is known, so far, of the support in which GIS techniques and tools provide the evaluations in which the authors indicate that they deal with sustainability. In agreement with what Patterson et al. [6] and Sala et al. [5] affirm, the previous examples expose the complexity of SA precisely because of the diversity of interpretations depending on the principles in which sustainability is presented. Among the cited studies, sustainability assessments were perceived from the perspective of land use and occupation and its urban and rural planning, by the selection and suitability of areas, by the relation of life satisfaction and air quality, and by the supply and demand of ecosystem services, for the bioenergetic potential of areas and for the quality and management of water resources. This scenario turns out to corroborate the idea that, despite the use of GIS being pointed out as a methodological trend in SA [11], there is still no clarity on the themes in which these geospatial techniques work. The researchers might ask what the directions of its application in future works are, and if they are paths that can lead decision-makers to direct the studied areas towards sustainable development.

Thus, the researchers understand that a broad analysis, which is capable of understanding several scientific publications on the subject, such as an analysis of scientific mapping through bibliometrics, can help to answer these questions. Bibliometric works can be understood as a set of methods that help in the analysis of academic literature in a quantitative manner, but also in understanding the changes that occur over time in the field of research being analyzed. One of the main methods for exploring a field of research is scientific mapping (or bibliometric mapping), which consists of revealing the conceptual, social, or intellectual structure of scientific research, in addition to its evolution and dynamic aspects over time [30].

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